Kinesiology for Occupational Therapy

Third Edition

MELINDA F. RYBSKI

SLACK Incorporated

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Preface

This book is written for occupational therapists and occupational therapy students. The purpose of this book is to explore and explain how movement occurs from a musculoskeletal orientation.

This text includes descriptions of how joints, muscles, and bones all interact to produce movement. General information about muscles and assessment of strength, as well as joints and assessment of joint motion, are contained in two chapters that will elucidate this idea of movement. There are seven chapters devoted to how movement is produced, focusing on shoulder; elbow; wrist; hand; posture; hip and pelvis; and knee, ankle, and foot. Being able to visualize the internal mechanisms of joint movement and to accurately assess observable joint characteristics is an important part of understanding movement.

To understand how movement is produced, kinesiology concepts are explained with regard to forces acting on the body and how these forces influence not only movement, but ultimately our intervention with clients.

Because this book is written for occupational therapists, the first chapter briefly explains concepts particularly related to the profession of occupational therapy. Terminology is defined according to the *Occupational Therapy Practice Framework: Domain and Process, Third Edition* as well as the *International Classification of Functioning, Disability and Health* terminology. Relevant tenants of the occupational therapy profession are explained since they relate to all aspects of occupational therapy practice.

Once one understands how movement is produced and how to assess strength and joint motion, the next logical step is to learn about appropriate intervention. The last chapters are devoted to describing intervention frames of reference used in occupational therapy. It is important to be able to clearly articulate to our clients, their families, other professionals, and third-party payers what we are doing and why.

While this textbook focuses on a very small part of the occupational therapy domain (musculoskeletal client factors), it is imperative for the occupational therapist to remain true to occupational therapy values of client-centered, holistic, and systems-oriented practice. Include the client and family in the entire intervention process, which will ensure better treatment outcomes and improved client satisfaction.

Instructor's materials include class activities, discussion questions, and learning tasks.

—Melinda F. Rybski, PhD, MS, OTR/L

Section I

Foundational Knowledge

1

Occupational Therapy Conceptual Foundations

Melinda F. Rybski, PhD, MS, OTR/L and Lori DeMott, OTR/L, CHT

Occupational therapy is defined as "the therapeutic use of everyday life activities (occupations) with individuals or groups for the purpose of enhancing or enabling participation in roles, habits, and routines in home, school, workplace, community, and other settings" (American Occupational Therapy Association [AOTA], 2014a, p. s1). This definition, from the *Occupational Therapy Practice Framework: Domain and Process, Third Edition* (the *Framework*), reflects the philosophy and values of the profession and clarifies the distinct value of occupational therapy. Occupational therapists improve health and quality of life by using meaningful and necessary activities of daily life for increased participation in occupations (AOTA, 2016). Long-established values of the profession include a holistic, client-centered, occupation-based, and systems-oriented approach focused on participation and health (AOTA, 2014a; Cole, 2010).

Systems Oriented

The International Classification of Functioning, Disability and Health (ICF), developed by the World Health Organization (WHO) as a part of a "family" of classifications for application to various aspects of health, was written to "provide a unified and standard language and framework for the description of health and health-related states" (WHO, 2001, p. 3). This classification system and conceptual model can provide a uniform language to describe health and health-related conditions and a conceptual model to visualize the relationships of functioning and disability with contextual factors.

The *Framework* also provides consistent language and concepts that can be used by internal and external audiences to clearly express the role of occupational therapy contribution to health promotion and participation in occupation (AOTA, 2014a). The ICF and *Framework* documents reflect a shift from a disease perspective to one related to health. Health and wellness involves individuals, organizations, and societies and is seen as an active process of making choices for an optimal state of physical, mental, and social well-being. The *Framework* is aligned with global health trends emphasizing health and wellness as well as a growing awareness of the need to provide opportunities and resources for success in activity participation (occupational justice).

Taking a systems-oriented approach, larger contexts of intervention are recognized. With an expanded view of who the client can be, intervention is directed not only toward those clients who may already have activity limitations and participation restrictions, but also toward those who may be at risk for health conditions or toward the population as a whole.

A systems-approach recognizes the variety of contexts in which intervention occurs. The ICF considers the physical, social, and attitudinal environment in which people live and includes detailed descriptions of environmental factors that include products and technology; natural environment and human-made changes to the environment; support and relationships; attitudes; and services, systems, and policies. The *Framework* defines contexts as cultural, personal, temporal, virtual, physical, and social.

Benefits of systems-oriented frameworks may "influence universal design, public education and legislation, permit comparison across clients, studies, countries and clinical services,

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populations, predict health care system usage and costs and provide evidence for social policies and laws" (Jette, Norweg, & Haley, 2008, p. 964). Determining the health of populations and prevalence of health outcomes in terms of health care needs and effectiveness of health care systems can serve public health purposes. Further, the use of a standard language can help in policy development in the areas of social security, employment, transportation, and access to technology (Unstun, 2002). As Madden, Choi, and Sykes (2003) state, "the use of a common framework, with its common definitions and classifications, thus helps to produce meaningful information for decision making and policy development and increases the likelihood of improved outcomes for people with disabilities" (p. 676).

Systems-oriented approaches in occupational therapy (also called *overarching frames of reference* [Dunn, 2000], *conceptual models* [Reed & Sanderson, 1999], or *occupation-based frameworks* [Baum, Christensen, & Haugen, 2005]) include relationships between the person, environment, and occupational performance with the focus on occupation (Cole, 2010). The Canadian Model of Occupational Performance focuses on the relationships between person-environment-occupation (PEO) and is an example of a conceptual umbrella on which intervention can be based. Other occupation-based models are Occupational Behavior (Reilly, 1969), Model of Human Occupation (Kielhofner & Burke, 1980), Occupational Adaptation (Schkade & Schultz, 1992a, 1992b), Ecology of Human Performance (Dunn, Brown, & McGuigan, 1994), and Person, Environment, Occupation, Performance (Christiansen, 1994).

Holistic and Client Centered

The ICF framework is described as a biopsychosocial model that integrates aspects of the more traditional medical model with the social model advocated by the disability community (Crimmins & Seeman, 2004; WHO, 2001). The ICF model integrates the need to cure and prevent disease (medical model) with the goal of increasing participation in daily life (social model; Iezzoni & Freedman, 2008). The ICF model describes "the situation of each person within an array of health or health related domains … made within the context of environmental and personal factors" (WHO, 2001, p. 8). The ICF framework describes functioning and disability as "a dynamic interaction between health conditions and contextual factors" (WHO, 2001, p. 8).

The *Framework* also reflects a holistic understanding of the client. Just like the ICF and the biopsychosocial model, the practice of occupational therapy involves intervention that is remedial (medical model) and social (social model). Kielhofner and Burke (1977) identified paradigm shifts that have occurred in the history of occupational therapy. The first paradigm shift was from a focus on occupation to a mechanistic or reductionistic model. This occurred between 1940 and 1970 and was a result of greater alignment with the medical model. From this shift, three models emerged: kinesiology (including the biomechanical and rehabilitation approaches), psychoanalytic (psychodynamic), and sensory integrative (neuroscience, motor control). Since the 1980s, occupational therapy has moved toward a focus on occupation itself and broader models (e.g., the ICF model and occupation-based models) and away from the primary emphasis on physical, sensory, psychological, emotional, or cognitive components of function.

The profession's early roots in humanism and pragmatism are evident in the *Framework* with the "dedication to the betterment of the human condition and the right of each person to respect, dignity and a meaningful and productive role in society" (Cole, 2010, p. 78). Client-centered practice is driven by respect for the client and caregivers and for the choices they make for their lives. Intervention is individualized based on active participation of the client in determining goals with clients assuming ultimate responsibility for decisions about occupations they wish to resume. The therapist collaborates with the client to solve occupational performance issues.

In providing services that are client centered, occupational therapists use many different types of reasoning, which may include procedural, interactive, pragmatic, conditional, and narrative thinking. The practice of occupational therapy requires the use of scientific and objective knowledge used in procedural reasoning; the understanding of the illness experience based on the subjective reality of each individual client used in interactive reasoning; and the use of conditional reasoning that integrates objective and subjective information with contextual factors. This is the melding of information from the person, environment, and occupation.

In a client-centered practice, the activities, roles, and tasks of the person are considered, as are systems and services that can support the person. The client is an active participant in the intervention process and assumes responsibility for his or her care. The therapist collaborates with the client in establishing treatment priorities and provides education, information, and resources in the community to help clients develop skills and behaviors that prevent disabilities and promote healthy lifestyles (Law, 1998).

In a study by Neistadt (1995), 99% of occupational therapists who were surveyed reported that they routinely identify clients' priorities for treatment, although more formal means of assessment would ensure that all clients were helped to delineate their goals. Northern, Rust, Nelson, and Watts (1995) found that therapists did involve clients and families in the goal-setting process, although there were some discrepancies in the verbal preparation of client and family for intervention and potential outcomes; in attempts to elicit client concerns; and in the level of collaboration to establish treatment goals. Occupational therapists involve their clients in the treatment process. A client-centered approach has been shown to result in shorter hospital stays, better goal attainment, and improved client satisfaction (McAndrew, McDermott, Vizakovitch, Warunek, & Holm, 1999).

Occupation Based

Occupation is used to organize and define occupational therapy's domain of concern (AOTA, 1995a). The unique focus on occupation is a distinguishing feature of our profession (Rogers, 2007). It is the client's designation of the meaning and importance of each occupation or activity that is the focus of intervention. This is consistent with the occupational therapy views of the relationship between occupation and health and that people are occupational beings (AOTA, 2008, p. 625). By using these everyday activities, or occupations, increased functional performance that is meaningful to the client is the outcome of occupational therapy intervention. Purposefulness helps to organize while meaningfulness of activities motivates clients. Moyers (1999) lists nine principles of occupation that guide occupational therapy interventions:

1. Occupations act as the therapeutic change agent to remediate/restore impaired abilities or capacities in the performance components.
2. Occupations facilitate transfer of performance component skills to multiple contexts.
3. Occupations are selected to enhance motivation for making change.
4. Occupations promote self-exploration and identification of values or interests.
5. Chosen therapeutic occupations start with the current capacity of the client.
6. Occupations create opportunities to practice skills.
7. Occupations are selected to support the most appropriate intervention approach.
8. Active engagement in occupations produces feedback that successively grades performance.
9. Successful occupational experiences are necessary for achieving goals (pp. 270-272).

These principles of occupation apply to all models, frames of references, and interventions relevant to occupational therapy.

Evidence Based

Occupational therapy is a science-driven profession and, as such, uses the best available evidence to inform and guide clinical decision making. Evidence comes not only from the results of research, but also from accumulated clinical experience, education, and reasoning and from client and family preferences and values (Arbesman, Lieberman, & Metzler, 2014; Institute of Medicine Committee on the Health Professions Education, 2003; Spring, 2007). When providing interventions with strong to moderate supporting evidence that is compatible with the environmental and organizational context, interventions can be client based, with improved client outcomes, and are cost effective.

These conceptual foundations are reflected in the AOTA Vision 2025 to guide the Association's strategic priorities. The vision statement, "Occupational therapy maximizes health, well-being, and quality of life for all people, populations, and communities through effective solutions that facilitate participation in everyday living," is further defined by four guideposts (AOTA, 2018). Provision of services that are culturally responsible and customized reflects the guidepost of accessibility. The collaborative guidepost advocates for cooperative interactions between occupational therapists and clients within systems. Effective occupational therapy is evidence based, client centered, and cost effective. The final guidepost is that occupational therapy is influential in changing policies, environments, and complex systems (AOTA, 2017).

The *Framework* is an official document of the AOTA providing constructs that define and guide the practice of occupational therapy. The *Framework* is based on the core values and beliefs of the profession and uses much of the language of the ICF from the WHO.

The Domain section of the *Framework* summarizes the areas in which occupational therapy has an established body of knowledge and expertise. The Domain complements the WHO conceptualization of participation and many of the ICF constructs (AOTA, 2014a; WHO, 2001). The Process section of the *Framework* describes the services provided by occupational therapists that are client centered and focused on participation and engagement in occupations.

Occupational Therapy Domain

The *Framework* identifies five specific aspects of the domain of occupational therapy practice, which are interrelated and of equal value. The first, occupations, includes many of the same items that are classified as activities and participation in the ICF model. Occupations include activities of daily living, instrumental activities of daily living, rest and sleep, education, work, play, leisure, and social participation. Improvement or enhancement of occupational performance is often a desired outcome of intervention. Occupations will be defined by the client as part of an occupational profile in which the therapist gains an understanding of the client's history, interests, values, and priorities that forms the basis of intervention.

The remaining four aspects of the occupational therapy domain are factors that may influence the client's ability to successfully engage in occupations and participate in health-promoting activities. These include client factors (body functions, body structures, values, beliefs, and spirituality); performance skills (motor skills, process skills, and social interaction skills); performance patterns (habits, routines, roles, and rituals); and contexts and environments (cultural, physical, personal, social, temporal, and virtual). All aspects of the occupational therapy domain interact to influence the client's performance.

Contextual factors are those related to the physical environment, cultural and social systems, simulation of environmental conditions, and spiritual aspects of being. This definition of contextual factors is very similar to that used in the ICF. Environmental factors are those in the natural environment and in the human-made environment and include social attitudes, customs, rules, practices, institutions, and other individuals. Personal contextual factors are those components that are not part of the health condition, including age, race, gender, educational background, experiences, personality and character style, aptitudes, other health conditions, fitness, lifestyle, habits, upbringing, coping styles, social background, profession, and past and current experience (WHO, 2001).

Occupational Therapy Process

The occupational therapy domain and occupational therapy process "are inextricably linked" (AOTA, 2008, p. 627).

The occupational therapy process includes evaluation, intervention, and targeting of outcomes. Evaluation includes the occupational profile and analysis of occupational performance, and there is an ongoing interaction between the elements of the occupational therapy process. Intervention includes developing the intervention plan, implementing the intervention, and reviewing the effectiveness of the intervention and progression toward desired outcomes. Outcomes, determined early in the occupational therapy process, are the end result of the interventions.

Evaluation

The *Framework* describes assessment as a process that involves two steps. Step one is assessment of the occupational profile of the client in order to gather information about the client's interests, values, needs, and goals. By starting the assessment process with the occupational profile, this client-centered focus can be incorporated throughout the treatment process. This assessment stage is where the therapist and client begin the collaborative process of therapy.

Therapeutic rapport is established with the client as the therapist uses his or her own unique characteristics of personality, style, perceptions, and judgments as part of the therapeutic process (AOTA, 2008). The intention is to understand the perspective of the client, with these particular limitations, within the specific context and environment. Clients are considered the experts regarding their own situations and methods for problem solving. Evaluation does not always have to start with the occupational profile nor is assessment in this area ever completed. Ongoing collaboration between the therapist and client continuously determines if the client's needs and goals are being addressed. The therapeutic use of self uses clinical reasoning, empathy, and a collaborative approach with the client.

The occupational profile includes information about the client's medical and occupational histories, patterns and habits in daily life, interest and needs, roles, and valued occupations (AOTA, 2008). Have the client talk with you about previous conditions and how that may influence the current problem. Discuss the current problems the client is having, what caused the limitation, how long it has lasted, and under what conditions the problem seems to get better or worse. Careful consideration of the client's concerns helps to establish rapport, understand the client's perspective about the limitation, identify underlying factors causing the limitation, and suggest intervention strategies that are based on meaningful client occupations and roles. A template of the occupational profile is available from AOTA through this website: https://www.aota.org/~/media/Corporate/Files/Practice/Manage/Documentation/AOTA-Occupational-Profile-Template.pdf.

In step two, an analysis of the client's occupational performance is done. Occupational performance is the interaction of the client, context, and activity that enables successful engagement in the areas of occupation. Areas of occupation, performance skills, performance patterns, contexts, and specific client factors are considered regarding how these might enhance or hinder engagement in desired occupations. The correct choice of assessment outcome instrument is dependent upon the purpose of measurement and type of injury (Schoneveld, Wittink, & Takken, 2009).

Step two is more focused on the component factors leading to the occupational performance participation restrictions identified in step one. The client's actual performance may be observed in the context in which it normally occurs so that performance skills and patterns can be clearly seen.

Observation is a valuable means of analyzing the client's movement patterns. Not only can you look for symmetry of hips and shoulders, but you can notice any compensatory movements or pain behaviors such as grimacing or muscle guarding. Coordination of movement can be easily seen as well as overall body posture. Visually, you may observe areas of edematous tissue and scars, wounds, or deformities. These are examples of what may be specifically assessed in occupational performance analysis.

Performance measures have an effect on the therapeutic process. Clarification, accountability, objectivity, and measurement feedback are essential to the client-centered, occupation-based perspective in treatment. For example, lifting objects over 5 pounds (routinely a question asked on a self-report functional measure) may influence the interventions of treatment. If this measure is important to the client's roles or occupations, this encourages the task of lifting over 5 pounds to increase client awareness and accountability; people innately have increased awareness to those items they are measured against. Figure 1-1 illustrates how measurement influences intervention.

The psychometrics of any test determine how well the measurement evaluates the construct of interest. Occupational therapy theory and the ICF have established the definition and contribution of meaningful activity and participation to health and wellness. The need for continued precision of these outcome measures that understands the constructs of activity and participation are paramount to practice and research. Coenen et al. (2013) published a qualitative study that found that eight commonly used patient-reported outcome (PRO) measures used in therapy were linked to the ICF category of activity and participation.

PRO measures that comprise the relevant components of body functions and structures and those of activity and participation will contribute to a common language that explains the phenomena of occupation in context. There is continued debate regarding the ability to transfer the improved components of strength and range of motion (ROM) to improved occupational performance. The identified increased use of PRO measures in treatment has influenced the overall process of rehabilitation as a contribution of focus to activity and participation (Valdes et al., 2014). The use of reliable and valid measures that closely align with occupational therapy theory will direct client-driven meaningful goals, provide therapy process accountability, and facilitate feedback about outcome expectations. The psychometrics of evaluation that more closely align with the value of occupation are the tools, as the tools used to measure activity and participation, the closer occupational therapists will be to providing the most effective interventions. The simplicity of the saying "we are what we measure" demonstrates the awareness that measurements that are used can influence distinct and directive behaviors of the therapist and the client.

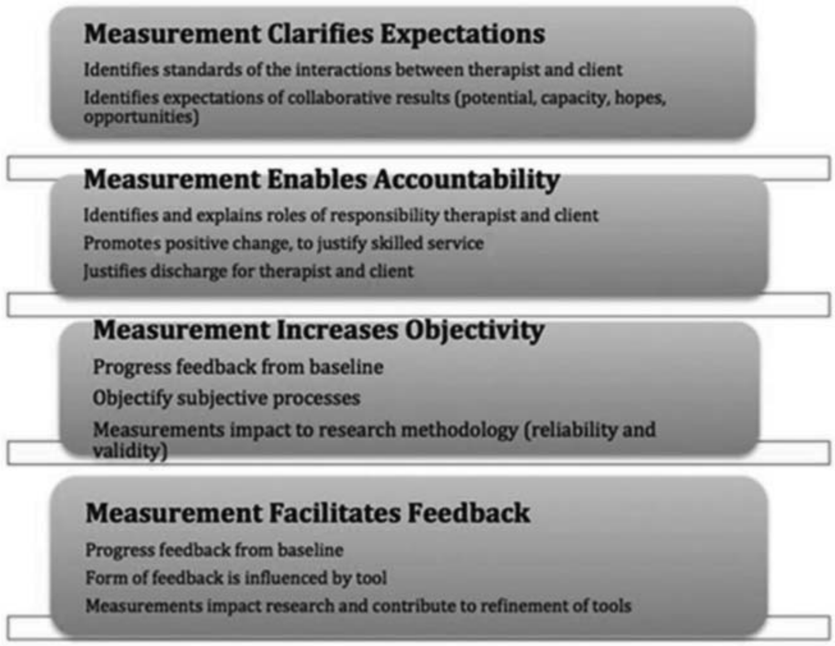

Figure 1-1. Measurement influences intervention.

Intervention

The outcome of occupational therapy intervention is directed toward "facilitating engagement in occupation related to health, well-being, and participation" in collaboration with the client (AOTA, 2014a, p. s14). Outcomes of the intervention determine future actions with the client and include occupational performance, prevention (of risk factors, disease, and disability), health and wellness, quality of life, participation, role competence, well-being, and occupational justice (AOTA, 2014a).

Types of occupational therapy interventions include occupation- and activity-based intervention, preparatory methods and tasks, education and training, advocacy, and group interventions.

Occupation-based intervention uses client-centered activities, collaboratively chosen by the client and therapist, that are meaningful and relevant to the client in the expected environment. The actual task is done in the same context as is typically done and that meets the client's goal. This is the most beneficial and most challenging level of intervention. Fisher (1998) called this *adaptive or compensatory occupation*, which comprised active participation in chosen occupations but also included using assistive devices, teaching alternative methods, or modifying the environment as goals of intervention. The intervention is focused on improved occupational performance and is not directed toward remediation of impairments.

Systems- or occupation-based models, such as the PEO Model (Law et al., 1996), provide an overarching theory about the relationship between occupation, the person, and the environment. How is this theory used in practice? Theories applied to individual clients in specific practice situations are considered frames of reference, practice models (Kielhofner, 2009; Reed & Sanderson, 1999), or intervention approaches. Using frames of reference, practitioners link the "concrete particular with the abstract general" (Mattingly & Fleming, 1994).

Intervention is guided by both the occupation-based models and by frames of reference. Trombly (1993) calls this "layers of occupational functioning," where all parts of domains and roles need to be considered in treatment, including tasks, activities, abilities, and capacities. Knowing that the client wishes to resume a homemaking role would also entail assessment of the ability to prepare meals, perform specific tasks related to meal preparation, and have the necessary physical and cognitive capacities to perform specific activities.

Frames of reference are not necessarily occupation based. These models of practice were developed as guidelines to address specific disability areas. Several different practice models may be used simultaneously to address different limitations. Initially, restorative/restoration approaches may be used with the client to improve limitations at the body structure and body function levels. If further progress is not made or if the client wants to see more immediate results, compensation/adaptation approaches may be used in conjunction with other approaches or alone.

A frame of reference matches the client concerns with the abstract theory, so it is specific to the individual and specific areas of practice. Crepeau and Schell (2003) stated that "major theories in occupational therapy differ in purpose, scope, complexity, extent of development and validation through research, and usefulness in practice" (p. 204). Some occupational therapy theories are useful in one area of practice and not another.

A frame of reference is:

> [A] set of interrelated, internally consistent concepts, definitions and postulates derived from or compatible with empirical data [and] provides a systematic description of or prescription for particular designs of the environment for the purpose of facilitating evaluation and effecting changes relative to a specified part of the profession's domain of concern. (Mosey, 1986, p. 12)

The concepts and relationships are drawn from evidence to explain possible causes of factors contributing to function or dysfunction (Tufano, 2010).

Each frame of reference has specific assumptions about the causes of activity and participation restrictions and provides guidelines for intervention. The frame of reference provides a framework on which to explain problems in occupational performance, to select assessment methods relevant to the problems, and to develop an intervention plan based on evidence. Regardless of the frame of reference used, referring to an overarching occupation-based model will ensure that all parts of the PEO relationship are included in the client-centered goals.

Not all clients who are seen by occupational therapists are ready to participate in occupations or purposeful activities. Preparatory methods are used to prepare the client for occupational performance and may include physical agent modalities, orthotics/splinting, or exercise as examples. Pendleton and Schultz-Krohn (2001) call these *adjunctive methods*, which also include ROM, inhibition or facilitation techniques, and sensory stimulation. Fisher (1998) calls them *rote exercise* and *practice activities exercise*. These are activities done for a purpose but with little meaning.

The activities originate with the therapist and not the client, with the focus on remediation of impairments at the client factor level. Occupation-based activities engage the client in the intervention process and have meaning and relevance to them. Infusing occupation into purposeful activities and preparatory methods is part of the creative challenge therapists may face. Barriers to occupation-based intervention may include limited institutional support with the expectation that preparatory methods alone will enable successful integration into roles once the client is discharged. Reimbursement is not always straightforward, so there is a need to justify treatment (Rogers, 2007).

Having clients actively participating in choosing priorities and setting goals will engage the client meaningfully in the intervention process and make the intervention more occupation based (Deshaies, Bauer, & Berro, 2001). Give clients choices of activities. Identify clients with similar interests and arrange occupation-based groups so that socialization and peer mentoring can facilitate the intervention, and the intervention can be more fun and meaningful. Use the facility to its fullest potential: have the client use the vending machines; go to activity rooms; walk on the hospital grounds and community areas. Go on outings to homes, job sites, and schools or to other places that have meaning for the client (Deshaies et al., 2001; Rogers, 2007).

Five different intervention approaches are identified in the *Framework*. They include create/promote (health promotion), establish/restore (remediation/restoration), maintain, modify (compensation/adaptation), and prevent (disability prevention; AOTA, 2014a; Moyers, 1999). These approaches are the specific strategies that direct assessment and intervention planning, selection, and implementation (AOTA, 2014a, p. s33). Table 1-1 illustrates the relationship between theory, intervention approaches, and some common frames of reference used in occupational therapy. The dark ink indicates the primary function of the frame of reference while the gray ink is a secondary function. For example, the biomechanical frame of reference is primarily a remediation approach, but some of the strategies can also be considered to fall within the maintenance or prevention approaches.

Remediate

The biomechanical approach (discussed later in this book) is a remediation (establish/restore) approach. The intention of this approach is to change the underlying structures that are limited by disease, trauma, or overuse with the understanding that these gains will lead to improvement in occupational performance. The biomechanical approach focuses on "the intersection of motion and occupational performance" (Kielhofner, 2009, p. 70). The focus is on remediation of limitations in tissue integrity, structural support, ROM, strength, coordination, and endurance.

Remediation approaches are selected when there is an expectation for reduction in the limitations in client factors that influence performance in areas of occupation. It may involve learning new skills, slowing the decline in abilities, or maintaining or improving quality of life (Moyers, 1999). Examples of remediation techniques are the use of enabling activities, sensorimotor techniques, graded exercises, physical agent modalities, or manual techniques (Moyers, 1999). Arts, crafts, games, sports, exercise, and daily activities may also be used to improve the function of a specific body structure or function, and each of these therapeutic methods would be tailored to each individual to fit the capacities and goals of that person.

If the remediation is to be considered successful and to be considered occupational therapy, the intervention will need to occur in a natural context. Moyers (1999) adds "simply expecting improvements in impairments to automatically produce change in level of disablement without addressing performance in occupations within the intervention plan is inappropriate" (p. 276). Intervention that concentrates on client factors must also be contextually meaningful and occur in a natural environment to avoid being rote exercise or contrived occupation. The biomechanical approach used in occupational therapy intervention is the remediation approach discussed in this text because this approach is most beneficial in intervention for clients with decreased strength, endurance, and ROM.

Compensate/Adapt (Rehabilitation)

Compensation and adaptation (modify) approaches are often referred to as the *rehabilitation approach*, and this approach concentrates not on the client factors, but instead on performance in occupations. An assumption of this approach is that the performance of the activity or task that the person sees as important is the focus of the intervention. Techniques used in this approach include changing the task, altering the task method, adapting the task object, changing the context, educating the family and caregiver, and adapting

Table 1-1

APPROACHES TO INTERVENTION

Occupational Therapy Framework

↓

Theory

↓

Intervention Approaches

Create/Promote	*Remediate*	*Maintain*	*Compensate*	*Prevent*
	Cognitive Behavioral		Cognitive Behavioral	Cognitive Behavioral
		Cognitive Disabilities	Cognitive Disabilities	
	Neurodevelopmental			
	Proprioceptive Neuromuscular Facilitation			
	Biomechanical	Biomechanical		Biomechanical
	Sensory Integration			
	Psychodynamic		Psychodynamic	
		Rehabilitation	Rehabilitation	

Note: Lighter text indicates a secondary emphasis in intervention.

the environment. Disability prevention may be considered part of this approach in that education of the client and caregivers is vital in preventing further disease or disability, especially in those who already have impairments or limitations.

Commonly, the biomechanical and rehabilitation approaches are seen as a continuum of intervention for physical limitations, and the process is fluid and not linear. The focus of the rehabilitation approach is on the client's remaining strengths. Tasks and task objects are adapted to these remaining strengths, and new methods of completing tasks are taught to clients to promote independence in performance areas, increase client satisfaction, and enhance participation.

The compensation and adaptation intervention approach is used when there is little expectation for change in client factors and subsequent performance skills. This approach may be selected when there is limited time for intervention or when the client or family prefers this approach to remedial techniques, seeing compensation and adaptation as providing more immediate success in performance of the areas of occupation (Moyers, 1999).

The rehabilitation approach is discussed in this text as an intervention strategy for use with those clients with movement impairments preventing full participation in occupations for which remediation is not possible. Both biomechanical and rehabilitation interventions are used extensively in occupational therapy and require knowledge of the structure and function of the body; knowledge about specific diagnostic categories and procedural reasoning; and knowledge about specific individual clients and their activities, roles, and values.

Create/Promote (Health Promotion)

This approach clearly reflects the emphasis on health in the practice of occupational therapy. Health promotion services are directed toward the general population and do not assume that there is any disability or dysfunction present (although health promotion can and does occur with clients with limitations, too). Teaching the well elderly to eat well and to arrange their environment for greater mobility and safety is an example of a health promotion activity in people without limitations. Inclusion of client hobbies and interests in intervention plans is often a way health is promoted for those with limitations.

Maintain

Maintenance approaches are used to support the client's current level of functioning. Without intervention at this level, it is assumed that performance would decrease, occupational needs would not be met, or both, thereby affecting health and quality of life (AOTA, 2008). This may be an appropriate approach to use for people with degenerative diseases where preserving the current level of functioning is a successful outcome.

Prevent (Disability Prevention)

The disability prevention approach is designed to address clients who are at risk for developing occupational performance problems. This approach may be used with clients with and without a disability. Backpack awareness programs for school-aged children are directed toward children without disabilities but with continual poor posture due to inappropriately worn backpacks, who could develop dysfunction and pain. Secondary consequences of an injury or disease would be another area of prevention intervention. A person with a spinal cord injury may have areas of insensate skin as a secondary result of the spinal cord injury. Disability prevention intervention would address the necessity of pressure relief, awareness of areas lacking sensation, and methods of skin inspection to prevent the development of decubitus ulcers.

Outcomes

The final aspect of the process of occupational therapy service delivery is targeting of outcomes. The types of outcomes and outcome measures to be used are selected early in the intervention process and are the end result of intervention. Outcomes may be measurable and reflect treatment goals that relate to engagement in occupations while other outcomes may be those that are experienced by the client and are able to return to habits, routines, roles and rituals (AOTA, 2014a). Outcome measures are selected based on:

- Valid, reliable, and sensitive measures
- Consistency with targeted outcomes
- Congruency with client goals
- Ability to predict actual or future outcomes

Occupational therapy intervention is designed to "improve the occupational performance of persons who lack the ability to perform an action or activity considered necessary for their everyday lives" (AOTA, 1995b, p. 1019), as well as to achieve the outcomes of prevention of injury or disability, promotion of health, and quality of life (Moyers, 1999). Outcomes of the intervention determine future actions with the client and include occupational performance, prevention (of risk factors, disease, and disability), health and wellness, quality of life, participation, role competence, well-being, and occupational justice (AOTA, 2014a). Outcomes are the end result of occupational therapy intervention and involve the conceptual interrelationships between health, participation, and engagement in occupation. These are used to measure progress and adjust goals and interventions and are interwoven throughout the occupational therapy process.

The use of outcome measures will redirect occupational therapy practice from reductionistic bottom-up approaches to a top-down, client-centered approach. Scientists and clinicians use measurement as a way of understanding the impact of a phenomena on an individual, establishing a baseline measure to monitor change over time, evaluating client needs, and evaluating the impact of an intervention. Outcome measures provide credible and reliable justification for intervention. The validity of the measures and their meanings assist in all aspects of therapeutic decision making (Law & MacDermid, 2014). The clinical decisions made in practice and choices of intervention approaches are influenced by the selection and results of outcome measures. The objective goals that are established are generated from the particular metric of that measure. Table 1-2 lists outcome measures used by occupational therapists.

PRO measures that comprise the relevant components of body functions and structures and those of activity and participation will contribute to a common language that explains the phenomena of occupation in context. The increased use of PRO measures in hand and upper extremity rehabilitation contributes to a greater focus on activity and participation (Valdes et al., 2014). While performance-based measures involve direct observation of a client's performance, PRO instruments gather subjective information about a client's perceptions of success and goal attainment, such as confidence, self-efficacy, sustainability in valued occupations, and overall health and well-being (Lesher, Mulcahey, Hershey, Stanton, & Tiedgen, 2016). The importance of these outcome measures is paramount as they describe aspects of performance that are not observable. The use of PROs is more closely aligned with the profession's client-centered values and can result in enhanced communication with clients and payers, improved documentation of client outcomes, and guidance in directing client care (Lesher et al., 2016; Shanahan, 1992; Valdes et al., 2014).

Figure 1-2 illustrates the influence of measurement on practice and the profession. Clinical utility measures are performance-based outcome measures (e.g., ROM, strength, and sensation) and also include those outcome measures that specifically address the attributes of activity and participation. Specifically, those outcome measures that are focused on occupational concerns, demonstrate the flow of influence to research and then the contributory power to the choice of treatment interventions that occurs in evidence-based practice. From the contribution to research, we can see these relationships benefit our profession by utilizing precision of measures specific to occupational theory and the Vision 2025.

In the AOTA Occupational Therapy Vision 2025, directives are provided that guide the strategies of the profession to promote the professional culture to meet the identified challenges. The philosophical influences come from the values, beliefs, and principles of the discipline that, until recently, was limited in the ability to measure occupational performance (Law & Baum, 2005). By necessity, the directives of our Vision's strategic priorities are fundamental to the collection of evidence or data to support and guide the implementation of the organizational mission. To achieve these overarching core tenets, to be effective with our clients, to influence public policy, to collaborate with all professionals, and be accessible and culturally responsive to our populations, the measurement of occupational performance is paramount (AOTA, 2017). Occupations in context (occupational performance measures) are being investigated to provide the best evidence to support the theories of occupational therapy. The AOTA Vision statements are based upon the suppositions of client-centered, evidenced-based, and occupation-based practice (AOTA, 2017) and are grounded on the measurement indicators within the reports of high-quality research studies. This new knowledge in turn provides the tools to assist the practitioners in deciding the best occupational interventions.

Overview of This Text

This text covers in detail only a small part of the domain and process of occupational therapy. By focusing only on the study of movement (kinesiology), client factors, performance skills, and context and environmental aspects of the occupational therapy domain are the focus as these directly relate to movement. Detailed explanations of the evaluation of these areas are included in each chapter. Within each chapter,

Table 1-2

Outcome Measures Used by Occupational Therapists

Name of Outcome Measure	**Resource**
Michigan Hand Outcomes Questionnaire	University of Michigan, 1998
The Jebsen Hand Function Test	Jebsen et al., 1969
Disabilities of the Arm, Shoulder, and Hand (DASH)	Institute for Work and Health, 2006a
The Short Form 36 Health Survey	Ware, Kosinski, & Gandek, 2005
Nine-Hole Peg Test	Mathiowetz, Volland, Kashman, & Weber, 1985
Work Limitations Questionnaire	Lerner, Amick, & Glaxo Wellcome, 1998
Employee Comfort Survey, Button Board from the Arthritis Hand Function Test	Backman, Mackie, & Harris, 1991
Quick DASH	Institute for Work and Health, 2006b
Canadian Occupational Performance Measure	Law et al., 2005
Functional Independence Measure	Uniform Data System for Medical Rehabilitation, 1997
Self-Liking/Self-Efficacy Scale, Role Checklist	Oakley, 2006
Health Assessment Questionnaire	Fries, Spitz, Kraines, & Holman, 1980; Tafarodi & Swann, 1995
Moberg Pickup Test	Ng, Ho, & Chow, 1999
Patient-Reported Outcomes Measurement Information System–Health Assessment Questionnaire	Choi et al., 2012
Functional Dexterity Test	Aaron & Stegink Jansen, 2003
Task Questionnaire	Boynton & Darragh, 2008

Adapted from Lesher, D. A., Mulcahey, M. J., Hershey, P., Stanton, D. B., & Tiedgen, A. C. (2016). Alignment of outcome instruments used in hand therapy with the Occupational Therapy Practice Framework: Domain and Process, 3rd Ed and the International Classification of Functioning, Disability and Health: A scoping review. *American Journal of Occupational Therapy*, *71*(1), 7101190060p7101190061-7101190060p7101190012. doi:10.5014/ajot.2017.016741

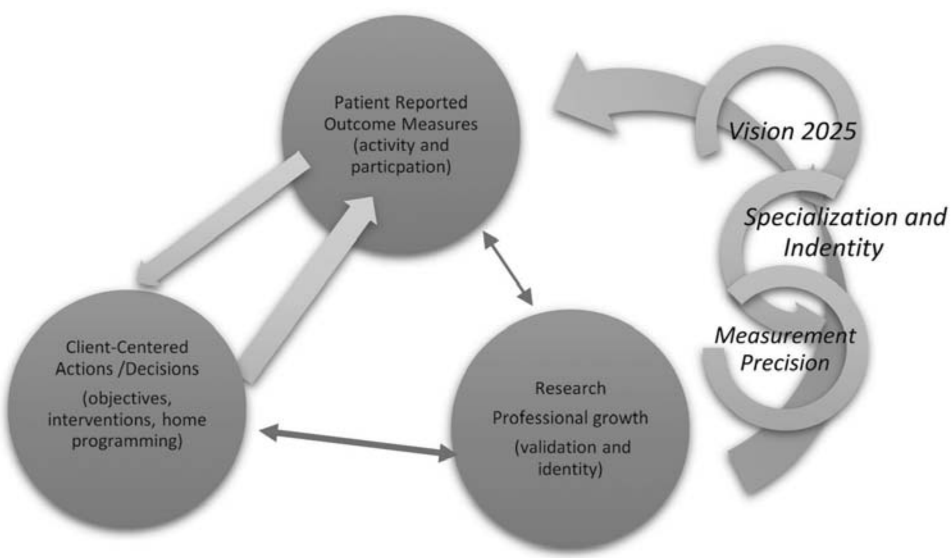

Figure 1-2. Measurement influence on practice.

evaluation of the person via the occupational profile will remind the reader to stay true to the conceptual foundations of occupational therapy, which value client-centered, holistic, and occupation-based intervention collaboratively completed with the client. While seemingly reductionistic with the focus on muscles and joints, the relationship of the person, environment, and occupation are always part of the treatment process.

Only a few intervention approaches are addressed in this text. A thorough explanation of the concepts and methods used in the biomechanical remediation approach and rehabilitation adaptation/compensation approaches are presented in the last two chapters. Occupational adaptation and motor control intervention approaches are also included as additional treatment options for movement limitations. Seen as a continuum, if remediation efforts for increasing structural limitations are unsuccessful or have plateaued, the next logical step is to adapt or compensate for the limitations. Disability prevention and maintenance approaches are also discussed in the intervention chapters.

This text is comprised of three distinct sections. Section I is designed to provide background information, knowledge, and facts that will be applied to later sections. The chapters in this foundational section pertain to basic concepts about movement, factors that influence ROM, and factors that influence strength. Terminology is explained that will be used throughout the text, and the relationships between body structures and functional movement are introduced. Assessment of joint movement and strength is included in this section. This section is provided to enable greater understanding of body structure and function as a basis of movement necessary for performance in areas of occupation.

Section II discusses how the general principles introduced in Section I apply to specific joints. How is joint motion produced at the wrist? What bones and muscles are involved? Is this a stable joint? These chapters that focus on specific joints relate structural anatomy to functional motion. Readers are encouraged to palpate the anatomical structures (muscles and bones) and to see and feel how these structures work together to produce joint movement. Most joints are actually made up of multiple articulations; each articulation contributes to the overall motion produced at that joint, so these articulations are discussed separately and as contributors to joint motion. Not every structure of the joint is included or discussed in detail; only those structures that most influence movement or stability are included. A summary chart describing joint movements, the plane and axis in which the movement occurs, normal limiting factors in movement production, the specific "end-feel" per motion, and the muscles producing the motion is provided for each joint to recapitulate information presented in the chapter.

Detailed descriptions of muscles are provided so that students can clearly see how muscle orientation affects muscle action. It is not always clear how one muscle can have multiple and seemingly incongruent muscle actions without seeing how a muscle acts at different joints. A clear understanding of normal joint movement is essential to occupational therapy practice and is the basis of the biomechanical intervention approach. Knowing how a normal joint should move is the essence of assessment. Specific factors that are relevant to the assessment of individual joints are discussed, and specific joint pathology is provided as an overview of possible limitations in function related to specific structures and disease processes or trauma.

Section III of this text provides different intervention strategies that could be used if there are activity limitations or participation restrictions due primarily to musculoskeletal or motor impairments. Remediation via the biomechanical approach and motor control theories and adaptation/compensation via the rehabilitation and occupational adaptation approaches are the primary intervention strategies discussed. For each approach, intervention principles are provided and explained, as are examples of goal statements and specific methods that could be used to implement the intervention selected.

Summary

- Occupational therapy is a systems-oriented, holistic, and client-centered practice that uses occupation to organize and define occupational therapy's domain of concern.
- Occupational therapy uses occupation, or the everyday things that people do, as the basis of intervention.
- The occupational therapy process involves evaluation, intervention, and outcomes.
- The occupational therapy process is inextricably linked to the occupational therapy domain.
- Intervention may be occupation based and use purposeful activities or preparatory methods.
- Intervention approaches include remediation, compensation/adaptation, health promotion, maintenance, or disability prevention.
- Outcomes include occupational performance, adaptation, health and wellness, participation and prevention, quality of life, role competence, self-advocacy, and occupational justice.
- This text focuses on movement; client factors, performance skills, and context and environmental aspects of the occupational therapy domain; biomechanical remediation, rehabilitation adaptation/compensation, occupational adaptation, and motor control approaches are presented relative to limitations in movement.

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2

Kinesiology Concepts

Melinda F. Rybski, PhD, MS, OTR/L; Samia Rafeedie, OTD, OTR/L, BCPR, CBIS; and Jane Baumgarten, OTR/L

Human movement is an extremely complex phenomenon requiring precise interplay between the skeletal system and the neuromuscular system to allow purposeful goal-directed movement. Kinesiology provides the occupational therapy practitioner with one lens through which to view and analyze movement in the context of human occupation. "Occupation is everything people do to occupy themselves, including looking after themselves … enjoying life … and contributing to the social and economic fabric of their communities" (Law, Polatajko, Baptiste, & Townsend, 1997, p. 32).

Kinesiology can be viewed as the study of motion and the internal and external forces involved in movement. An understanding of these forces and their impact on the body facilitates the delivery of interventions that better analyze and thus maximize occupational performance. Execution of a motor task can be improved through an understanding of the task demands, an analysis of an individual's capabilities, and the resultant adaptations to maximize task performance. Occupational therapy practitioners can use the concepts of kinesiology to provide clients with strategies for performing activities of daily living, to design and/or modify adaptive equipment, to evaluate the safety and efficiency of home and work environments, or to design therapeutic activities and exercise programs, all of which are elements of maximizing an individual's participation in their community.

According to Gench, Hinson, and Harvey (1995), a further refinement in the science of movement includes two subsections of kinesiology: anatomy and mechanics. Human anatomy is the study of the structure of the human body and its parts and the identification and description of body structures. Mechanics is the study of forces and motion; when applied to the living human body, this is most often referred to as *biomechanics*, the application of mechanics to the analysis of biological and physiological systems. Basic concepts that must be understood with regard to movement include components of anatomical position and body movements, planes of motion and axes in the human body, and the structure and classification of joints. Figure 2-1 illustrates the relationship between the sciences associated with movement.

Biomechanics is a term that describes the application of kinematics and kinetics to the mechanics of human movement, an integral concept in the study of kinesiology. *Kinematics* is a word used to describe motion of the body without regard to force, which is related to time, space, and mass (Lippert, 2017). Samuels (2018) defines osteokinematics as the "movement of the skeletal system through these planes of motion using a body standing in the anatomical position as the reference" (p. 6). Kinematics includes discussions on planes, axes, and types of motion (linear or rotatory). Kinetics, on the other hand, is an analysis of forces that create motion or maintain equilibrium. When considering kinetics, a variety of concepts need to be considered, including Newton's Laws, forces (including vectors), torque, and biomechanical levers. An understanding of the biomechanics can support an occupational therapy practitioner in evaluating and intervening with a client who has a musculoskeletal disorder or is being seen for preventative measures related to wellness and body mechanics in order to prevent injury or pain. Analyzing the components of force, the mechanical advantage (MA) of lever systems, and the creation of movement in the body impact a clinician's clinical reasoning and decision making.

Rybski, M. F.
Kinesiology for Occupational Therapy, Third Edition (pp. 17-35).

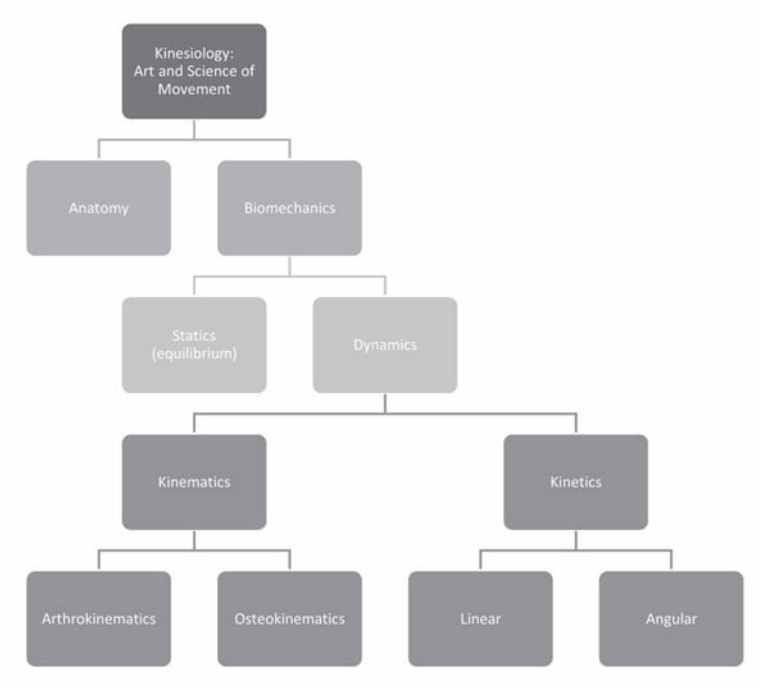

Figure 2-1. Sciences of movement.

Kinesiology and the *Occupational Therapy Practice Framework*

The *Occupational Therapy Practice Framework: Domain and Process, Third Edition* (the *Framework*) describes the concepts that define occupational therapy practice and facilitates an understanding of the basic tenets of the profession. The *Framework* guides the practice of occupational therapy, in conjunction with the knowledge of the practitioner and the existing evidence regarding efficacy of services. The *Framework* is divided into two major sections: the domain, which describes the areas of concern addressed by occupational therapists, and the process, which identifies the steps in the occupational therapy process and the actions involved in each step. The domain of occupational therapy includes several factors where an understanding of kinesiology and motion in the human body will positively affect the outcome of services. In the area of occupation, kinesiological principles can be applied to activities of daily living, work, play, leisure, and social participation to enhance client outcomes. Client factors such as body functions and body structures refer to the "physiological function of body systems … and anatomical parts of the body" (American Occupational Therapy Association, 2014), and an understanding of kinesiology can be utilized to maximize client function. Performance skills are "small units of engagement in daily life occupations" (American Occupational Therapy Association, 2014, p. S7), which can be positively affected by the application of kinesiology principles for client benefit. In the process of delivering occupational therapy services, an understanding of kinesiology will positively affect analysis of occupational performance and the planning, execution, and follow-up modification of intervention sessions.

Anatomic Position and Body Movements

Anatomic position is defined as the position in which the person is standing erect, facing forward, with the arms at their sides, palms facing forward, and the fingers and thumbs in extension (Kendall, McCreary, & Provance, 1993). It is the reference position for labeling body parts, and movements are typically described with respect to anatomical position, unless otherwise specified.

Basic trunk and/or limb movements, some of which occur in multiple joints, include flexion, extension, and hyperextension; lateral flexion to the right and left; rotation to the right and left; abduction and adduction; internal and external rotation; pronation and supination; inversion and eversion; and radial and ulnar deviation (Table 2-1).

Planes and Axes of Movement

Planes and axes provide a three-dimensional (3D) system for describing movements in space. Because space is 3D, each of these dimensions must be described by a plane in which motion occurs. The three principal (or cardinal) planes are described with respect to anatomical position, and an understanding of the planes of the body is essential to describing the space and direction in which movement occurs (Muscolino, 2006). The three basic planes in the body are the sagittal and frontal (coronal) planes, which are oriented vertically, and the transverse (horizontal) plane, which is oriented horizontally.

Table 2-1

Terminology Related to Joint Movements (From Anatomical Position)

Motion	**Description**
Flexion and extension	• Flexion and extension occur in the sagittal plane around the mediolateral (coronal, or X) axis, which extends from side to side. Flexion (often referred to as *bending*) occurs in the anterior direction in the neck, trunk, joints of the upper extremity, and the hip. Flexion of the knee, ankle, and toes occurs in the posterior direction. Extension (often referred to as *straightening*) occurs in the direction opposite of flexion. The term *hyperextension* describes movement beyond normal ROM in the direction of extension. Dorsiflexion occurs as a flexion movement of the ankle as the foot moves toward the anterior surface of the tibia. Plantarflexion is an extension movement of the foot as it moves away from the tibia at the ankle joint.
Lateral flexion	• Lateral flexion also occurs in the frontal plane around the anteroposterior axis and includes lateral (sideways) movements of the neck and trunk.
Horizontal abduction and adduction	• Horizontal abduction and adduction are shoulder movements that occur in the transverse plane around a vertical (longitudinal, or Y) axis. From a flexed position of the shoulder, horizontal abduction is movement of the shoulder away from midline in a lateral direction, and horizontal adduction involves movement toward midline in a medial direction.
Internal and external rotation	• Internal and external rotation also occur in the transverse plane around a vertical axis. In the upper and lower extremities, movement of the anterior surface of the extremity toward the midline of the body is referred to as *internal* (or *medial*) rotation, and movement away from midline is referred to as *external* (or *lateral*) rotation.
Rotation of the head, neck, trunk, and pelvis	• Rotation of the head, neck, trunk, and pelvis also occurs in the transverse plane around a vertical axis through the center of the body and may be described as rotation to the right or left, or rotation occurring in a clockwise or counterclockwise direction.
Movements of the scapula	• Scapular adduction (retraction) describes movement of the scapula toward the vertebral column and scapular abduction (protraction) describes movement of the scapula away from the vertebral column. • Elevation of the scapula refers to superior (or upward) movement of the scapula and scapular depression refers to inferior (or downward) movement of the scapula. • Upward rotation of the scapula is described by upward movement of the glenoid fossa and lateral movement of the inferior angle of the scapula, while downward rotation includes downward movement of the glenoid fossa and medial movement of the inferior angle of the scapula.
Pronation and supination of the forearm	• Pronation and supination of the forearm refers to rotation of the forearm in the transverse plane around the vertical axis of the arm. In supination, the volar surface of the hand faces anteriorly, and in pronation, the palm is oriented posteriorly.
Radial and ulnar deviation of the wrist	• Radial and ulnar deviation occurs in the frontal plane around the anteroposterior axis. Radial deviation (abduction) refers to lateral movement toward the thumb side of the hand away from the body, while ulnar deviation (adduction) refers to movement toward the little finger side of the hand toward the body.

Adapted from Houglum, P., & Bertoti, D. B. (2012). *Brunnstrom's clinical kinesiology* (6th ed.). Philadelphia, PA: F. A. Davis and Kendall, F. P., Provance, P. G., Rodgers, M., & Romani, W. (2005). *Muscles: Testing and function, with posture and pain*. Philadelphia, PA: Lippincott Williams & Wilkins.

The sagittal plane extends from front to back, divides the body into the right and left sides (Figure 2-2), and movements in the sagittal plane are anterior-posterior or posterior-anterior. Examples of movements in the sagittal plane include flexion and extension of the trunk (bending forward and backward while facing forward) and flexion and extension of the shoulder, elbow, wrist, and fingers while in anatomical position.

The frontal (coronal) plane extends from side to side and divides the body into front and back. Movements in this plane go from right to left or left to right (Muscolino, 2006). Movements include bending the trunk in a side-to-side fashion and abduction (moving away from the body to the side) and adduction (moving toward the body) of the shoulders and hips.

The transverse (horizontal) plane divides the body into upper and lower sections. This plane has a horizontal orientation as opposed to the sagittal and frontal planes, which are oriented vertically. Movements that occur in the transverse plane are typically rotational, including turning the head from

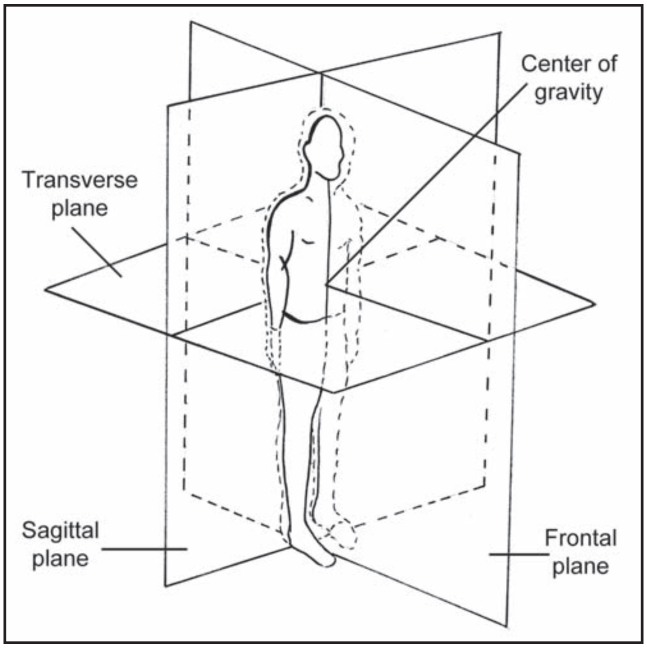

Figure 2-2. Planes and axes.

Table 2-2

Motions in Each Plane and Axis

Plane and Axis	Movements
Sagittal plane around the mediolateral (frontal, coronal, X) axis	Flexion, extension, and hyperextension
Frontal (coronal) plane around the anteroposterior (sagittal, Z) axis	Abduction, adduction, lateral flexion, radial and ulnar deviation
Transverse (horizontal) plane around the vertical (longitudinal, Y) axis	Supination, pronation, internal and external rotation, neck and trunk rotation, horizontal abduction and adduction

side to side, twisting at the waist, and internal and external rotation of the upper and lower extremities with the body in anatomical position.

The intersection of the center of all three of these planes is the center of gravity (COG; Kendall et al., 1993). Planes that do not lie in line with any one of these planes in one of the three basic planes are described as oblique planes (Neumann, 2010).

An axis is an imaginary straight line around which rotary or angular movement occurs. The axis around which movement occurs is always perpendicular to the plane in which the movement is occurring. For each of the principal planes, there is a corresponding axis and, therefore, movement can be described as occurring within a plane and around the associated (perpendicular) axis. The axis that is perpendicular to the sagittal plane is called the *mediolateral axis*, named by its directional orientation, although it is also referred to as the *frontal, coronal, or X axis* in various publications (Muscolino, 2006; Neumann, 2010). It runs in a left-to-right or right-to-left direction. Movements around the mediolateral axis include flexion and extension of the trunk, shoulders, elbows, wrists, fingers, hips, and knees, as well as dorsi- and plantarflexion of the ankle.

The axis that is located perpendicular to the frontal plane is referred to as the *anteroposterior axis* as it is oriented from the front to the back or back to the front of the body. It is also called the *sagittal* or *Z axis* by some authors. The abduction and adduction that occurs at the shoulders and hips when doing a jumping jack is an example of movement in the frontal plane around the anteroposterior axis. Other motions occurring in the frontal plane around the anteroposterior axis are lateral flexion of the trunk, radial and ulnar deviation at the wrist, and inversion and eversion of the foot.

The axis located perpendicular to the transverse plane runs in a superior-inferior direction and is called the *vertical axis*, but may also be labeled the *longitudinal* or *Y axis*. Shaking one's head "no" is an example of movement in the transverse plane around the Y axis. Motions occurring around this axis include internal and external rotation, horizontal abduction and adduction, and pronation and supination of the forearm.

The importance of understanding planes and axes lies in the ability of this 3D system to describe movements clearly and consistently (Table 2-2). Movement in the sagittal plane and around the corresponding mediolateral axis is best visualized from the side of the body. Movements taking place in the frontal plane and around the anteroposterior axis are best observed from the front of the body. Motion in the transverse plane and around the longitudinal axis are most easily visualized from a superior or inferior perspective. Using an index card that is pierced by a rod (such as a pencil) to represent a plane and its corresponding axis can be a valuable and portable tool to help practitioners and students alike to visualize these concepts.

It is critical for the learner to be able to visualize both the orientation of and the relationship between the planes and axes to fully understand a description of movement, as well as to properly conduct assessments such as manual muscle testing and passive range of motion (PROM).

Joint Classifications

Neumann (2010) describes a joint as the junction or pivot point between two or more bones. Joints can be classified either by how much motion is available at the joint or by the type of tissue that comprises the junction between the components of the joint (Resnick & Kransdorf, 2005). Classification of joints based on available motion includes three basic categories: synarthroses, amphiarthroses, and diarthroses. Synarthroses are joints that essentially allow no motion. Amphiarthroses are joints that are slightly moveable, and diarthroses are joints that move freely in the absence of pathology (Table 2-3; Resnick & Kransdorf, 2005). The classification of joints based on the type of connecting tissue overlaps with the classification based on available movement and includes fibrous, cartilaginous, and synovial joints.

Table 2-3

JOINT CLASSIFICATIONS

JOINT TYPE	CHARACTERISTICS	TYPES	EXAMPLES
Synarthrosis (fibrous)	• Immovable joints • Connective tissue or hyaline cartilage	• Suture	• Skull
		• Syndesmosis	• Distal radioulnar joint • Distal tibiofibular joint • Sacroiliac ligament
		• Gomphosis	• Teeth insertion into mandible and maxilla
Amphiarthrosis (cartilaginous)	• Slight movement	• Symphysis	• Symphysis pubis • Manubrioalsternal joint • Intervertebral disc
		• Synchondrosis	• Physeal plate (growth plate) • Sphenooccipital joint
Diarthrosis (synovial)	• Most numerous in body • Freely moveable	• Hinge (ginglymus)	• Elbow; knee
		• Pivot	• Atlantoaxial joint in the spine; humeroradial joint
		• Condyloid	• MCP joints of the hand
		• Saddle	• Carpometacarpal joint of the thumb
		• Ball and socket	• Shoulder • Hip

Fibrous Joints (Synarthroses)

There are three types of fibrous joints. The bones of a synarthrodial joint are joined by dense fibrous connective tissue that directly unites bone to bone. An example of this is a suture joint in the skull. A syndesmosis is a fibrous joint (Lippert, 2017) that is held together by an interosseous ligament or membrane, and motion is limited to the stretching or extensibility of the connecting ligament or membrane (Resnick & Kransdorf, 2005). The distal radioulnar joint is an example of syndesmosis. A gomphosis is a fibrous joint characterized by a peg in socket alignment, such as the articulation between a tooth and the mandible.

Cartilaginous Joints (Amphiarthroses)

There are two types of cartilaginous joints: symphyses and synchondroses. The junction of a symphysis joint is formed by fibrocartilage or hyaline cartilage, and they are typically characterized by relatively restrained movement. Examples of symphysis joints include the interbody joints of the spine, the symphysis pubis, and the manubriosternal joint. Synchondroses are temporary joints that are present as the skeleton grows but become thinner and are ultimately replaced by bony union as skeletal maturity is reached (Resnick & Kransdorf, 2005).

Synovial Joints (Diarthroses)

Synovial joints allow much greater freedom of motion, and the adjacent bones are separated by a distinct space referred to as the *joint cavity*. The entire joint is encased in a fibrous joint capsule (Rybski, 2012), and connective tissue does not directly connect adjacent bony surfaces. The articulating surfaces of the bones comprising the joint are covered by a layer of connective tissue, usually hyaline cartilage. This tissue, which varies in thickness depending on the size, functional demand, external forces, and joint, serves as a shock absorber and decreases friction within the joint. The fibrous joint capsule is composed of a tough outer layer and a thin, more fragile inner layer called the *synovial membrane*. The synovial membrane secretes synovial fluid into the joint space, nourishing the articular cartilage and lubricating the joint surfaces, decreasing friction within the joint. Outside of the capsule, ligaments, fasciae, aponeuroses, and tendons provide support to the joint, and synovial sheaths surrounding the tendons promote gliding. In addition, fluid filled sacs called *bursae* increase lubrication and thus gliding between adjacent layers of tissue (Figure 2-3).

Classification of Synovial Joints

Synovial joints can be classified by degrees of freedom or the directions in which they move. A uniaxial joint is constructed in such a way that only one degree of freedom exists in the joint, meaning that rotary movement occurs around one axis and takes place within the corresponding plane of the body. A hinge joint (ginglymus joint) is a type of uniaxial joint that typically

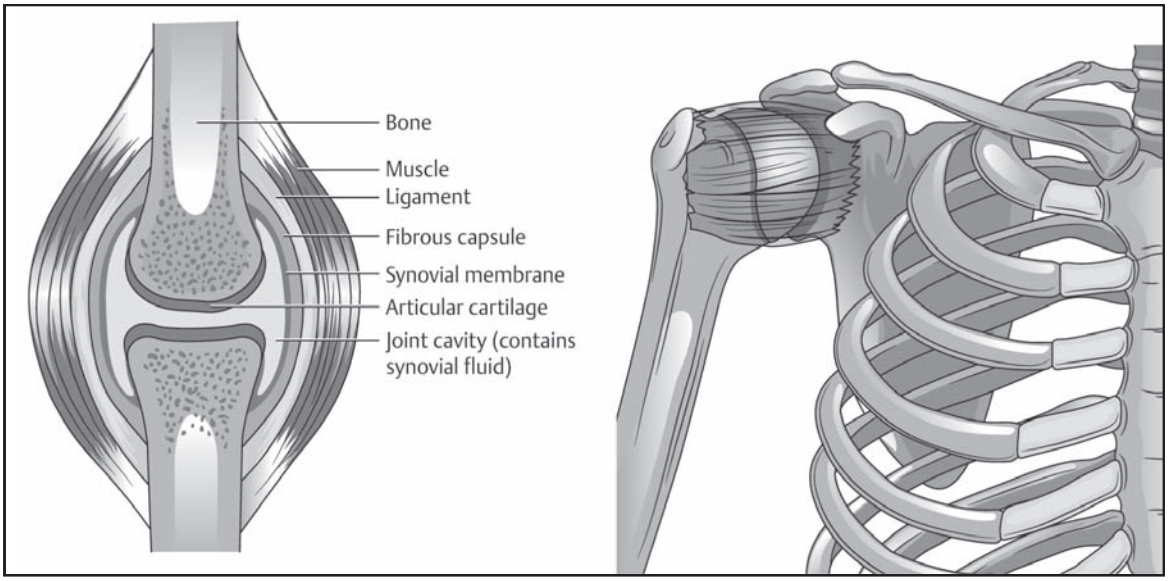

Figure 2-3. Structure of a synovial joint.

connects a concave surface with a convex surface and moves in flexion and extension (Figure 2-4). From the anatomic position, movement occurs in the sagittal plane around the mediolateral axis. Examples of hinge joints include the elbow and knee. Another type of uniaxial joint is a pivot joint (trochoid joint), in which one component of the joint is shaped like a ring and the other component rotates within it (Figure 2-5). From an anatomic position, the only movement that occurs is rotation in the transverse plane around the longitudinal axis. Examples of this type of joint include the atlantoaxial joint in the cervical spine, in which the second cervical vertebra has an upward bony projection providing an axis around which the first cervical vertebra rotates, and the humeroradial joint of the elbow.

Biaxial joints present with movement of the bony components in two planes and around two axes; therefore, they have two degrees of freedom. The condyloid (or ellipsoid or ovoid) joint has an oval or egg-shaped convex surface that fits into a reciprocally shaped concave surface, allowing the concave surface to slide over the convex surface in two directions (Figure 2-6). The movements include flexion/extension and abduction/adduction. Circumduction is also present in these joints but is actually a sequential combination of the already mentioned movements. The metacarpophalangeal (MCP) joints of the hand are condyloid joints. The saddle joint is also biaxial, so named because the joint components fit together like a rider on a saddle, with two degrees of freedom (Figure 2-7). In a saddle joint, each bony component is convex in one plane and concave in the other, with flexion and extension in one plane and abduction/adduction in another. The carpometacarpal joint of the thumb is an example of a saddle joint.

Triaxial or multiaxial joints have multiple degrees of freedom with distinctly different movements occurring in the three cardinal planes of motion and around the three cardinal axes. Ball and socket joints are one type of multiaxial joint, in which a spherical head at the end of one bone fits into and moves within a cup or saucer like concavity in the bone with which it articulates. This type of articulation is found in the glenohumeral joint of the shoulder, where the head of the humerus (ball) sits in the glenoid fossa (socket; Figure 2-8). In the hip, the head of the femur (ball) sits in the acetabulum (socket) of the pelvis. The structure of these joints allows for movement in flexion and extension (sagittal plane, X axis), abduction and adduction (frontal plane, Z axis), and internal and external rotation (transverse plane, Y axis). The plane joint is another type of multiaxial joint. Plane joints are typically composed of flat or slightly curved, irregularly shaped bones. This joint structure allows for multidirectional gliding between two or more bones. An example of plane joints is the intercarpal articulations in the wrist, at which slight gliding motions occur between the carpal bones during wrist motions.

Types of Motion

Movement can occur as linear (translatory) or angular (rotational) motion, but during every day activities, a combination of the two is necessary. According to Lippert (2017), the majority of the movement within the human body is angular and movement outside of the body is more linear in nature; however, it is not uncommon to see both types of movements occurring simultaneously. For example, a person walking down the street is traveling in a linear fashion from point A to point B. However, each of the joints of the lower extremities (hips, knees, and ankles) are moving in an angular fashion to advance the legs forward. Movement in the body is rarely only one type of motion.

Linear motion is defined as motion that occurs when all parts of the object move at the same time, in the same direction, and travel the same distance. Linear motion can be further described as either rectilinear or curvilinear (Lippert, 2017). Rectilinear movement occurs in a more or less straight line from one location to another, such as a person being pushed in a wheelchair down a hallway. When a person shrugs the shoulders up and down into elevation and depression, this would be considered linear motion.

When the trajectory is curved, the motion would be curvilinear, such as when a person throws a ball and the path of

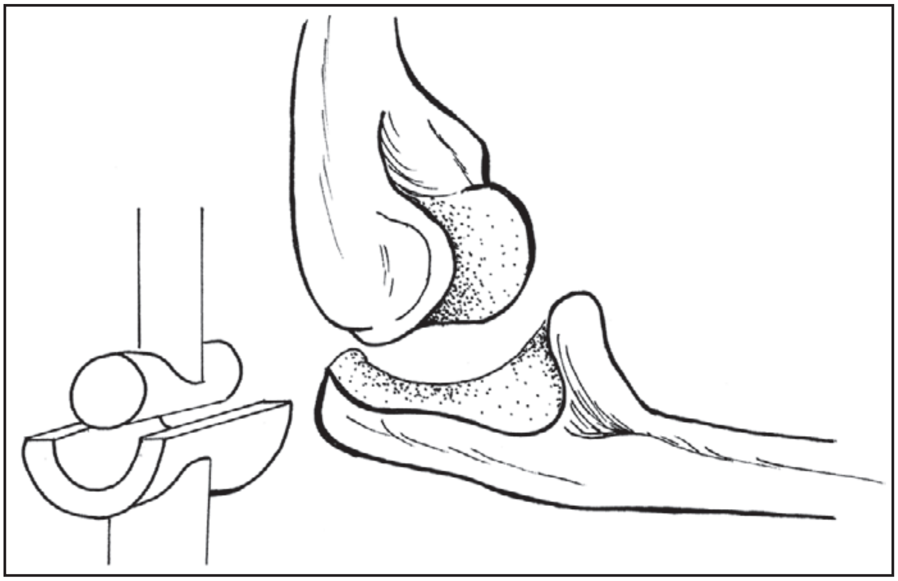

Figure 2-4. Uniaxial or ginglymus joint.

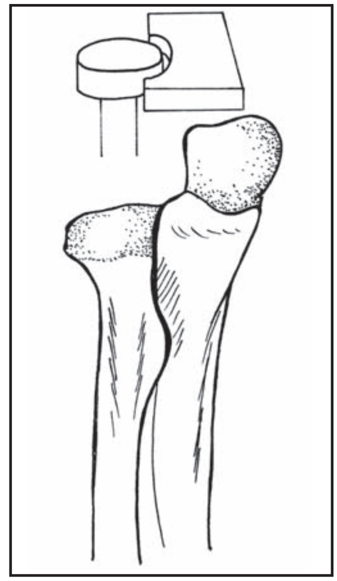

Figure 2-5. Pivot or trochoid joint.

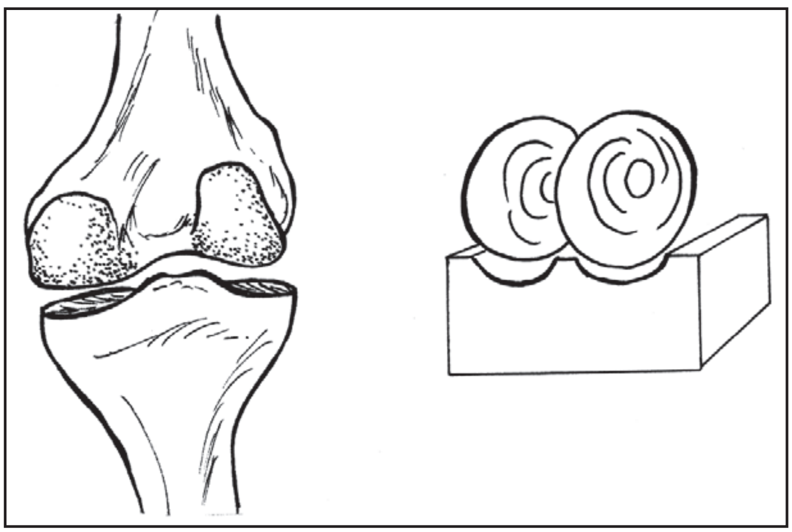

Figure 2-6. Condyloid or ellipsoid joint.

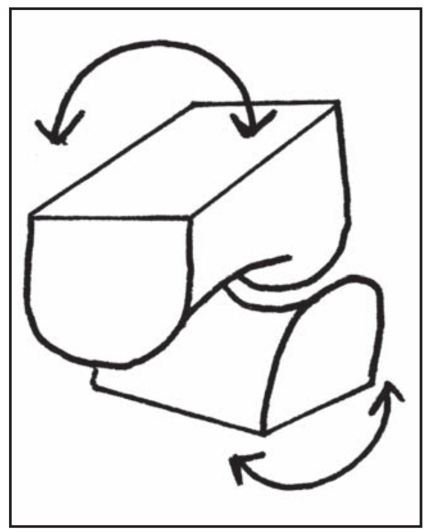

Figure 2-7. Saddle joint.

the object represents a parabola. Angular motion is defined as motion that occurs when all parts of the object move at the same time, in the same direction, but at different distances from the axis of motion. Angular motion occurs when a person swings his or her leg, or flexes his or her knee, the foot travels farther through space than does the ankle or leg. The ankle and the middle of the leg itself are closer to the knee joint, or joint axis than the foot (Lippert, 2017).

Arthrokinematics

Following the discussion of osteokinematics, which deals with the movement of bones around a joint axis, we will now consider the relationship of joint surface movement, which is referred to as *arthrokinematic motion* (Lippert, 2017). The terms typically utilized to describe this motion are *roll*, *slide* (or *glide)*, and *spin*. Roll occurs when multiple points on one

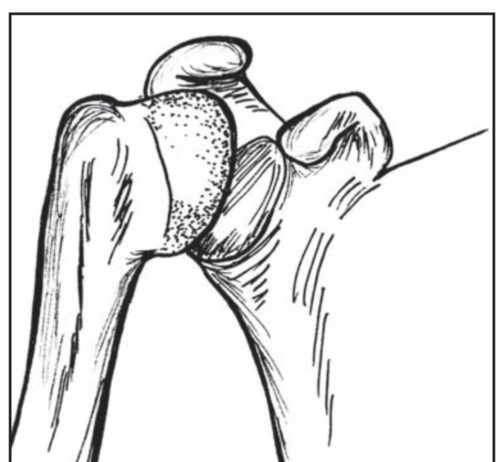

Figure 2-8. Ball and socket joint.

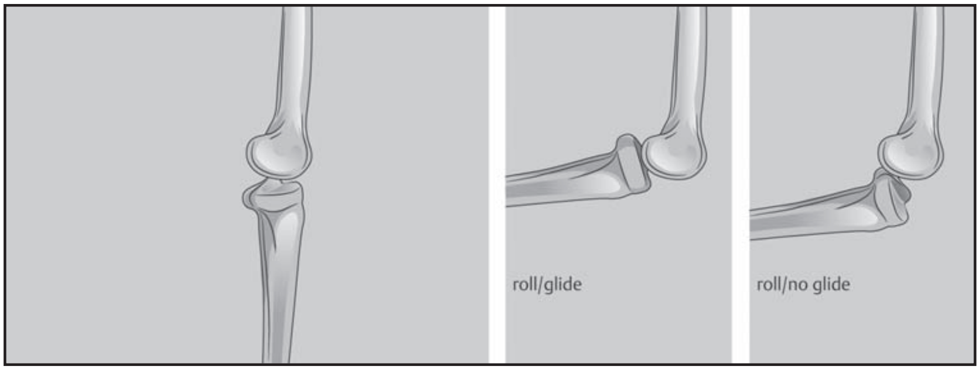

Figure 2-9. Knee arthrokinematics.

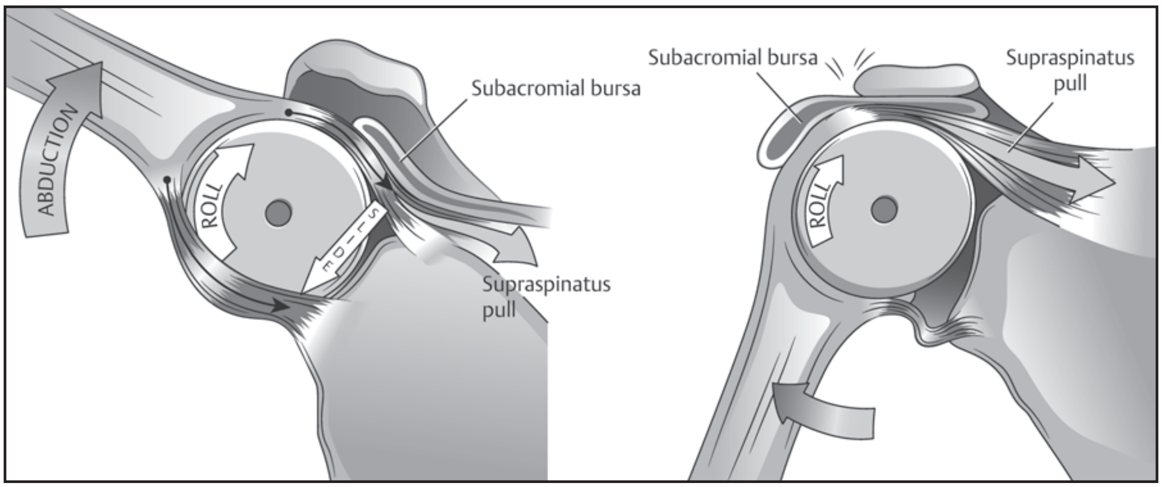

Figure 2-10. Convex-on-concave motion.

rotating articular surface contact multiple points on the other articulating surface, such as a tire rotating along a paved road. Slide (or glide) occurs in a joint when a point or set of points on one articular surface contacts multiple points on another articular surface, such as when a box is being pushed up a ramp or incline. Lastly, spin occurs when one single point on one articular surface rotates on a single point on another articular surface, like a top spinning on one point on the floor. "Essentially, the same point on each surface remains in contact with each other" (Lippert, 2017, p. 35).

Understanding arthrokinematics is essential for occupational therapy practitioners because this type of movement can be generated passively by a clinician to a client during intervention techniques utilized to increase range of motion (ROM). In general, rolling and sliding occur simultaneously to achieve optimal joint motion and maintain proper joint congruency. If a joint does not demonstrate simultaneous sliding and rolling, one joint surface is at risk for rolling off of the other joint surface before the full ROM is achieved. An example provided by Lippert (2017) describes the knee joint requiring roll and glide to keep the joint surfaces aligned. If rolling and sliding do not occur simultaneously, unhealthy relationships between the bones of a joint can occur, as depicted in Figure 2-9.

The relationship between the articulating joint surfaces is essential for optimal, safe motion, as described in the convex-concave patterns of movement, in which osteokinematics and arthrokinematics are analyzed together. When a convex joint surface moves on a fixed concave joint surface, the roll and slide occur in the opposite direction (convex-on-concave; Figure 2-10). When a concave surface moves on a stationary convex surface, the roll and slide occur in the same direction (concave-on-convex). During abduction of the shoulder, the convex head of the humerus rolls in a superior direction and slides in an inferior direction. Another example of convex-on-concave can be seen when a person is sitting down on a chair with a fixed distal lower extremity. When the person rises to standing, the convex head of the distal femur rolls anteriorly as it slides posteriorly.

Conversely, an example of concave-on-convex is when a person is sitting on a swing and kicking the lower leg forward and back. The concave end of the proximal tibia rolls and slides in the same direction on the stable, convex end of the femur (Figure 2-11). For a visual of these patterns of movement, please see https://www.youtube.com/watch?v=RHY0LCkayg&feature=youtu.be. According to Samuels (2018), there has been evidence of joint arthrokinematics that appear to be inconsistent with these rules as described. However, the fundamentals of these patterns that occur during human movement can be appreciated by acknowledging that rolling and sliding happen synchronously to produce efficient and safe movement.

Kinematic Chains

In the examples listed previously, open- vs. closed-chain movement is also highlighted. Open-chain movement occurs when the distal segment of a joint moves on a relatively fixed proximal segment, such as the person sitting on a swing and kicking the lower leg back and forth. In contrast, closed-chain movement occurs when the proximal segment of the joint moves on a fixed distal segment, such as when a person rises from a sitting to standing position with the feet planted. In other words, the feet are fixed to the floor during a closed-chain movement, as compared to the person swinging the legs on a swing, where the legs (or distal segment) are free to move back and forth.

This concept of open- and closed-chain movements must be considered when clinicians prescribe exercise. Sometimes referred to as *kinematic chains*, these movements enable the body to transform stereotypical angular motion of joints into efficient curvilinear motion (Smith, Weiss, & Lehmkuhl, 1996). Kinematic chains are several joints that unite successive segments, creating a series of connected links that allow motion (Lippert, 2017). Imagine an orchestra conductor: the wave of his baton represents an open kinematic chain, while the sway of his body in time to the music represents a closed kinematic chain.

Joint Congruency

According to Lippert (2017), "How well joint surfaces match or fit is called joint congruency" (p. 36). When a joint is congruent, there is maximum contact between the articulating surfaces and the two parts are tightly compressed, making it challenging to distract or separate them. In this position, the joint capsule and ligaments holding the bones together are taut, or tight. This position would be considered close packed, and further passive movement of the joint is not possible. An example of a close-packed position at one extreme of ROM is full flexion of the patellofemoral joint of the knee.

When the knee is flexed, the lateral and medial patellar movements, which can be accomplished manually while the knee is extended, are unavailable. Another example of a close-packed position is MCP flexion (Lippert, 2017). When the MCP joint is extended, there is significant abduction and adduction of the fingers, but when flexed, these motions are unavailable. The tibiofemoral joint at the knee is also in a close-packed position in full extension. Clinical relevance of the close-packed position includes assessment for stability and joint integrity. A joint in a close-packed position is more likely to be injured than if it were in an open-packed position. If edema is present, it is more difficult for a client to move into a close-packed position (Lippert, 2017).

All other positions of the joint are called *open-* or *loose-packed*, where the joint surfaces do not fit perfectly. Clinically, this is also referred to as a *resting position*. Parts of the joint capsule and supporting ligaments are lax, and there is very little congruency between the articular surfaces. Open-packed positions permit additional or accessory motions (Lippert, 2017) since the ligaments and capsular structures are lax. Accessory motion is defined as movement in surrounding joints that accompanies active motion in the primary joint. Accessory motion is necessary for normal ROM but cannot be isolated voluntarily (Thomas, 1997). This can be seen in the scapula and clavicle as the humerus is flexed or abducted. As the humerus is raised, the scapula rotates upwardly and may protract, while the clavicle moves forward and elevates. This movement of the scapula and clavicle occurs without conscious control and is essential for full humeral elevation.

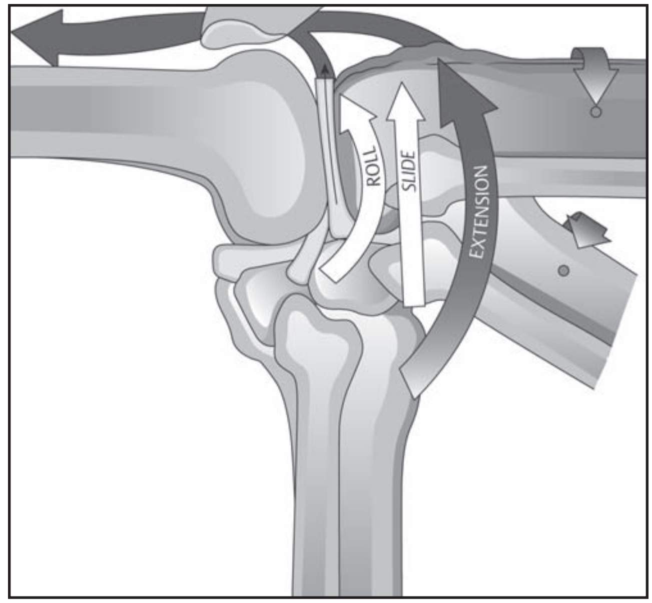

Figure 2-11. Concave-on-convex motion.

Another example of accessory motion is the downward movement of the humeral head in the glenoid fossa during shoulder elevation accomplished by rotator cuff muscles. Although the deltoid muscles are primarily responsible for elevating the humerus, if downward movement of the head of the humerus in the glenoid fossa did not occur, the greater tuberosity would hit the acromion process. The rotator cuff muscles allow the accessory motion necessary for the deltoid muscles to complete humeral elevation without pain or impingement (Smith et al., 1996).

Joint play "is the arthrokinematic movement that happens between joint surfaces when an external force creates passive motion at the joint" (Lippert, 2017, p. 32). It can also be defined as the accessory movement present in a joint, which is not under volitional control but is critical to achieve full function or ROM at a joint. Joint play is the extensibility of the joint capsule or the "give" that occurs when joints are passively distracted. Specific joint mobilization techniques are used to restore or maintain joint play and should only be implemented by a trained clinician.

Kinetics

Kinetics is an analysis of the forces that create motion or maintain equilibrium and begins with a review of Newton's laws. Understanding these theories will help clarify movement of the human body, which is of interest to the occupational therapy practitioner.

Newton's first law, the law of inertia, states that if an object is at rest it will remain at rest unless acted upon by an external force, and that an object in motion will remain in motion in a straight line and in a constant velocity unless acted upon by an external force. To understand this law, one must understand the concept of net force, which is defined as the sum of all forces acting on the object. In outer space, an object may be subjected to no external forces, resulting in a net force of zero, and Newton's first law would apply to that object. However, we practice occupational therapy on Earth where there is a constant presence of the external force of gravity, which is always the same in magnitude and direction, and variable external forces such as friction and air currents (Pippard, 1972).

Newton's second law, the law of acceleration, states that the acceleration of an object is directly proportional to the combined forces acting on it, and inversely proportional to the mass of the object. This equation is explained by the equations F = ma (force equals mass times acceleration) and a = F/m (acceleration equals force divided by mass). For acceleration to occur, the force applied to an object in the desired direction must exceed the external force(s) acting on the object in the opposite direction (Pippard, 1972).

Newton's third law, the law of action and reaction, states that for every action, there is an equal and opposite reaction, resulting in a net force of zero. The propulsion of a rocket clearly illustrates this law, as the thrust produced by the gases and fuel is directly opposite the direction in which the rocket moves (Pippard, 1972).

To illustrate Newton's laws on Earth, let us consider a person sitting perfectly still in a wheelchair on a perfectly level surface. According to Newton's first law, an object at rest will remain at rest in the absence of an imbalance of external forces. The force of gravity is a constant external force acting in a downward direction on the wheelchair, but according to Newton's third law, the downward force of gravity will be neutralized by an equally strong force being generated in the opposite direction from the surface on which the wheelchair is resting. With a net force of zero, the wheelchair will not move unless another external force acts on the wheelchair, creating an imbalance of forces. On Earth, if the wheelchair is set in motion as a result of the application of an external force, it will not follow Newton's second law and it will not remain in motion in a straight line at a constant velocity. Perhaps it would do this in outer space, but not on Earth, as the external force created by the friction between the wheels of the wheelchair and the surface on which it rests creates an imbalance of forces and will result in deceleration of the wheelchair.

The weight of the person in the wheelchair will also lead to a gradual deceleration of the wheelchair. Understanding these concepts can inform and positively impact the delivery of occupational therapy services. If the person in the wheelchair presents with upper extremity weakness that affects his or her ability to propel the wheelchair functionally, the occupational therapy practitioner can recommend a lightweight wheelchair with tires that will produce less friction with the ground to offset the weakness, decrease energy cost, and enhance occupational engagement. These concepts can be applied to myriad clinical scenarios. With gravity as a constant external force, when a person presents with upper extremity weakness that affects sustained or prolonged movement against gravity, the occupational therapy practitioner is tasked with developing adaptations using rubber bands, springs, or other elements to assist movement against gravity and allow participation in valued occupations. For the client with challenges with acceleration, deceleration, and coordinated movement, the therapist will strive to increase or decrease the effects of friction in the environment, as well as providing alternative strategies to manage these challenges.

Forces

The discussion of Newton's laws leads to a discussion of forces and how they influence movement. A major external force that must always be considered is the force of gravity, or the attraction of the Earth for objects within its sphere of influence. Gravitational force is "always directed vertically downward toward the center of the Earth" (Lippert, 2017, p. 109). In kinesiology, we are also concerned with the effects of the Earth's pull on the body as we need to be able to generate enough muscular force to overcome the pull of gravity in order to engage in meaningful occupation. This leads to the concept of the COG. The COG is the part of the body about which all the parts are exactly balanced with each other, and it is the point of the body at which the entire weight of the body may be considered to be balanced.

Lippert (2017) defines COG as the "balance point of an object where torque on all sides is equal" (p. 99). When examining a solid sphere, cube, or rectangle, finding the COG is made simple by locating the object's geometric center. If trying to balance a volleyball or pencil on a fingertip, the COG is that point at which the ball and pencil perfectly balance. The COG for any solid object will remain unchanged despite the object's position in space. However, if that object changes in shape or weight distribution, the COG will change, as in a volleyball being run over by a car or a pencil being sharpened. Lippert (2017) goes on to define the COG in the human body as "the point at which planes of the body intersect" (p. 99). The COG in the body typically lies a little anterior to the S2 vertebra, although the exact location varies (Samuels, 2018). The COG in humans will also shift as people age and their bodies change. For example, in the process of aging, if degeneration of the vertebrae leads to a shortening of overall height, then the COG will be lower.

Specific COG for each body segment have also been determined and become important when analyzing the impact of external forces on the body. Each segment of the body is acted upon by the force of gravity and, therefore, has its own COG. The COG is approximately 4/9 or 45% of the length of the segment measured from the proximal end. Once a person moves out of anatomical position, the COG changes (Schenck & Cordova, 1980). There are several factors, in addition to COG, that affect a person's stability and may impact the intervention approach, the fabrication of an orthosis, or a clinical decision about an assistive device like a cane or crutches.

One factor affecting stability is the weight of the body, or object. Given equal height, the more an object weighs, the greater its stability. An example offered by Lippert (2017) includes a comparison between football players who are linebackers and those who are halfbacks. A linebacker is traditionally heavier, making it harder to push the player down.

Linebackers are also typically slower than halfbacks. Halfbacks are usually lighter and faster, but easier to knock down. There is an inverse relationship between stability and speed. When weight is added to the body, the COG shifts. For example, if a person is carrying a heavy grocery bag in the right hand, the COG will move toward the side carrying the load. To increase stability, the person carrying that bag will lean toward the left to bring the COG within the base of support (BOS). The BOS "is that part of the body that is in contact with the supporting surface" (Lippert, 2017, p. 110); and the line of gravity is a vertical line that would be drawn passing through the COG toward the center of the Earth. In other words, if a person is standing in an anatomical position, the COG will be just anterior to the S2 vertebra, and the BOS would be the two feet firm on the ground. An imaginary line from the top of the person's head, passing through the COG, to the point in between the two feet would be the line of gravity.

An example depicting the relationship between the COG and BOS can be made with a smartphone placed on a tabletop. If the smartphone is completely on the table, it will be very stable. If the smartphone is slid toward the edge of the table so that part of it is over the edge, it will become less stable; finally, it will fall off of the table when the COG falls outside of the BOS. The size of the BOS relative to the surface on which it rests is also a consideration because if the surface is not large enough to adequately support the object, the object will be unstable. When people have challenges with balance while walking, they tend to widen their stance and walk with a larger BOS. Infants learning to walk will do this as well; they will automatically compensate for the instability by spreading their legs apart while walking to increase the BOS. Clinicians will also prescribe walkers, crutches, and canes to facilitate an increase in the BOS if a person has challenges with strength or balance. When the BOS is wider, the person is more stable.

Lastly, the height of the COG above the BOS is also something to consider when working with a person who is not stable in standing. Clinicians often work with individuals recovering from neurological injuries, including strokes. When a person is recovering from a stroke, that person may have weakness on one side of the body and may feel unsafe or unstable in a standing position. During rehabilitation, the remediation of balance and motor control may be initiated with the person in quadruped, or while sitting on the edge of a mat to ensure a lower COG, thereby creating greater postural stability. As balance improves, the client may progress to working in a bipedal position.

Friction is an external force that is explained in part by Newton's third law since it is largely dependent upon the net force generated between two adjacent surfaces. The amount of friction between a person's feet and the surface on which he or she is moving can either increase or decrease stability and safety. If a person is walking on ice, he or she will be less stable because there is less friction between the supporting surface and the BOS than if the person is walking on carpet. Carpet, however, will make it much more challenging to push a front-wheeled walker, making it potentially less safe.

Forces may be internally or externally generated; can facilitate, impede, or prevent motion; and must be considered when planning therapeutic intervention. Pushing is an external force that causes compression, while pulling is a force that causes tension between two articulating surfaces.

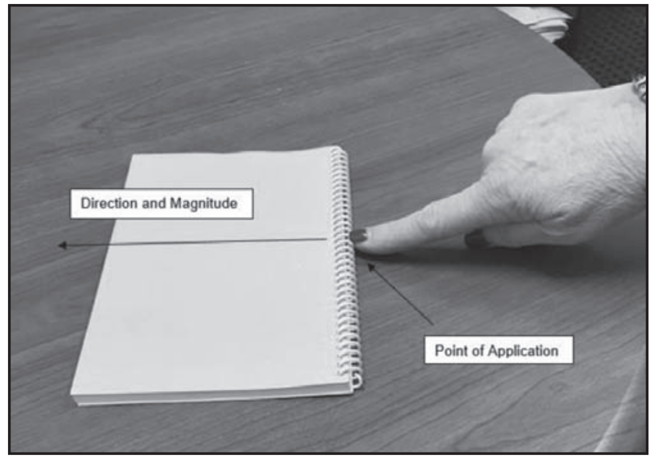

Figure 2-12. A pictorial representation of a force vector.

Internally generated force requires muscular contraction and has an effect on bones and ligaments. When a clinician is working with a stroke survivor, passive motion may be generated by the clinician to maintain the ROM in the person's affected upper extremity. Active motion may also be generated by asking the client to move the weak arm by activating his or her own muscles at the shoulder, elbow, wrist, and digits. Internal and external forces can be analyzed with regard to magnitude and direction using force vectors.

Force Vectors

A force vector is a pictorial representation of the point of application, direction, and magnitude of a force. Point of application is the exact point at which a force is being applied. A force vector is drawn as a line that indicates the direction of the force (Figure 2-12). One end of the line represents the point of application, and the magnitude of the force is depicted by the length of the line (Samuels, 2018). An example of a force vector outside of the body is a person pushing a notebook across a table. Where the person's finger meets the spiral binding is the point of application. An imaginary line can be drawn indicating the direction that the force is being applied. The length of the line would be dependent upon how much force is being exerted on the notebook in order to overcome the external forces that are already at play, such as gravity and the friction between the notebook and table.

An example of an internal force vector is the elbow joint. Consider the bones comprising the elbow joint (humerus, radius, and ulna) as well as the biceps generating the internal force. The point where the biceps muscle inserts into the forearm, or its distal attachment, would be considered the point of application for this force vector. The line that would be drawn toward the proximal attachment of the biceps muscle would represent the "line of pull," or direction of the force. The line of pull would end with an arrow, representing the magnitude of the force of the muscle contraction. In order to analyze the line of pull, the origin and insertion of the muscle must be known. Understanding "the relative position of the attachments to one another, which point is more moveable, the side of the joint(s) that the muscle crosses, the available motions at the joint(s) it crosses, and the angle at which it pulls" (Lippert,

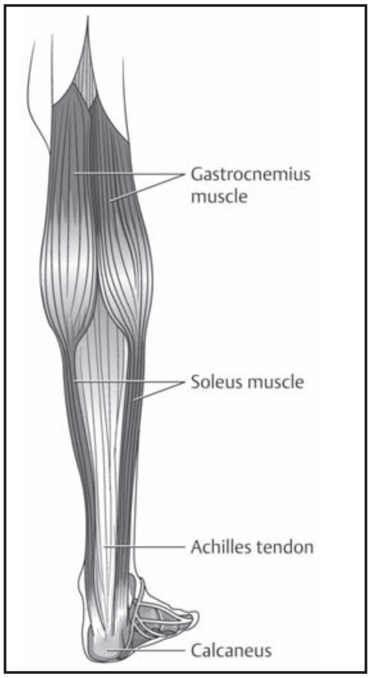

Figure 2-13. Linear forces.

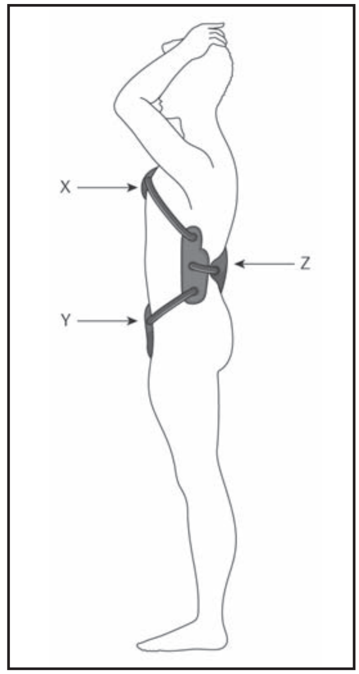

Figure 2-14. Back brace forces.

2017, p. 58) will provide information about how that muscle will generate movement. Having an appreciation of the line of pull will facilitate understanding of force vectors at a joint. Most muscles have a diagonal line of pull (Lippert, 2017), and that line of pull represents the composite of a vertical force (humerus) and a horizontal force (forearm) in the previously mentioned example.

To understand the effect of force on a joint, one needs to look at the angle formed by the moving part and the line of pull. If this angle is less than 90 degrees, there is a force of compression or approximation on the joint, meaning that the articulating surfaces are being pushed closer together (Lippert, 2017). When that angle is greater than 90 degrees, the force on the joint is one of distraction, with the joint surfaces moving apart. Compression and distraction are both linear (translatory) forces. Pure rotation occurs when there is exactly 90 degrees between the moving lever (forearm) and the line of pull (biceps). At exactly 90 degrees, there is neither a force of compression nor distraction on the joint. During elbow flexion, the forearm is the moving lever, and the angle formed by the forearm and the line of pull of the biceps determines the force on the elbow joint. The forces on a joint and the available joint space must be carefully considered by an occupational therapy practitioner when implementing a program to increase PROM in a joint. For a dynamic visual of these concepts, please visit https://www.youtube.com/watch?v=9hLC9Iz6xCI (brachioradialis) and https://www.youtube.com/watch?v=T7-a92JKHpY (biceps).

Analysis of Forces

Forces can be described by the effect they produce on a joint in the human body.

Linear Force Systems

A linear force system is when two or more forces act upon an object in the same line with roughly the same point of application (Lippert, 2017). Examples of linear force systems in the body include the gastrocnemius and soleus working in the "same line" and serving to plantarflex the foot, and the psoas and iliacus muscles working in the "same line" to flex the hip (Figure 2-13).

Parallel force systems are composed of two or more forces acting on an object, in the same plane, and in the same or opposite direction. These action lines never converge. An example of this type of system is found in the body where the abdominals and back extensors impact the stability and movement at the trunk. Parallel force systems can also be utilized in orthotic management. For example, a client who has a lumbar laminectomy or posterior spinal fusion may have movement precautions for the spine of "no bending, no lifting, and no twisting." Clinically, those precautions are accompanied by a back brace to provide security and stability to the surgical site. Lippert (2017) provides an example of such a brace. In Figure 2-14, forces X and Y are parallel and applied in the same direction, while force Z is parallel but applied in the opposite direction. In order for the brace to be effective, force Z must be in between forces X and Y.

A force couple exists when two or more muscles, which alone generate force in different linear directions, contract simultaneously and produce rotary movement (Neumann, 2010). If two hands are on a steering wheel of a vehicle, the right hand is pulling down and the left hand is pulling up. The result is that the car will turn to the right. An example of a force couple in the body is the movement at the scapula when a person abducts or flexes the humerus. The upper trapezius is a prime mover for elevation and upward rotation of the scapula, as well as an assist with adduction. The lower trapezius is a prime mover for depression and upward rotation

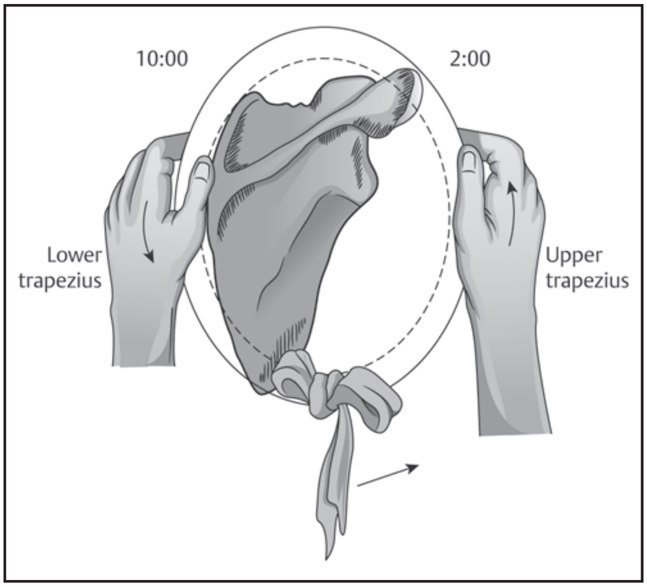

Figure 2-15. Wheel and axle mechanics.

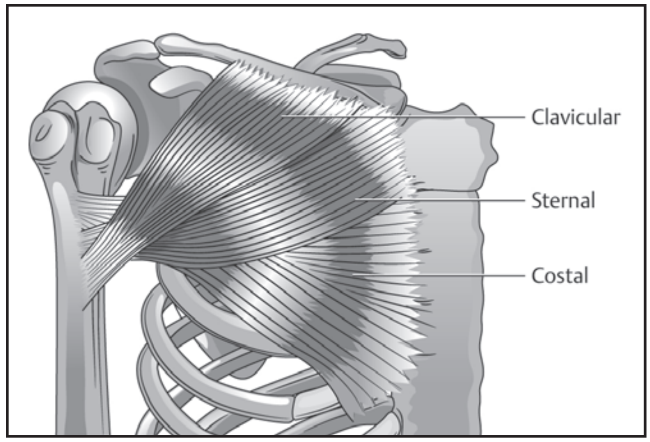

Figure 2-16. Pectoralis muscle motions.

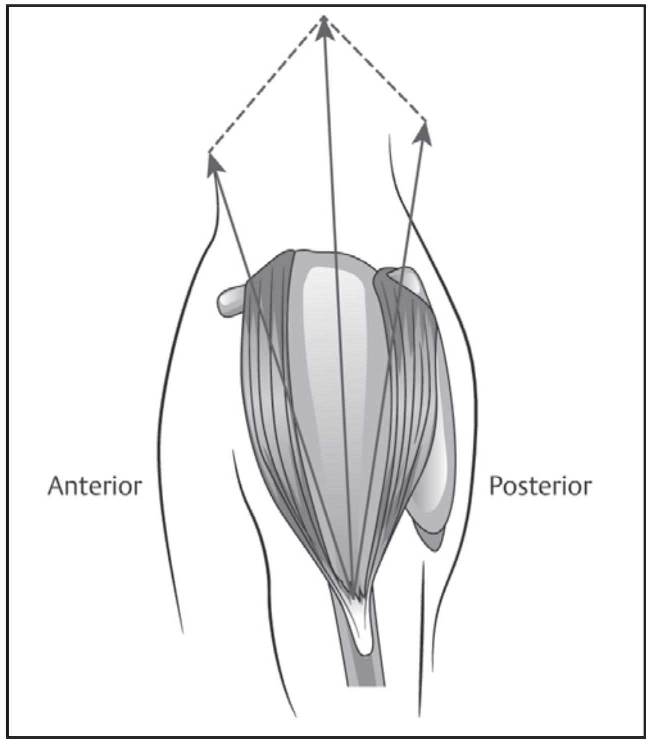

Figure 2-17. Deltoid muscle motions.

and is an assist for adduction. Lastly, the serratus anterior is a prime mover for abduction and upward rotation. When these muscles work together as a force couple, the result is upward rotation of the scapula because all of the other actions these muscles are responsible for will neutralize or cancel each other out (Figure 2-15).

Concurrent Force Systems

A concurrent force system exists when two or more forces act at a common point of application but in divergent directions. This is not a very common force system in the human body, but two examples include the pectoralis major and deltoid muscles (Figure 2-16).

In Figure 2-16, the clavicular portion and sternal portion of the pectoralis major have common attachments on the humerus but produce different motions when contracting individually. The clavicular portion contributes to shoulder flexion from 0 to 60 degrees. The sternal portion contributes to shoulder extension from 180 to 120 degrees (Lippert, 2017). When both portions of the muscle contract simultaneously, the resultant action is humeral adduction and internal rotation (Kendall et al., 2005).

The deltoid muscle also functions as a concurrent force system (Figure 2-17). The anterior deltoid primarily serves as a shoulder flexor and the posterior deltoid serves primarily as a shoulder extensor. When both are working simultaneously with the middle deltoid, pure humeral abduction is achieved.

A clinical application of a concurrent force system is the use of a dynamic orthosis for the fingers, as shown in Figure 2-18. In the figure, the loop of this dynamic outrigger orthosis is being pulled in two different directions: one into extension and the other into a radially abducted direction, creating a resultant force that is desired for this client's recovery.

Rotary Movements

Forces can also create rotary movements in the human body. *Torque* is a term that describes the force needed to produce rotation around an axis, such as the elbow flexion necessary for a person to bring the hand to the mouth when eating. Neumann (2010) considers torque a rotary equivalent of force, creating rotation of an object (lever), just as a push or a pull will move an object down a linear path. Two aspects of torque that must be considered include the strength of the force (magnitude) and the length of the moment arm, or lever arm. A moment arm is described as an imaginary line between the axis of rotation and the point along the line of pull of the muscle at which the two lines intersect at a right angle (Lippert, 2017). Torque can be calculated using the following formula:

$$\text{Torque} = (\text{force}) \times (\text{moment arm})$$

"The amount of torque a lever has depends on the amount of force exerted and the distance the force is from the axis" (Lippert, 2017, p. 107). An example commonly utilized to

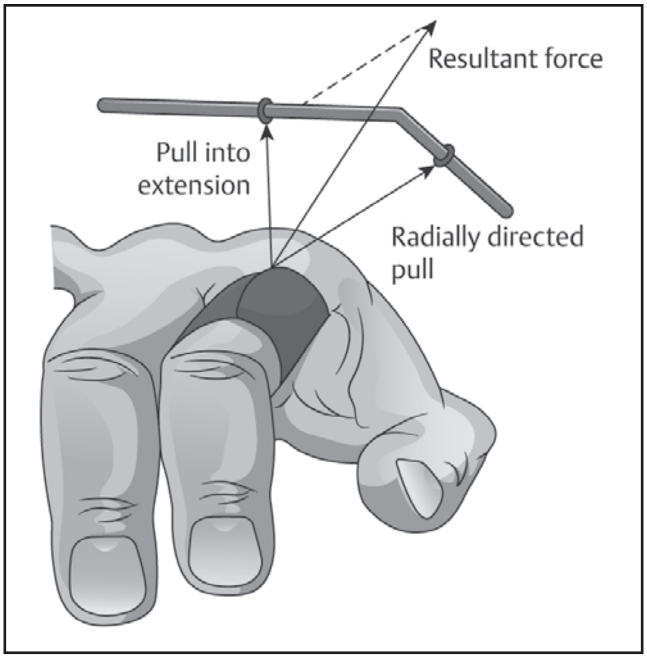

Figure 2-18. Dynamic finger orthosis forces.

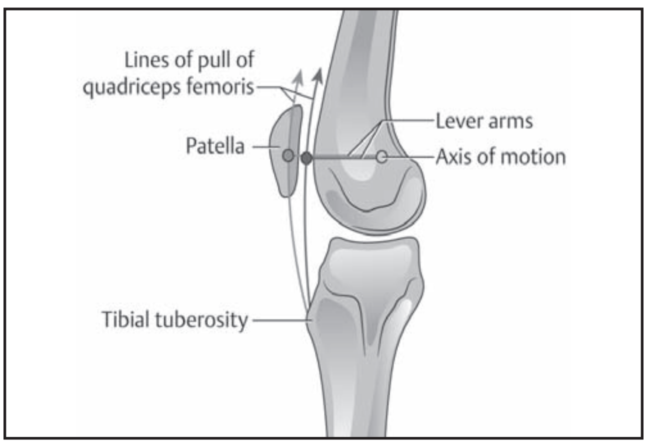

Figure 2-20. Torque application at the knee.

understand these concepts is the use of a wrench. When a person is using a wrench, the force applied, or torque, is a twisting force that is exerted by the person on the wrench. Torque can be increased by either increasing the force that is applied to the wrench or increasing the length of the handle. Either of these two approaches would make using the tool successful; however, the longer handle will make using the tool more efficient.

Neumann describes internal torque as "the product of the internal force and the internal moment arm" (2010, p. 15). The internal force is the amount of force created by muscle contraction to generate a rotational movement. In Figure 2-19, assuming that the muscle contraction for the biceps is the same in both A and B, it is clear that more internal torque will be generated in picture B with the longer moment arm than in picture A with the shorter moment arm. The same muscle producing the same amount of force will generate a different amount of torque in different positions.

As the angle of the elbow joint in Figure 2-19 changes, the amount of torque produced varies depending on the length of

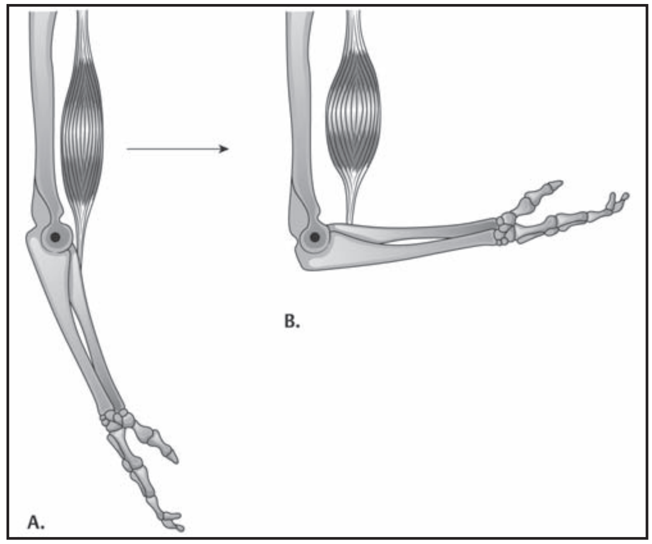

Figure 2-19. Internal torque of biceps muscle.

the moment arm. When the elbow is near full extension or full flexion, the moment arm is very short as there is very little distance between the axis of rotation and the line of the pull of the biceps. Lippert (2017) refers to the force generated by the muscle as stabilizing "in that nearly all of the force generated by the muscle is directed back into the joint, pulling the two bones together" (p. 109), which was identified as compression at a joint. As the elbow continues to move through its ROM, the angle between the axis of rotation and the line of pull will change. When the angle of pull is at 90 degrees, the force generated by the muscle is primarily angular in nature. This means that in that moment, the force will create more of a rotating force compared to a stabilizing force at the joint. The more angular force a muscle has, the less stabilizing force that same muscle will have and vice versa.

At midrange of the joint, the greatest angular force is produced. Past this point, the force being generated is less angular and more dislocating in nature as the adjacent articular surfaces are moving apart from each other (Lippert, 2017). In the discussion about force vectors, this was identified as distraction of the joint. In summary:

> [A] muscle is most efficient at moving, or rotating, a joint when the joint is at or near 90 degrees. A muscle becomes less efficient at moving or rotating when the joint angle is at the beginning or near the end of the joint range. (Lippert, 2017, p. 109)

A common example of the application of torque in the body is the change in angular force created at the knee joint by the patella. Any bone or bony prominence that changes the direction of pull of a muscle will change the length of the moment arm and, therefore, change the torque generated by the muscle if the force is constant. Without the patella, the quadriceps would have a shorter moment arm, creating more of a vertical line of pull. The patella holds the quadriceps tendon further from the axis of the knee joint, increasing the length of the lever arm, serving as an anatomical pulley. This increases the efficiency of the quadriceps by allowing it to generate greater torque without needing to produce more muscular force (Figure 2-20).

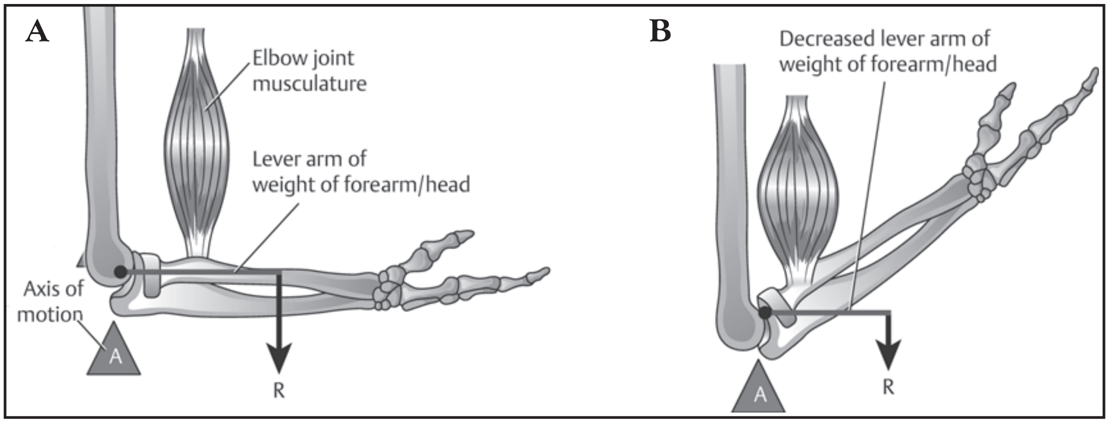

Figure 2-21. Moment arm differences.

If a force is applied exactly through the center of a joint (or through the axis of rotation), there is no torque. This is quite rare in the human body as a person must constantly overcome the effects of gravity to maintain a particular position or create motion. According to Neumann (2010), external torque is the product of the external force (e.g., gravity) and the external moment arm. The force of gravity creates external torque, which impacts the body, or specific segments of the body, during movement. "Measurements of the human body are needed to solve most problems in biomechanics" (Roberts & Falkenburg, 1992, p. 179) and actual measurements can be taken when necessary. Each segment of the body is acted upon by the force of gravity and has its own COG. As described earlier, the COG is approximately 4/9 or 45% of the length of the segment as measured from the proximal end of the segment. This measurement is used to determine the moment arm when calculating external torque (Roberts & Falkenburg, 1992).

Given that the force of gravity is constant, analysis of the diagrams in Figure 2-21 indicates that A has the larger moment arm and, thus, is subject to greater external torque. In A and B, the COG is approximately 4/9 the distance from the proximal end of the forearm to the end of the body segment and is represented by the letter R for resistance. In B, the elbow joint is at a different angle than in A, thus creating a different COG and a shorter moment arm than the one depicted in A. Therefore, if the muscle contracts with the same force in both positions, position A will generate more torque because of the longer moment arm.

Biomechanical Levers

Torque is required to move levers found in the body. Our musculoskeletal system is based on biomechanical levers, which can be thought of as rigid bars being acted upon by parallel forces that cause rotary movement.

In Figure 2-22, there is one child on either side of the axis, or fulcrum. The children represent a parallel force system creating rotation at the axis. One child can represent resistance and the other child can represent the effort. The four components of a lever can be seen: a rigid bar (which can also represent bones in the body), an axis (A) or fulcrum (point of rotation), an effort force (E), and a resistance force (R). It is important to understand how levers in the body work as this will support the analysis of force during meaningful activities.

The effort force is the force pulling in the direction of the desired movement. The resistance force is the force that resists the intended motion. If there is equilibrium, differentiating the effort force from the resistance force is arbitrary. Movement will cause rotation and it will always occur in the direction exerted by the effort force unless there is equilibrium. Depending on where the forces are in relationship to the axis, levers are classified into three classes.

A first-class lever exists when forces are exerted on opposite sides of the axis or fulcrum. A seesaw is an example of a first-class lever. To balance a seesaw, the child with more body mass will sit closer to the axis so that the greater mass can be overcome by the smaller gravitational force exerted by the smaller playmate. The smaller child's position further from the axis produces a longer lever arm so less effort is required to move or balance the seesaw. The smaller child will have greater leverage further way from the axis.

The same idea that a longer lever produces increased force can be seen in Figure 2-23. The muscles depicted in the figure are of the same size, cross-section, and fiber type, but they cross the joint at varying distances from the joint axis. Muscle B has a lever arm that is twice as long as Muscle A, so Muscle B has greater leverage and can produce more force to move the bone.

Common examples of first-class levers are a seesaw, scissors (actually, a double first-class lever), splints, and the atlanto-occipital joint of the neck. Figure 2-24 shows several examples of first-class levers. When using scissors, the effort comes from the muscles closing the scissors, the resistance is what is being cut, and the fulcrum is the screw holding the scissors together. Examples in the body include the atlanto-occipital joint in which the weight of the head is balanced by the neck extensors, or the intervertebral joints in sitting or standing where the trunk is balanced by the erector spinae acting on the vertebral axis.

In a second-class lever, the weight or resistance is situated in between the effort force and axis. A second-class lever occurs when a large amount of weight is supported or moved by a smaller force. A second-class lever is considered a force magnifier (Lafferty, 1992). Archimedes is reputed to have said in 200

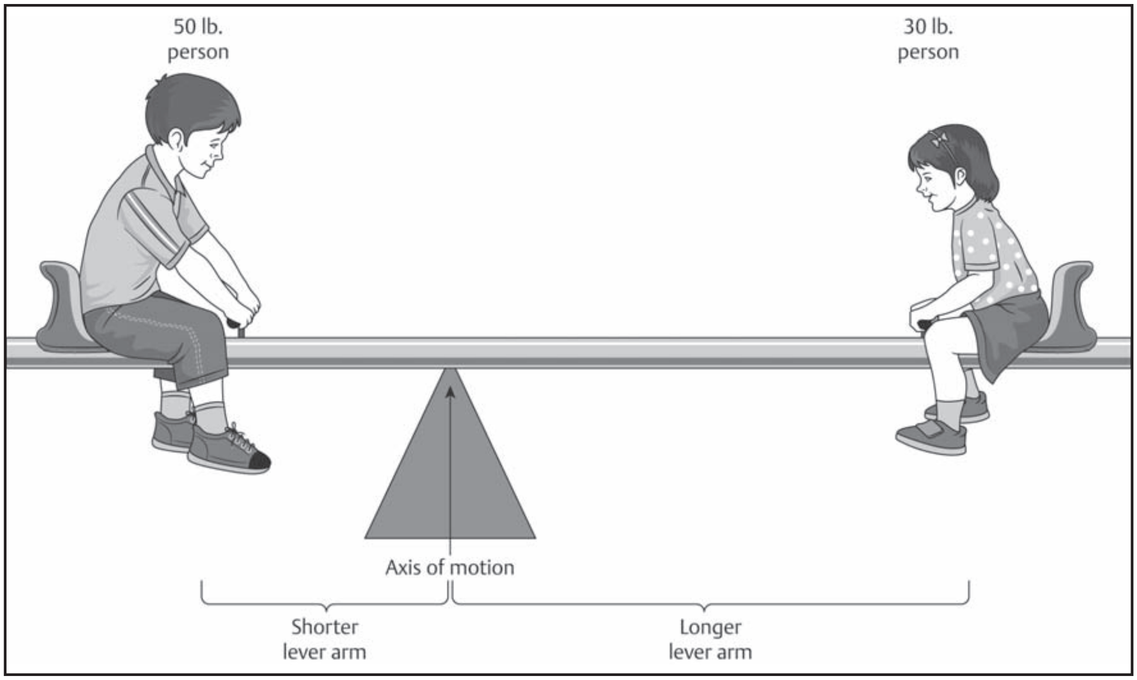

Figure 2-22. Seesaw: first-class lever.

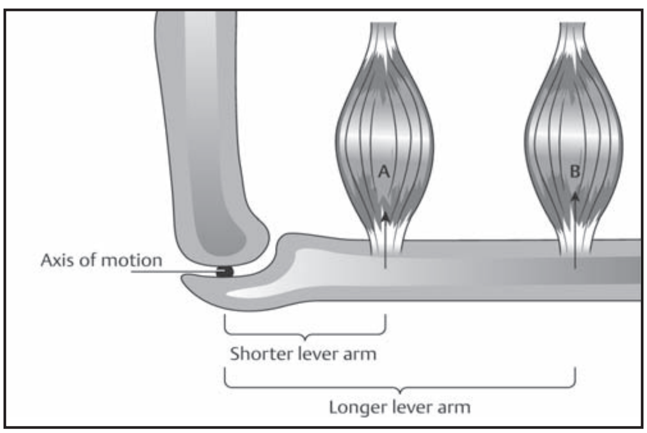

Figure 2-23. Lever arm and muscle force.

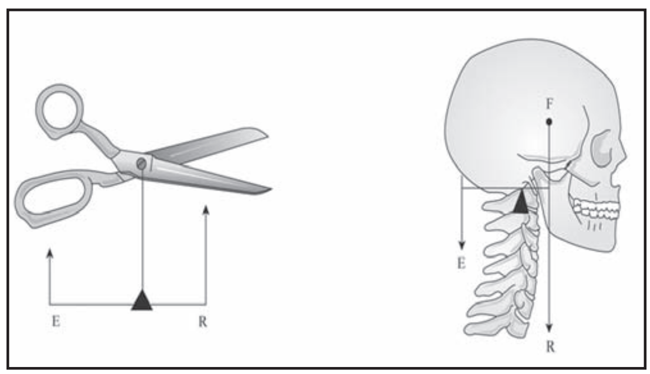

Figure 2-24. Examples of first-class levers.

B.C., "Give me a fulcrum on which to rest and I will move the Earth!" Second-class levers are able to move large masses with little force. Common examples are a wheelbarrow, nutcracker, or faucet handle, and some of these are shown in Figure 2-25.

There are few examples of second-class levers in the body. Rising up onto one's toes is an example in the body where the metatarsophalangeal joints are seen as the axis, the muscles inserting into the heel are the effort forces, and the weight of the body acting through the ankle is the resistance force. The forearm and brachioradialis are also identified as a second-class lever because the COG of the forearm is between the elbow and the insertion of the brachioradialis muscle (Gench et al., 1995).

Third-class levers are the most common in the body. In third-class levers, the effort force is located in between the axis and the resistance force. Third-class levers permit speed or movement of a small weight for a long distance and are considered force reducers (Lafferty, 1992) because the effort force is greater than the resistance or load. A broom, fishing pole, tweezers, chopsticks, and a crab's pincer are examples of third-class levers (Figure 2-26).

Anatomically, small muscular forces can produce large movements of long bony segments. The deltoid, extensor carpi radialis, and iliopsoas muscles are examples of third-class lever systems in the body. Biceps brachii is another example and an animated website demonstrates the actions of levers at http://www.enchantedlearning.com/physics/machines/Levers.shtml. The muscle forces must always be greater than the force of resistance, which sacrifices MA to produce wide ranges of motion and high-velocity movements (Greene & Roberts, 1999).

Levers differ in their capacity to balance and overcome resistance; this is known as MA. MA measures the efficiency of the lever and is the ratio between the effort arm (force) and resistance arm (force). MA is the relative effectiveness of the effort force compared to the resistance force. The longer the effort force arm is relative to the resistance force arm, the greater the MA. The following formula can be used:

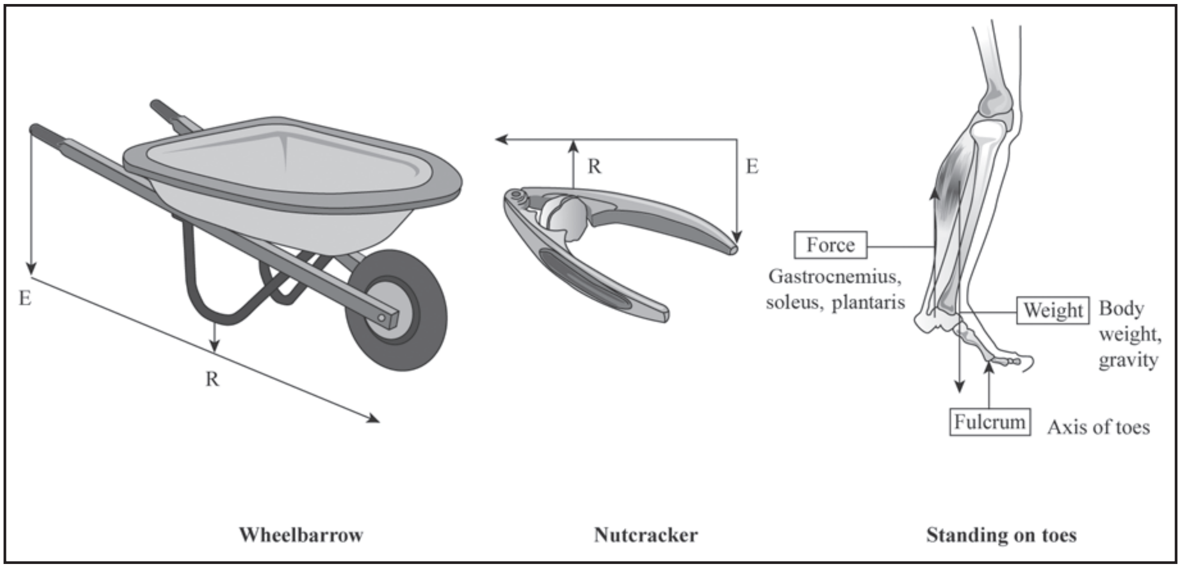

Figure 2-25. Examples of second-class levers.

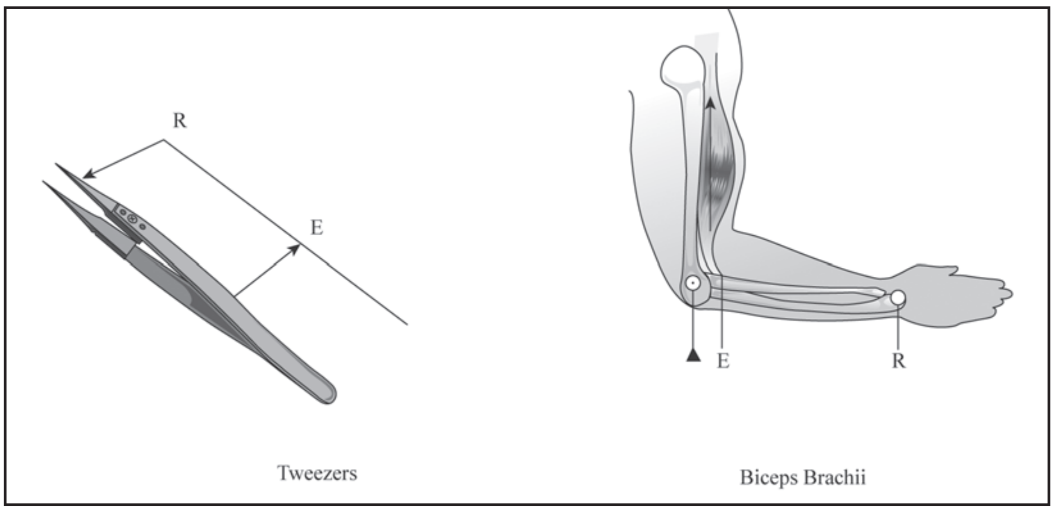

Figure 2-26. Examples of third-class levers.

$$MA = \frac{\text{length of the effort arm}}{\text{length of the resistance arm}}$$

When the MA is greater than 1, than that lever will have good MA and increased efficiency. If the MA is less than 1, then that lever will have poor MA and will not be as efficient.

First-class levers can vary in the amount of MA, depending on the location of the axis in relation to the resistance force and effort force arms. In second-class levers, the effort arm is always greater than the resistance arm, so second-class levers have significant MA (always less than 1). Conversely, in third-class levers, the effort arm is shorter than the resistance arm, so there is poor MA (always greater than 1). Third-class levers have the least capacity to overcome resistance. In the human body, muscles that attach further from the joint generally have greater MA than muscles that attach closer the joint; however, this will vary depending on the position in the ROM (Muscolino, 2006).

Gench and colleagues (1995) point out that it may seem paradoxical that the levers least found in the body are the levers that are capable of the greatest MA. They add that this would be true if we used our bodies to move great amounts of weight slowly. However, our bodies are more often used in activities requiring movement of smaller weights or moving quickly, and this is consistent with an abundance of third-class lever systems.

While it may seem that the predominance of third-class levers would make the human body perform inefficiently and ineffectively, there are distinct benefits to this arrangement. In a third-class lever, while the magnitude of the force needed to move the joint is great, the movement produced distally is through a much greater arc than that produced proximally. The shorter the lever arm of the effort force produced, the greater the movement of the distal end of the lever (Levangie & Norkin, 2011). This greater movement and speed is not true in a second-class lever, where there is MA and efficiency in terms of force output but relatively little change in

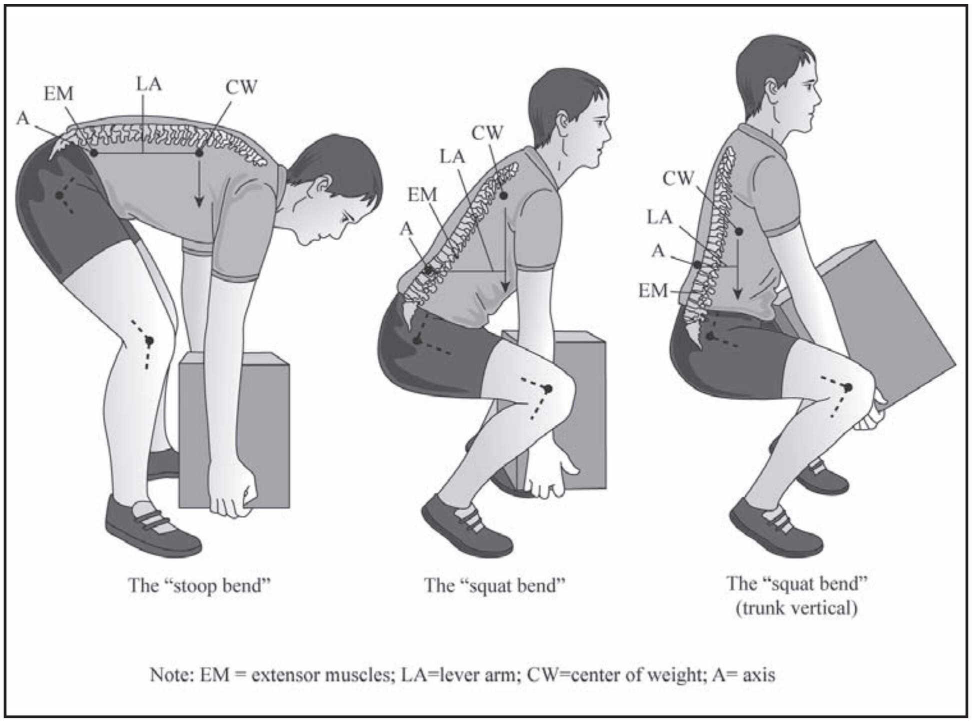

Figure 2-27. Forces involved in lifting.

distal movement. There is an inverse relationship between distance and MA when comparing second- and third-class levers; an example of this would be the biceps and brachioradialis and the impact these two muscles have on the forearm.

The biceps muscle is an example of a third-class lever, as the insertion of the muscle is closer to the axis than the COG of the forearm (resistance arm). The effort arm is shorter than the resistance arm, yielding poor MA. The insertion of the brachioradialis (effort arm) is distal to the COG of the forearm (resistance arm), making the effort arm longer and creating good MA. The biceps favors distance, or a larger ROM, as compared to the brachioradialis, which sacrifices distance with an unfavorable ability to achieve the ROM that the biceps can achieve.

These concepts are critical to occupational therapy practitioners who work in settings where proper body mechanics and ergonomics are utilized by clinicians and clients alike. Joint protection techniques such as using the strongest muscles possible for activities and holding objects closer to the body decrease the effort required to complete a task. In Figure 2-27, changing the length of the lever arm when lifting can reduce the risk of injury. In the stoop bend, the body segment from the hip to the head is longer, creating greater gravitational (external) torque. This necessitates greater internal force to overcome the gravitational pull and come to a standing position. This also increases the risk of back strain and is an example of poor body mechanics. In the "squat bend," the back is straight and the person is more upright. This decreases the gravitational (external) torque, and thus decreases the internal force required to rise to a standing position, decreasing back strain. The "squat bend" reduces the lever arm even further, decreasing the gravitational (external) torque acting on the back, further decreasing the internal force required to stand up, and further decreasing the risk of injury.

Summary

Occupational therapy practitioners need a basic understanding of human anatomy, movement, and the forces that affect the actions necessary to engage in meaningful occupations. Through this understanding, clinicians can develop meaningful interventions or design an orthosis with the right fit and purpose. Occupational therapy practitioners are experts at analyzing complex tasks, and since movement is complex, an understanding of its component parts is critical for efficient and effective therapeutic intervention. The foundations of kinesiology have been presented in this chapter, with a focus on biomechanics within the context of movement. People are constantly moving while working, eating, playing, and sleeping. Therefore, movement capabilities should be analyzed in preparation for client care. Appreciating the kinematics, or motion of the body without regard to force, is essential for the understanding of osteokinematics. Understanding the anatomy of a joint as well as the movements occurring in the joint (roll, slide/glide, or spin), also known as *arthrokinematics*, will facilitate a clinician's decisions regarding therapeutic exercises and activities. ROM is a beneficial intervention for many clients, but if done incorrectly, can also lead to pain or damage to a joint. Understanding the relationship between the articulating joint surfaces is critical for optimal, safe interventions to increase ROM. Proper technique should be taught to the client, family, and caregiver as well.

Movement of the body through various planes of motion around specific axes and in directions necessary to engage in activity is produced by the generation of internal force and impacted by external forces in the environment. Therefore, the discussion of kinematics is not complete without consideration for kinetics, or the analysis of forces that create motion or maintain equilibrium. The laws of physics related to inertia, acceleration, and action/reaction apply to the body as well as to other physical objects. Gravity is a constant force acting on the body, as are other external forces including friction, wind, water, other people, and objects. Gravity can be taken for granted as a force that must be overcome; however, for a person with weakness after a spinal cord injury or one with a progressive condition like multiple sclerosis, overcoming gravity can be an enormous challenge and must be addressed during occupational therapy intervention. A person may benefit from adaptive approaches such as using a universal cuff to hold a spoon when eating, or a remedial approach to strengthen weak muscles to engage in valued occupations. External forces such as those supplied by dynamic orthoses may also be necessary for a stroke survivor who receives PROM to maintain range and prevent unwanted joint limitations or contractures.

Without internal forces, bodies could not be in motion as they are created through muscle contractions impacting bones and ligaments. Forces are organized in linear force systems, which act on the body as first-, second-, or third-class levers. By identifying the line of pull of a muscle acting on a bone during an action, conclusions about the effectiveness of the muscle action in terms of stabilization or mobilization can be made. The ability to analyze MA and make recommendations for proper body mechanics and preventative measures is key for an occupational therapy practitioner who is working with a client who needs to move and work as efficiently as possible. This chapter lays the foundation for these skills and connects these concepts to clinical practice, which can be built upon by specialized training and experience.

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3

Range of Motion

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Range of motion (ROM) is the amount of movement that occurs at a joint and can be defined as the measurement of motion available (or the arc of motion available) at a joint or through which the joint passes, resulting from the joint structure and surrounding soft tissue. ROM measures the magnitude of rotary motion (or angular displacement) and is a measure of the joint osteokinematics (Houglum & Bertoti, 2012; Levangie & Norkin, 2011). Joint function is influenced by the several factors shown in Figure 3-1. The structure of the joint, externally applied forces, and internal forces are a few factors, and joint motion depends on the restraining effects of ligaments and muscles crossing the joint, skin and other soft tissues, the bulk of tissue in adjacent segments, and client factors such as age and gender. In addition, the measurement of ROM involves methodological factors such as accurate recording, instrumentation, and the type of testing done.

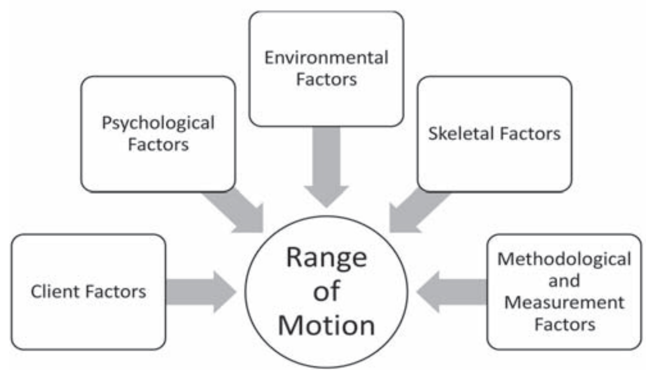

Figure 3-1. Factors influencing ROM.

Factors Influencing Range of Motion

Client Factors

Client factors are person-level factors such as genetics, gender, age, pain, and lifestyle choices affecting health as it relates to joint movement.

Genetics

Individual subject factors can vary due to genetic predispositions for greater motion (hypermobility) as is sometimes seen in hyperextension at the elbow. There may also be less motion (hypomobility), which may happen when there is soft tissue tightness or contractures that limit full joint motion.

Different activities put different stresses on joints, which may change the amount of motion that occurs. Gymnasts and cheerleaders, for example, may have greater wrist extension due to repeated handstands or placing body weight on extended wrists. Pianists may have more finger abduction and extension due to years of playing and reaching for keys at the far ends of the keyboard. Musicians of stringed instruments often need full and prolonged finger abduction and flexion to

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Kinesiology for Occupational Therapy, Third Edition (pp. 37-65).

move into different positions along the neck of the instrument and to apply pressure on the strings. Individual variability needs to be considered in assessment when the ROM is different from the expected or normative values. Questions asked about activities that are done currently and in the past may help explain variances in flexibility and would be valuable information gathered from the occupational profile.

Health Status

Decreased motion occurs for many reasons. The overall health of the client is important in determining the amount of motion that occurs. Joint disease or injury, edema, pain, skin tightness or scarring, muscle or tendon shortening due to immobilization, muscle weakness or muscle hypertrophy, muscle tone abnormalities, and excess adipose tissue are all possible reasons for decreased ROM.

The consequences of decreased motion are many. Supporting structures may become loose, creating joints that are unstable and painful. The joint structures may be insufficient to hold the joint in stable and functional positions during activities. Ligaments and muscles may be stretched and, combined with the effects of gravity, can lead to subluxation and instability of the joint. This is often seen in the shoulders of clients with hemiplegia where the shoulder and scapular muscles are inactive or diminished and the weight of the arm plus gravity pull the humeral head out of the glenoid fossa.

Inactivity of the muscles can lead to contractures due to muscle imbalance and the inability to perform normal activities. Muscles and tendons can lose their tensile strength. Scar tissue adhesions, which occur secondarily to chronic inflammation with fibrotic changes, can tear when the muscle is stretched. As muscles lose their normal flexibility, changes occur in the length-tension relationships. The muscles are no longer capable of producing peak tension, which can lead to pain and decreased strength.

Fatigue due to lack of sleep, pain, and emotional distress may prevent a client from participating fully in the therapeutic process. Fatigue may also influence the client's ability to communicate effectively and may interfere with concentration, memory, or attention to tasks. In addition, fatigue affects the physiologic properties of muscles and joints, limiting sustained, purposeful movement during activities.

Age and Gender

Age and gender are subject factors that also influence the amount of motion that occurs at joints. Normal age-related changes in bone, cartilage, tendons, and joints that affect ROM include the following (Bonder & Bello-Haas, 2009):

- Loss of tensile strength and mobility in collagen tissue occurs due to dehydration, increased density, and cross-linkage of fibers.
- Decreased ease of movement of tissues is due to decreased elasticity.
- Decreased ease of movement may be due to progressive diminution of hyaluronic acid, which helps to regulate the viscosity of tissues.

The concept that normal ROM may vary with age and gender with resultant decreased ROM has generally been supported in the literature. In a study of healthy community-dwelling older adults, the rate of decline in upper body flexibility was 0.5 degrees per year in males and 0.6 degrees in females; declines in hip flexion was 0.6 degrees in both males and females (Stathokostas, Little, Vandervoort, & Paterson, 2012). It has also been found that as people age, they use progressively smaller portions of the total available lower extremity ROM during ambulation, resulting in shorter strides. These changes have been attributed to changes in motor control, loss of motor units, and decreased fast twitch muscle fibers (Nordin & Frankel, 2012). In the lumbar spine, significant age-related reductions in lumbar flexion, extension, and lateral flexion were observed for both females and males, but the reductions in rotation were minor (Intolo et al., 2009).

However, in a study of lower extremity ROM, Roach and Miles (1991) found that normative values of hip and knee ROM may not be representative of the population. In their study, there were differences between the oldest and youngest subjects, but the differences were small and of limited clinical importance. Roach and Miles (1991) concluded that "any substantial loss of joint mobility should be viewed as abnormal and not attributable to ageing" (p. 664).

While age may be associated with a decline in flexibility, older adults still maintain the ability to improve flexibility with general exercise training programs and remaining active in daily life routines.

Normal age-related changes in joints can be offset somewhat by the types and level of activities in which one engages throughout life. Understanding all of the occupations in which the client engages throughout the lifespan will provide a more accurate picture of the health of the person. This is as true for the 35-year-old construction worker as it is for the retired 75-year-old grandfather who enjoys golf. Understanding desired occupations gives the therapist insight into the activity level and motivation as well as information about joint function.

Women generally have more flexible joints with greater ROM than men, and this is true throughout life (Bell & Hoshizaki, 1981; Stathokostas et al., 2012).

Pain

Pain management is often a part of the intervention process because, without this, intervention will not yield successful outcomes. Often, it is the complaint of pain that brings the client for intervention and not the underlying deficit. Pain presents both with sensory and emotional symptoms. Lack of comfort and often sleep, loss of activities, and loss of roles may cause withdrawal, introversion and depression, and anger and aggression. Pain and lack of customary life roles may develop into learned helplessness where the client avoids strenuous activities and where secondary benefits may be gained, such as excused participation in work activities or in less-desired roles.

Acute pain is experienced immediately following a physical injury and is proportional to physical findings. Chronic pain lasts months or years and can change the client's personality, cause disassociation from physical problems, and develop into a different clinical syndrome (Smith, Weiss, & Lehmkuhl, 1996).

It is essential for the occupational therapist to understand the client's pain and how pain is directly related to well-being and successful engagement in occupational tasks. Pain can limit all areas of occupational performance and is a significant reason for lost work days and disability. In self-care, clients

Table 3-1

DESCRIPTIONS AND POSSIBLE CAUSES OF PAIN

DESCRIPTIONS	**POSSIBLE CAUSES**
Intensity, duration, frequency increasing	• Condition worsening
Constant pain	• Suggestive of chemical irritation tumors, visceral lesions
Periodic, occasional pain	• May be activity or position dependent; likely to be mechanical, related to movement and stress
Episodic pain	• Related to specific activities
Morning stiffness that improves with activity	• Chronic inflammation and edema
Pain and aching progresses through day	• Increased congestion at a joint
Pain at rest	• Acute inflammation
Pain worse at beginning of activity	• Acute inflammation
Pain not affected by rest or activity	• Bone pain • Organic or systemic disorders (e.g., cancer)
Intractable pain at night	• May indicate serious pathology (e.g., tumor)
Pain at night	• Peripheral entrapment neuropathies (e.g., carpal tunnel, thoracic outlet syndromes)
Sharp pain	• Nerve injury
Burning pain	• Nerve injury
Deep, boring, localized pain	• Bone injury, trauma, or disease
Diffuse, aching, poorly localized pain	• Vascular pain
Pain that is hard to localize, dull, aching	• Muscle pain
Severe chronic or aching pain inconsistent with injury or pathology	• Somatic pain
Acute pain	• Muscle strain • Tendinitis • Contusion • Ligamental injury
Chronic pain	• Fibromyalgia • Chronic fatigue syndrome • Rheumatoid arthritis • Low back pain
Psychogenic or idiopathic pain	• Unknown cause • Malingering • Munchausen syndrome

may avoid performing certain activities of daily living (ADL) tasks to avoid pain, and pain may interfere with sleep. The client may be unable to perform job or household tasks and may have difficulty with roles of parent and spouse (Reed, 2013). Pain involves the intersection of body, mind, and culture, and it is important to talk with your client about the objective and subjective aspects to pain.

The objective aspect is the physiologic tissue damage producing the pain from a variety of causes (e.g., trauma, disease, idiopathic) and structures (e.g., nerves, bones, vascular, muscle). Subjectively, the client experiences pain perceptually, affectively, and cognitively.

The client can provide descriptions of location, quality, intensity, and duration of pain as the perceptual experience of pain. Ask the client about frequency of the pain and conditions in which the pain increases. Table 3-1 provides descriptions of pain and possible causes that may help you and the client better understand the pain experience. Have the client describe the pain and indicate what activities elicit pain responses. Sharp pain is usually associated with nerve pain or nerve root involvement or possibly due to a fracture, while a deep, localized pain may be due to bone pain. A dull, aching sensation pain that is difficult to localize may be attributed to muscle or vascular pain and psychogenic or idiopathic pain has no known cause.

The affective component includes the psychological factors of the pain experience. Significant correlations have been found between chronic pain and depression, anxiety and other psychiatric comorbidities, and psychosocial distress (Umphred, 2013). Diminished life roles, grief over loss of mastery, feelings of rage, helplessness, victimization, and defectiveness that can lead to social withdrawal are associated with pain and can add to family and marital dissonance.

The cognitive component includes what the client knows and believes about pain based on cultural background and past experiences as well as how the client expresses pain through verbal and nonverbal communication. Knowing a client's cultural understanding of pain is essential in providing a client-centered, meaningful intervention for each individual. Culture influences how pain is understood and expressed and what intervention is seen as appropriate. Expectations, manifestations, and management of pain are embedded in cultural context, and beliefs about illness guide individuals to specific types of intervention (Crepeau & Schell, 2003; Solet, 2008). Pain experiences have different meanings in different cultures. Different names are given to diseases in various parts of the world, and symptoms have different meanings in different cultures. For example, epilepsy is considered a shameful disease among some Greeks, while Ugandans believe that it is contagious and untreatable. Some Mexican Americans feel that epilepsy is a reflection of physical imbalance, while Mennonites believe is it a sign of favor from God (Jarvis, 2000).

Assessment

The assessment of a client's pain is an integral part of the evaluation process. Pain will invalidate many physical assessments because the client will be unable or unwilling to move through the total ROM. More importantly, pain may interfere with the client's ability to engage in desired occupations. For example, limitations in ADL might be seen in avoidance or slowed performance of grooming or showering tasks if the movement elicits pain. Pain can interfere with sleep, which can affect cognitive abilities such as attention and memory recall. The client may be preoccupied with thoughts of pain and so is unable to engage in leisure activities or socialize with friends. The client may be unable to resume work or parenting roles following injury or trauma. Pain is a significant reason for lost work days and disability and adds considerably to family and marital discord (Reed, 2013; Solet, 2008).

The assessment of pain includes understanding the painful experience that the individual client is experiencing and the direct impact pain has on activity. It is a highly personal experience, and individuals turn to their social environment for validation and meaning of their pain behavior and symptoms. Overt pain behaviors may include guarding or protecting a painful part, rubbing, grimacing, and sighing. The subjective pain experience is affected by cultural, historical, environmental, and social factors.

As with any occupational therapy assessment, a thorough occupational profile is the linchpin of any pain assessment. You will ask the client about any precipitating factors and what triggers the pain and makes it worse. You also want to ask what alleviates or minimizes the pain and what actions the client has taken that relieves the pain. Ask specific questions about how the pain affects participation in occupations and in sleep, appetite, school, work, walk, or movement.

The experience of pain is subjective, so self-report is the most valid measure of the experience (Jarvis, 2000; Magee, 2014; Solet, 2008). During the client interview, be aware of any indicators of pain such as grimaces, frequent position changes, and other nonverbal cues. Monitoring vital signs is also key to understanding pain levels during a musculoskeletal assessment. The Pain Behavior Checklist was developed to classify and record pain behaviors during client interviews (Dirks, Wunder, Kinsman, McElhinny, & Jones, 1993).

There are various ways to have clients tell you about their pain. There are verbal description scales where clients are asked to describe their pain by referring to a list of adjectives. Numeric rating scales are used, and usually clients are asked to rate their pain on a 0 to 10 scale, where 0 indicates no pain and 10 is indicative of maximal pain. The Borg Scale (Borg, 1982) has clients rate their pain on a 0 to 10 scale, and the scale items are operationalized so that a 1 indicates very weak pain, 2 is weak pain, 3 is moderate, and so on. Alterations in movement are expected with pain levels of 6 or greater (Palmer & Epler, 1998). A modification of this rating system is the Pain Disability Index, in which the client is asked to rate his or her level of pain on a 0 to 10 scale in the areas of family/home responsibilities, recreation, social activities, occupation (job), sexual behavior, and life support activities (e.g., eating, sleeping, breathing; Pollard, 1984). The Functional Status Index also looks at pain in relation to activity performance (Jette, 1980a). Clients can also be asked to keep a pain diary to record pain daily on a numeric scale during ADL, and they might also include medication, alcohol use, and emotional responses during the same period.

A visual analog scale is often used to visually represent the client's pain intensity. The client can either indicate his or her level of pain on a line (Cline, Herman, Shaw, & Morton, 1992), choose from six faces, or indicate his or her pain intensity on a thermometer (Brodie, Burnett, Walker, & Lydes-Reid, 1990). These scales may include numbers, drawings, and/or adjectives to further measure pain. There are no norms for this scale and it cannot be used to compare different clients, but is helpful to monitor the same client over time.

The McGill Pain Questionnaire (Melzack, 1975) combines several of these methods of gathering information about a client's pain. First, there is a list of 20 categories of adjectives to describe pain. Columns 1 to 10 describe qualities of pain (e.g., throbbing, pinching, dull), and columns 11 to 15 describe affective qualities of pain (e.g., tiring, blinding). Column 16 uses evaluative words about the overall intensity of pain (e.g., annoying, miserable, intense), and columns 17 to 20 include miscellaneous descriptors (e.g., spreading, squeezing, agonizing). One disadvantage to such an extensive list of descriptors is that not everyone you treat will be able to discriminate or be able to define all of the terms presented. The second part of the McGill Pain Questionnaire asks that the client indicate on a drawing of the body where the pain is and what type of pain is experienced. Finally, the client is asked to describe if and how the pain changes with time. In addition to client history, interview, and self-report, common pain assessments are listed in Table 3-2.

Table 3-2

PAIN ASSESSMENT TOOLS

NAME OF TOOL	RESOURCE
Brief Pain Inventory	Cleeland, 1991
Chronic Pain Grade Scale	Von Korff, Ormel, Keefe, & Dworkin, 1992
Functional Status Index	Jette, 1980b
Low Back Pain Rating Scale	Manniche et al., 1994
McGill Pain Questionnaire	Melzack, 1975, 1987
Oswestry Disability Index	Fairbank, Couper, Davies, & O'Brien, 1980; Fairbank & Pynsent, 2000
Pain Apperception Test	Petrovich, 1958; Ziesat & Gentry, 1978
Pain Behavior Checklist and Pain Rating Scale	Dirks et al., 1993
Pain Beliefs and Perceptions Inventory	Williams, Robinson, & Geisser, 1994
Pain Disability Index	Pollard, 1984
Pain scales (visual analogue, faces, thermometer, numeric, verbal)	Childs, Piva, & Fritz, 2005; Downie et al., 1978; Huskisson, 1974; Jensen & McFarland, 1993; McCormack, Horne, & Sheather, 2009; Rodriguez, 2001
Progressive Isoinertial Lifting Evaluation	Mayer et al., 1988
Quebec Back Pain Disability Scale	Kopec et al., 1995, 1996
Roland-Morris Disability Questionnaire	Roland & Morris, 1983
Short Form 36 Bodily Pain Scale	Chen et al., 2014; Hawker, Mian, Kendzerska, & French, 2011
Sickness Impact Profile	Post, Gerritsen, Diederikst, & DeWittet, 2001

There may be pain with active or passive movement. Pain with active ROM but not with passive ROM is most likely due to a muscle or tendon problem. This may be characterized by pain and limitation or excessive movement in some directions but not others. If only one movement is painful, this may suggest a sprain of a single ligament, and often there is greater pain at the extreme end of the range. Pain with passive ROM is likely due to tight joint structures, ligamental injury, cartilage injury, or inflammation. A capsular pattern or capsulitis might be present if there is pain when the joint is passively moved in nearly all directions. If there is limitation in motion because of pain and pain is present during distraction of joint surfaces but not compression, this is likely due to stretching of ligaments or the joint capsule. If there is pain during compression of joint surfaces that is relieved by distraction, this is probably due to thinning or loss of cartilage, inflammation within the joint, or a surface abnormality (Magee, 2014).

Intervention

Pain management strategies draw upon the gate control theory (Melzack & Wall, 1965). This theory indicates that impulses from large sensory nerve fibers at segmental levels of the spinal cord enable nonpainful sensory input to stimulate the same transmission cells that the pain receptors do. This would inhibit the transmission of the pain input. Every time you rub your knee after banging it against something, you are demonstrating this theory; mechanoreceptors are superseding the pain messages. The activation of the mechanoreceptors competes for transmission with the pain input, so by rubbing your knee, the sensation of pressure, not pain, is felt. The faster signals of the mechanoreceptors, activated when you rub your knee, blocked the reception of the slower pain message. This response is believed to have evolutionary basis where movement and pressure were required for flight or fight and sensation of pain was not as necessary to survival (Muscolino, 2006). One physiologic explanation for the gate theory mechanism is that the local stimulation of non–pain-mediated sensory afferents closes the gate at the spinal cord level, thereby preventing further transmission of pain impulses.

A further elaboration on the gate theory was proposed by Melzack and Katz (2004). The neuromatrix theory indicates that the brain creates a perceptual experience in the absence of external inputs due to sensory and afferent links to large portions of the brain, thus producing the multidimensional pain experience. The heightened sensitivity and altered autonomic nervous system activity creates a chronic state of high alert that perpetuates the pain cycle.

Another theory about the mechanism of pain is that the body is stimulated to release endogenous opiate substances, which increases the circulation of neuropharmacologic agents (endorphins), which then decreases the pain (McCaffrey, Frock, & Garguilo, 2003). It has been found that the inhibition of pain input is enhanced by the client's concentration on competing activities that have important implications for occupational therapists and the use of meaningful occupation as the means of intervention.

Pain is a complex sensory experience influenced by the body, mind, and culture (Chesney & Brorsen, 2000). The experience of pain is based on one's belief system, so pain can be viewed from different perspectives. Jarvis (2000) identified three different pain perspectives. The first perspective is the scientific or biomedical view. In this view, pain has a cause and effect, and the human body functions much like a machine. By observing and measuring those parts that are not functional or are painful, pain-free function can be restored. The naturalistic or holistic approach (as seen in some Native Americans, Asians, Hispanics, Arabs, and Black people) believes that human life is only one aspect of nature as a part of the larger cosmos. Pain and dysfunction are evidence of lack of harmony or imbalance. It is the individual as a whole (physical, psychological, spiritual, and social), not the particular impairment, that is significant. The third perspective, the magico-religious view, sees the world as a place where supernatural forces dominate. Jarvis (2000) includes voodoo, witchcraft, and faith healing (including Christian Scientists, Roman Catholicism, and Mormonism) as holding beliefs related to this approach. It is clear that culture and your belief about health and disease would influence your perceptions and experience of pain, and these need to be part of the client assessment.

Occupational therapists are uniquely qualified to address both the physical and psychological needs of people with acute and chronic pain. In cases where the pain cannot be completely alleviated, the occupational therapist can provide strategies for adaptation due to the holistic and multifaceted approaches used in intervention (Fisher et al., 2007). The unique emphasis on function and the influence of pain is important because function is how clients perceive their quality of life. Advances in disruption of the pain receptors, new medicines for the control of pain, and cognitive therapy for altering pain perception are being explored as part of the multifaceted approach to pain (Basbaum & Julius, 2006; Julius & Basbaum, 2001).

Intervention for acute pain is directed toward the underlying cause of the pain. As an example, an improperly aligned joint due to lack of humeral rotation during forward flexion or improper placement of the humeral head in the glenoid fossa may require realignment to alleviate the pain. Pain disturbing sleep may be indicative of systemic pain arising from one of the body's systems other than the musculoskeletal system. Until the origin of the pain is identified, pain reduction will be minimal (this clearly reflects a scientific perspective). The underlying assumptions to this approach are that every pain has a source and that the intervention you provide must be directed toward and influence that source. Isolate the cause of the pain and treat that specifically.

A variety of methods are used to treat both acute and chronic pain. These interventions include occupation- and activity-based interventions to improve occupational performance and community participation (Schwartz, 2017) as well as use of modalities, exercise, cognitive-behavioral approaches, relaxation and stress management, client and family education, and environmental adaptations, often as part of an interdisciplinary team (Zimmerman, 2003). Multimodal, individualized, multidisciplinary interventions that included preparatory, purposeful, and occupation-based activities resulted in higher health-related quality of life for clients with low back pain (Grunnesjö, Bogefeldt, Blomberg, Strender, & Svärdsudd, 2011; Scascighini, Toma, Dober-Spielmann, & Sprott, 2008).

Cognitive-behavioral therapy (CBT) techniques are used to modify behavior and dysfunctional thoughts. Thinking and behavior are interrelated, and by changing negative thinking patterns (such as overgeneralizing, magnifying negatives, and catastrophizing), healthier, more positive thoughts can heighten a person's sense of control over pain (Chesney & Brorsen, 2000). CBT methods might include hypnosis, behavioral modification programs, and counseling in addition to pacing (learning to do activities without pain), assertiveness training (for the expression of needs and feelings), and enhancement of self-efficacy (Chesney & Brorsen, 2000; Dudgeon, Tyler, Rhodes, & Jensen, 2006; Fisher et al., 2007). The aim of intervention is to teach the client to use techniques to modify behavior and dysfunctional thoughts. There is strong evidence to support the use of internet-delivered, cognitive-behavioral intervention to reduce pain and decrease the severity of depression and generalized anxiety for clients with chronic pain (Macea, Gajos, Daglia Calil, & Fregni, 2010), while cognitive-behavioral interventions only had a small benefit for the mood and function of clients with fibromyalgia (Poole, Siegel, & Arbesman, 2017b). Self-management programs were found to have a small-to-moderate beneficial effect on pain and disability for those clients with chronic musculoskeletal conditions, especially those with arthritis (Schwartz, 2017).

Relaxation and stress management programs include interventions that teach relaxation (e.g., mindfulness training) and guided imagery. Mindfulness-based stress reduction (MBSR) and CBT were compared to usual care for clients with chronic low back pain and, while there was no difference between MBSR and CBT, MBSR was an effective treatment option for this population (Cherkin et al., 2016). Strong evidence supported the use of guided imagery, mindfulness intervention, and emotional disclosure for mood, function, and pain but did not appear to have long-term benefits for clients with fibromyalgia (Poole et al., 2017b). Yoga was effective to reduce pain intensity, frequency, and pain-related disability for those with musculoskeletal pain. Yoga was seen to be cost effective and is a valuable part of intervention providing pain relief and enhancing self-efficacy and self-confidence (Büssing, Michalsen, Khalsa, Telles, & Sherman, 2012; Paguette, 2017b; Ward, Stebbings, Sherman, Cherkin, & Baxter, 2014). The use of virtual reality programs and games can also serve as a distraction, and users have shown decreased activity in known pain centers in the brain (Hoffman, 2004). Complementary practices such as imagery, meditation, spiritual practices, Qigong, reiki, and tai chi are used to decrease pain (McCormack, 2009; Meriano & Latella, 2008; Trail-Mahan, Mao, & Bawel-Brinkley, 2013). Mirror therapy has been used for chronic pain (in which the use of the noninjured side is reflected in mirror, giving the illusion of function in an injured hand) with some success and is another option (Grünert-Plüss, Hufschmid, Santschi, & Grünert, 2008).

Modalities are often used for pain control and may include massage, ice massage, cold packs, acupressure, iontophoresis, phonophoresis, laser therapy, self-massage, transcutaneous electrical nerve stimulation, electric stimulation, thermal agents, and biofeedback. Deep heat is used for muscle spasm, sprains, strains, and tendonitis to loosen soft tissue contractures and for treatment of chronic arthritis, bursitis, fracture, and inflammation (Meriano & Latella, 2008; Rochman & Kennedy-Spaien, 2007). Moderate support for combining aerobic exercise, massage, ischemic pressure, and thermal therapy for fibromyalgia clients (Casanueva-Fernández, Llorca, Rubió, Rodero-Fernández, & González-Gay, 2012) and exercise combined with transcutaneous electrical nerve stimulation improved in tender-point count, pain, and self-report (Mutlu, Paker, Bugdayci, Tekdos, & Kesiktas, 2013). Magnetotherapeutic intervention was used with clients with neck and shoulder pain with moderate evidence to support use with this population (Bruder, Taylor, Dodd, & Shields, 2011; Kanai & Taniguchi, 2012). Acupuncture has been used to decrease pain as well (Vickers & Linde, 2014). Kinesiotaping, used as either the sole treatment or in conjunction with other treatment methods, improves pain and disability outcomes (American College of Sports Medicine, 2009; Kelle, Guzel, & Sakalli, 2016; Klein, Brockmann, & Assmann, 2015; Nelson, 2016).

Exercise and movement training are other pain management interventions. Functional body retraining might include instruction in body mechanics, energy conservation, work simplification, and proper posture (Chesney & Brorsen, 2000; Dudgeon et al., 2006; Fisher et al., 2007). Muscle tension reduction training might involve teaching the client to recognize ineffective muscle tension and to reduce or reverse compensatory patterns (Rochman & Kennedy-Spaien, 2007). Soft tissue management such as massage, strain-counterstrain, and myofascial release are other techniques to decrease pain (Chesney & Brorsen, 2000).

Various types of exercise have been used including aerobic exercise, resistance training, flexibility, functional body retraining, and aquatic exercise. Aquatic exercise decreases pain in clients with fibromyalgia (Poole, Siegel, & Arbesman, 2017a) and resistance training decreases pain in client with neck and shoulder pain (Lange, Toft, Myburgh, & Sjøgaard, 2013), general shoulder pain (Brudvig, Kulkarni, & Shah, 2011; Ho, Sole, & Munn, 2009; Yiasemides, Halaki, Cathers, & Ginn, 2011), and for clients with chronic or acute musculoskeletal conditions (Kristensen & Franklyn-Miller, 2012; Paguette, 2017a).

Intervention for chronic pain involves establishing functional goals. By working toward clear, functional goals, attention is directed away from the pain and toward an observable result of intervention. Clients may not become pain free but instead must be taught how to tolerate and manage their pain. Lifestyle and habit changes, such as alcohol and medication reduction, smoking cessation, monitoring fluid intake and nutrition, and quality and quantity of sleep, are also part of the multidimensional treatment of chronic pain (Cimmino, Ferrone, & Cutolo, 2011). Intractable pain may require medication or surgery. Education for the client and family that focuses the neurophysiology of pain is another strategy to reduce pain ratings, improve function, and help clients develop strategies to cope with pain. Occupational therapists may also teach family members to ignore a client's pain behaviors to increase function and not inadvertently reinforce these negative behaviors (Breeden & Rowe, 2017).

Cultural Variations

Few studies have been done that indicate trends related to culture, race, or ethnicity (Van Deusen & Brunt, 1997), although positioning in childhood and customary postures may be attributed to variability of lower extremity joint motion and related to culture (Demeter, Andersson, & Smith, 1996). Culture has a significant impact on how ADL are done. ROM requirements for ADL varies based on how the activities are done. In many countries, numerous activities are performed while squatting, kneeling, or sitting cross-legged, which demand a greater ROM than that typically required in western populations. For example, kneeling is the position commonly used while eating, socializing, and religious practices. Without taking into consideration these differences in ROM, many people in Asian and Middle Eastern cultures would be unable to continue with their usual lifestyle (Mulholland & Wys, 2001).

Biocultural variations in the musculoskeletal system have been identified by Jarvis (2000), which might affect the amount of joint movement available to a client. From this study, the following variations were found (Jarvis, 2000, p. 634):

- There is greater torsion of the proximal end of the right humerus in White people, but it is more symmetrical in Black people.
- Long bones are significantly longer in Black people than White people.
- Bone density varies by race, with Black people having the densest bones, then Chinese, Japanese, Inuit, and American White people.
- Curvature of long bones varies, with Native Americans having more anteriorly convex femurs while Black people generally have straight femurs.
- Length of the ulna and radius varies: The ulna and radius are of equal length in Swedes 61% of the time while only 16% of the time in Chinese. The ulna is longer than the radius in Swedes 16% of the time, and it is longer in 48% of the Chinese. The radius is longer in Swedes 23% of the time, but only 10% of the time in Chinese.
- Palmaris longus is absent in 12% to 20% of White people, 2% to 12% of Native Americans, 5% of Black people, and in 3% of Asians.

Psychological/Psychosocial Factors

Psychological and psychosocial factors also influence ROM. Client participation is a vital component to active movement and is related to the person's emotional state at the time the movement is requested. Understanding the client's perspective about the meaning of the limitations and potential losses of occupation is an important part of learning about his or her illness experience. Fear of injury or re-injury will prevent a client from engaging in activities that are perceived to be potentially painful. By not moving, the part is immobilized, and soft tissue changes will result. Anxiety and stress can cause muscle guarding, tightness in tissues, or inactivity.

In providing instructions for movement or engagement in activities, cognition is a variable as well. If the client cannot understand what movement or activity you are requesting, whether due to anxiety, depression, or inability to cognitively attend to the task, efforts at evaluation will be invalid, and intervention will be unsuccessful.

Environmental Factors

Temperature, level of noise, and the number of people in the room affect not only the comfort of the client, but also the

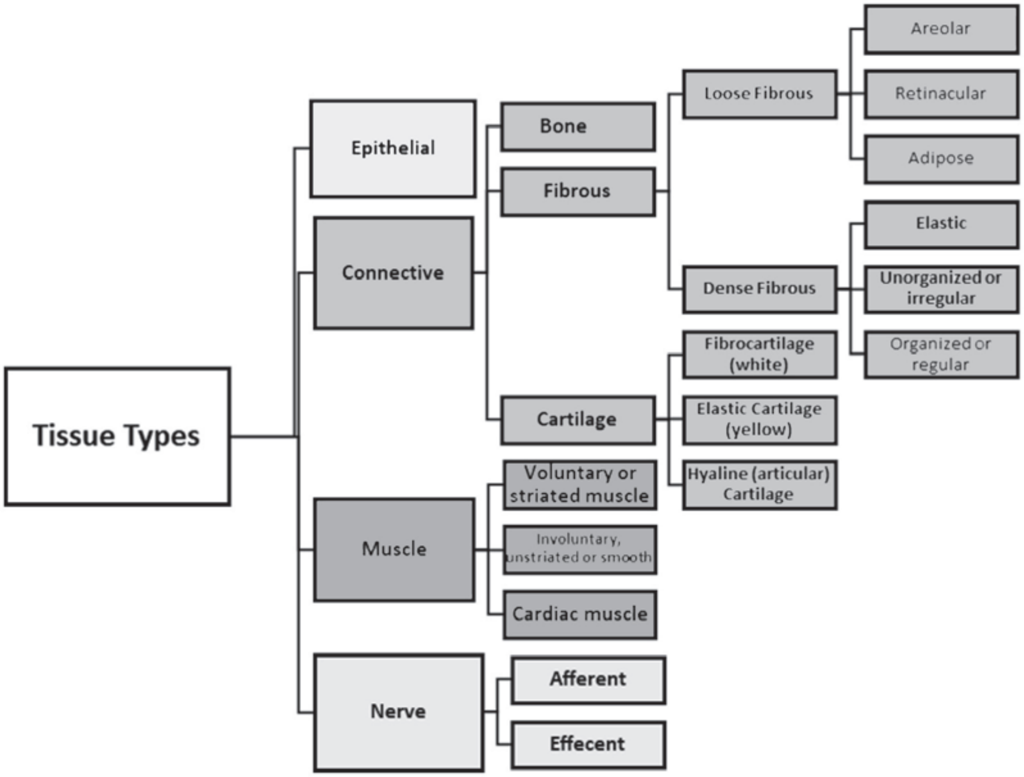

Figure 3-2. Differentiation of tissue types.

client's ability to attend to the task and the physiological readiness of muscles to respond. The time of day has a bearing on the amount of motion possible, as can be seen in clients with rheumatoid arthritis who are stiff in the mornings and able to move more comfortably later in the day. Less motion may be possible later in the day for some clients (e.g., clients with multiple sclerosis) due to fatigue.

Skeletal Factors

ROM is facilitated by the shape of the bones and the characteristics of the tissues around the joint. The shape of the bones allows certain types of movements but not others. The tissues comprising the joint provide stability and flexibility for joint movement. Muscolino states that "joints allow movement, muscles create movement, and ligaments and joint capsules limit motion" (2006, p. 161).

Types of Tissue

The amount of movement that occurs in a joint is based on the types of tissue that make up the joint. There are four major types of tissue in the body: epithelial, connective, muscle, and nervous, as illustrated in Figure 3-2 with details provided in Table 3-3.

Epithelial Tissue

Epithelium lines both the outside of an organ or organism (e.g., skin) and the inside cavities and lumen of bodies (e.g., blood vessels or the lining of the stomach). Epithelial tissue is characterized by a continuous surface of cells with few interruptions or gaps between adjacent cells. Several of the body's organs are primarily epithelial tissue, and examples include the lungs, kidneys, and liver. Many glands are also formed by epithelial tissue.

There are several types of epithelial tissue, and they have various functions. Epithelial cells protect underlying tissue from mechanical injury, harmful chemicals, pathogens, and excessive water loss. Many of the sensory receptors of the eyes, skin, ears, nose, and tongue are made of specialized epithelial tissues and are important in the reception of sensory information. Enzymes, hormones, and lubricating fluids are specialized epithelial tissue, as are endocrine and exocrine glands with secretory functions. Epithelial cells lining the small intestine absorb nutrients, and epithelial tissue in the kidney excretes waste products. Because epithelial tissue lines the walls of capillaries and the lungs, it helps to promote diffusion of gases, liquids, and nutrients (Currey, 2005; King, 2010).

Connective Tissue

Connective tissue is the passive element of the musculoskeletal system and includes fibrous tissues, cartilage, and bone. Some other specialized categories of connective tissue include lymphoid tissue and blood. Connective tissues provide the pathways for nutrients and waste disposal. In addition, connective tissues provide semipermeable barriers to pathogens and serve a protective and immunological function by providing a refuge for phagocytes, mast cells, and fibroblasts. Connective tissue also provides information to the central nervous system about internal and external forces acting on the body (Smith, 2005).

Fibers of connective tissue are made of varying degrees of collagenous or elastic types of tissues. Collagen, the most abundant protein in the body, offers tensile stiffness and strength,

Table 3-3

TYPES AND CHARACTERISTICS OF TISSUES

TISSUE	TYPES	SUBCATEGORIES	FUNCTION/DESCRIPTION
Epithelial			• Forms the epidermis of the skin • Surface layer of mucous and serous membranes • Serves function of protection, absorption, secretion • Specialized functions of movement of substances through ducts, production of germ cells, and reception of stimuli
Connective	• Bone		• Provides axial and appendicular skeleton • Provides protection for vital structures
	• Fibrous	• Loose fibrous (areolar) ◦ Adipose tissue ◦ Submucosa ◦ Fascia (superficial and deep) ◦ Liver ◦ Bone marrow • Dense fibrous ◦ Unorganized/irregular ¤ Fascia ¤ Dermis ¤ Periosteum ¤ Capsules of the organs ◦ Organized/regular ¤ Aponeurosis ¤ Tendons ¤ Ligaments	• Fibers, either collagen or elastic types • Binds or strengthens organs and muscles • Compartmentalizes tissues • Transports nutrients • Helps with immunological defense • Tissue functions within muscle • Provides gross structure to muscle • Serves as conduit for blood vessels and nerves • Generates passive tension • Recoils after stretch • Conveys contractile force
	• Cartilage	• Hyaline • White fibrocartilage • Yellow or elastic fibrocartilage	• Distributes joint loads over a wide area • Decreases stress of joint surfaces • Allows movement of opposing joint surfaces with minimal friction and wear
Muscle	• Voluntary/ striated/ skeletal		• Skeletal muscle pulls on bones and acts as lever system.
	• Involuntary/ unstriated/ smooth		• Smooth muscle ◦ Regulates the flow of blood in the arteries ◦ Helps with peristalsis ◦ Expels urine from urinary bladder ◦ Aids in childbirth ◦ Regulates the flow of air through the lungs
	• Cardiac		• Cardiac muscle pumps blood throughout the heart.
Nerves	• Efferent • Afferent	• Central nervous system • Peripheral nervous system	• Electrical and chemical impulses transmit sensory information to brain, muscles, and spinal cord.

while elastic fibers permit flexibility. There are three types of collagen tissues differentiated by the protein composition of the fiber. Type I collagen is found primarily in ligaments, tendons, fascia, and fibrous capsules and constitutes about 90% of the total collagen in the body. These thick fibers do not elongate much when stretched. Type II collagen is found in cartilage and intervertebral discs serving to resist pressure on joints. Collagen in arteries, the liver, and the spleen is type III collagen (Cooper, 2007).

There are three types of connective tissue: bones, fibrous tissues, and cartilage.

Bones. The purpose of the skeletal system is to protect internal organs, provide a rigid lever system, and present muscle attachment sites. Bones achieve this by providing a firm structural support to facilitate muscle action and body movement. Osseous connective tissue is the hardest of the connective tissue types. Bones are highly vascular and can self-repair. Bones can alter their properties and configuration based on stresses applied to the body. Adaptive remodeling occurs as a result, and calcium is laid down in response to stress (Muscolino, 2006; Snyder, Conner, & Lorenz, 2007). Bones will thicken in response to stress. However, in response to excessive demands, bone spurs or arthritic (degenerative joint disease or osteoarthritis) changes may occur (Muscolino, 2006).

Bone shape determines how stable the joint will be and the types of movement that occur at a joint. If the bony surfaces are congruent and provide a tight fit, then the joint will have articular stability. A saddle-shaped bone that fits into a socket and is concave-convex-concave in shape (biaxial saddle joint) will permit distinctly different movements than a convex bone that fits into the concave part of another bone, allowing motion in only one plane (as in a uniaxial hinge joint). The convex-concave surfaces are also associated with accessory motions that are possible only with passive movement (Trew & Everett, 2005).

Fibrous Connective Tissue. There are two types of fibrous connective tissue: loose and dense. Dense fibrous connective tissue is further subdivided into dense organized/regular fibrous tissues and dense unorganized/irregular fibrous tissues.

Loose connective tissue has the same types of fibers that dense connective tissue has (collagenous, elastic, and reticular tissue types), but it also has a relatively large proportion of ground substance, so these tissues lack the reinforcing structure found in dense connective tissue. Loose connective tissue, because of the larger proportion of gel-like ground substance, is easily distorted. However, when sufficiently distorted, loose connective tissue will resist further deformation due to the strength of the collagen fibers (King, 2010).

Types of loose connective tissue include areolar, adipose, and reticular tissues. Areolar loose connective tissue is characterized by a loose network of intercellular material, abundant blood vessels, and significant empty space with predominantly collagenous fibers. Areolar tissues surround blood vessels and nerves, and the epithelium rests on a layer of areolar tissue. It is also a component of mucus membranes found in the digestive, respiratory, reproductive, and urinary systems. Areolar tissue holds organs in place by filling in the spaces between organs, cushions and protects organs and blood vessels, attaches epithelial tissue to other tissues, acts as a reservoir for water and nutrients, and provides space for waste release from other tissues. Adipose tissue is dominated by fat cells (adipocytes), which serve to pad and insulate the body and to regulate body temperature. Reticular loose connective tissue forms the structure of organs (e.g., liver, pancreas) and lymph nodes (King, 2010). Made up of primarily type II collagen fibers that provide scaffolding for other cells (e.g., bone marrow and superficial and deep fascia), loose connective tissue is the focus of myofascial intervention techniques (Donatelli & Wooden, 2010).

Dense connective tissue is made up of fibers that are thicker and in closer contact than loose connective tissue, with either parallel or latticed arrangements (Smith, 2005). Dense connective tissue is composed primarily of type I collagen fibers, creating strong connections to bone and muscles. These tissues are supplied sparingly with blood vessels, which affects healing and repair. Dense connective tissue is considered organized/regular if all fibers are aligned in a single direction (e.g., tendons, ligaments, and aponeurosis), giving tensile strength in that direction.

Tendons attach skeletal muscles to bones for the purpose of transmitting the pulling force of a muscle to its bony attachment, thereby creating movement (Curwin, 2011; Muscolino, 2006). Considered inelastic and comprised of 80% collagen fibers, which are arranged parallel to direction of force application of muscle, tendons can withstand high tensile forces and exhibit viscoelastic behavior in response to loading (Cooper, 2007; Hamill, Knutzen, & Derrick, 2015). This makes tendons strong enough to sustain tensile forces from muscle contractions, but also flexible enough to change the direction of muscle pull (Nordin & Frankel, 2012). In addition to attaching muscle to bone, transmitting tensile loads, producing movement, or maintaining posture, tendons also position the muscle belly to be at an optimal distance from the joint. Further, the myotendinous junction, where the collagen fibers of the tendon and myofibrils of the muscle join, tends to act as a dynamic restraint to muscle actions (Nordin & Frankel, 2012). Tendons are a factor in joint stability because tendons become taut when muscles are contracted. Aponeuroses are considered within this tendon description because they are tendons that are flat rather than rope-like (Muscolino, 2006).

Ligaments connect bones to bones or two or more cartilages or structures together, thus strengthening and stabilizing joints during rest and movement. Ligaments also support various organs, including the uterus, bladder, liver, and diaphragm, and help maintain the shape of the breasts (King, 2010). The deeper surfaces of ligaments may form part of the synovial sheath of the joint, and superficial surfaces may blend with surrounding connective tissue. Ligaments may be found as thickenings in the wall of the joint capsule (e.g., in the glenohumeral ligaments), lie outside of the joint (e.g., in collateral ligaments), or be inside the joint (e.g., in the cruciate ligaments; Goss, 1973; Hamill et al., 2015; Nordin & Frankel, 2012). Ligaments are pliant and flexible, allowing movement of the bones, but strong enough to resist forces. While having the same general composition as tendons, the fibers of ligaments do not lie in a parallel arrangement but are multidirectional (Nordin & Franklel, 2012).

Ligaments and joint capsules enhance the mechanical stability of joints, help to guide joint motion, serve to prevent excessive motion, and act as static restraints to joint movement (Nordin & Frankel, 2012). Because a ligament can only stretch

6% of its length before rupture, joints where ligaments are the major means of supporting a joint are not very stable (Konin, 1999).

Ligaments are more flexible and contain more elastic fibers than tendons. Unlike tendons, ligaments gradually lengthen when under tension. Athletes, gymnasts, dancers, and martial artists, who engage in activities that apply frequent or constant stretch forces to ligaments, gradually increase the ROM available at their joints. The danger in this is when joints become too lax (hyperlaxity) because this can lead to joint weakness and possible future dislocations or subluxations. In normal joints, excessive movements such as hyperextension or hyperflexion may be restricted by ligaments, thereby limiting movement to certain directions only.

Ligaments respond to loads by becoming stiffer and stronger over time, so there is diminished strength of ligaments when a joint is immobilized. Because ligaments are so important in the stabilization of joints, they are also highly susceptible to injury. Ligaments must withstand a great deal of stress in daily activities, but because they have a relatively low blood supply, injuries can take up to 2 years to heal. Tensile injury to a ligament is a sprain that is rated 1 (partial tear), 2 (tear with some loss of stability), or 3 (complete tear with loss of stability) in severity. Because ligaments stabilize, control, and limit joint motion, any injury to a ligament will influence joint movement (Hamill et al., 2015). Injured ligaments tend to be less flexible and more prone to repeated injury or rupture under stressful conditions.

Dense irregular connective tissue includes joint capsules, periosteum, the dermis of the skin, white layer of the eyeball, labrum of the shoulder, menisci in the knee, and fascial sheaths in which the fibers are arranged randomly in all directions. This fiber arrangement enables these structures to resist tensile stresses in many directions, while tendons can only withstand unidirectional tension forces (Hamill et al., 2015). There is a higher proportion of ground substance than in the dense regular/organized connective tissues, and there is increased vascularity (Donatelli & Wooden, 2010; Goss, 1973). Because of more ground substance, dense irregular connective tissue reduces friction, acts as a shock absorber, and provides greater joint nutrition. These structures also increase joint congruity, which can enhance joint stability.

A specialized type of dense fibrous irregular connective tissue is periosteum, which is a double-layered membrane covering the outer surfaces of bone. Periosteum includes cells important in repairing and forming bone tissue and houses blood vessels, lymph vessels, and nerve fibers. It is a site of attachment for ligaments and tendons, and because there are nerve fibers, when a tendon is severely strained or torn, the periosteum can become inflamed and painful.

Cartilage. Cartilage is a nonvascular structure without a nutrient supply. This means that if there is injury to this structure, it does not heal well. It is composed of primarily type II collagen fibers, which are thinner and more flexible than the collagen fibers found in other types of connective tissue. Cartilage is found between bones of cartilaginous joints, at the caps of joints, and in the intra-articular discs.

Cartilage is strong, is flexible, and acts as a shock absorber for the joint. Cartilage is able to resist shear forces, and it deforms quickly to low or moderate loads and responds stiffly to rapid loads (Hamill et al., 2015). Cartilage also helps to distribute joint loads over a wide area to decrease stress on joint surfaces and to allow movement of opposing joint surfaces with minimal friction and wear (Muscolino, 2006; Nordin & Frankel, 2012; Nyland, 2006). While stiff and strong under tensile forces, cartilage buckles under compression and is subject to wear during one's lifetime.

There are three types of cartilage: elastic, fibrocartilage, and hyaline. Elastic cartilage is found in the epiglottis; laryngeal cartilage; and walls of the Eustachian tubes, external ear, and auditory canal. Elastic cartilage contains collagen and elastin fibers, so elastic cartilage has the firmness of cartilage plus great flexibility. Consider how flexible your ear is when passively moved; this is another example of elastic cartilage.

Fibrocartilage has tensile strength and the ability to withstand high pressure due to a great density of fibrous collagen fibers. It is the toughest form of cartilaginous tissue. It is found in the intervertebral discs, some articular surfaces, pubic symphyses, joint capsules, and when articular cartilage melds with a tendon or ligament. Fibrocartilage, also called *menisci* or *discs*, contains some elastic components to allow for accommodation of pressure, friction, and shear forces (Kisner & Holtgrefe, 2012). Because of the location of fibrocartilage in the joint, it helps to improve the fit between articulating bones. Interarticular fibrocartilage (seen in the sternoclavicular, acromioclavicular, wrist, and knee joints) serves to minimize the distance between joint surfaces, increase the depths of the articular surfaces, ease gliding movements, moderate the effects of great pressure, and lessen the intensity of the shocks to which the parts may be subjected (Muscolino, 2006; Nordin & Frankel, 2012; Nyland, 2006). Circumferential fibrocartilage surrounding the margins of the labrum of the hip and of the shoulder joints deepens the articular cavities and protects their edges.

Hyaline cartilage is the most common type of cartilaginous tissue. It is found on the articular surfaces of the peripheral joints, sternal ends of the ribs, nasal septum, larynx, bronchi, and tracheal rings. Hyaline cartilage provides slightly flexible support and reduces friction within joints by providing a smooth surface over which bones can glide.

Muscles

There are three kinds of muscles in the body. The first type, voluntary/striated/skeletal muscles, appear striped, attach primarily to the skeleton, and have contractions that are usually rapid and intermittent. The second type, involuntary/unstriated/smooth muscles, are found in areas where movement occurs without conscious thought, such as in the stomach, intestines, and blood vessels. Smooth muscles contract slowly and rhythmically, as is seen in peristalsis. Cardiac muscle is the third type of muscle and is a specialized heart muscle that has characteristics of both smooth and skeletal muscles. Muscles have good supply, enabling nutrition and waste removal. Nerves within the fiber and fascia carry both motor and sensory input to the nervous system. The type of muscle discussed in this text will be voluntary muscles as these are the muscles that produce human movement necessary for everyday tasks.

Muscles contain skeletal muscle tissue and a fibrous fascial connective tissue, collectively called the *myofascial unit*. The muscle fibers are the force generators for movement. The fascia transfers forces from the muscle contraction to the bone and provides a structural framework for the muscle. Fascia encloses the entire muscle (epimysium), groups of muscle cells within the muscle (perimysium), and each individual muscle cell (endomysium). The fascia then continues at both ends to create tendons that attach the muscle to bone (Muscolino, 2006). Examples of muscle attaching to bone via tendons would be the long head of the triceps, hamstring muscles, or the flexor carpi radialis muscle. Muscle-tendon attachments are the most common means of connecting muscle with bone. Muscles can also attach directly to the bone (trapezius muscle and coracobrachialis muscle) or attach via an aponeurosis (a broad and flat tendon), as can be seen in the abdominal muscles, latissimus dorsi, or palmaris longus muscle.

Characteristics of muscle and how force develops in muscle fibers and connective tissue to produce movement are discussed in detail in Chapter 4.

Nerves

The nervous system is composed of neurons, or specialized cells consisting of cylindrical bundles of tissue that originate from the brain and spinal cord, and branch repeatedly to innervate and coordinate the actions of every part of the body. Sensory neurons transmit signals to inform the central nervous system about the status of the body and external environment, and motor neurons connect the nervous system to muscles or other organs in the body. Neurons are distinctive because they communicate with other cells via synapses, which are electrical or chemical signals through membrane-to-membrane junctions.

Types of Joints

The shapes of the bones and the way in which the structures in a joint join together determine the movement at that joint. The bones of the humeroradial and humeroulnar (elbow) joints only permit the active movements of flexion and extension due to the shape of the bony surfaces. The radioulnar joint, which has movement around the bony axis, allows pronation and supination. Biaxial and triaxial joints permit active movement in two and three different planes and axes. Passive accessory movement (e.g., roll, spin, and glide) is dependent upon the shapes of the bones and the direction of movement. When observing or assessing the movement of the joint, consideration of the type of joint determines the movement you expect to see (joint classifications are described in Chapter 2).

Methodological Factors

Methodological variables affect the precision of measurement, the accuracy and stability of results, and the worth of the test to functional activities. These variables include how the testing is done, method of testing, instruments being used, and knowledge and experience of the tester. Methodology is concerned with the specific assessment chosen, domain of concern, and person conducting the assessment.

The purpose of an assessment in general is as follows (Asher, 1996; Hinojosa & Kramer, 1998):

- To support effective clinical reasoning
- To define the nature and scope of clinical problems
- To provide baselines against which to monitor progress
- To summarize changes that occur as a result of therapy and to define areas of treatment requiring revision based on changes in the client
- To allow peers and managers to critically evaluate the effectiveness of interventions and to develop directions for quality improvements
- To aid in the decision-making process regarding allocation of health care resources
- To aid in the classification of different kinds of client groups and in justification for the need for ongoing service provision
- To aid in the determination of a functional outcome; determination of discharge plans; and potentials for work, play, and self-care within the person's own context
- To provide an opportunity to establish rapport with the client and as an aid in communication with other professionals
- To provide a means of tracking improvements, which is often motivational for the client

There are ethical considerations in choosing and using assessment tools. Therapists are consumers of tests and measurement instruments and, as such, are accountable to clients for the choices made. It is the therapist's responsibility to elicit the client's best performance on any assessment by being familiar with the test in advance, maintaining an impartial and scientific attitude during testing, establishing a therapeutic and positive rapport with the client, and providing an optimal environment in which to give the test (Demeter et al., 1996).

As consumers of assessment tools, there are characteristics of the particular test that will provide the clinical information necessary for intervention given this particular client, in a particular setting or context, and for a particular functional limitation. Minimally, you should be familiar with the test's validity and reliability to determine if this tool is assessing the domain of interest consistently. How well the tool discriminates changes within the individual client and between two clients is important in documenting changes that have occurred because of intervention. If the test has norms, knowing on what population (age, gender, diagnosis, etc.) the norms are based will inform you of how well the results of the test will apply to your client. Because an important outcome of occupational therapy is resumption of roles and engagement in areas of occupation, an assessment must be related to functional performance. What is the level of performance that is being assessed: occupations, contexts and environments, performance skills, performance patterns, or client factors (e.g., ROM, sensation)? Length of stay often determines the depth of assessment. If a client is only going to be in your facility for 2 days, a ROM screen is perhaps a more appropriate assessment of joint motion than goniometric measurement of each joint. Cultural concerns, literacy, and language issues should also be considered during evaluation to elicit the best possible response from the client. Other test characteristics are whether the test is easy to administer, the time requirements to administer the test, and the cost of administration.

The decision to use a standardized or nonstandardized assessment is also a consideration. Nonstandardized assessments would include observation, interviews, and questionnaires that rely heavily on experience and clinical reasoning (Leubben & Royeen, 2005). A nonstandardized test has not undergone rigorous development or analysis. Many ADL tools that are "home grown" or developed specifically for a particular hospital or department are nonstandardized assessments.

Table 3-4

Comparison of Nonstandardized and Standardized Assessments

Nonstandardized	**Standardized**
More sensitive to individual client needs and environmental factors	Research evidence is available to read about the assessment and to support assessment development and use
May be administered within the context of dynamic assessment	Allows for critique of the assessment's level of quality: validity, reliability, and appropriateness for client
May be more sensitive to identifying changes in areas of occupational performance	Provides consistency in methods of administering and scoring
Training time to learn to use the assessment is often less than with standardized assessments	Provides a statistical basis to quantify client's performance results in comparisons to other clients (norms)
Administration may be more flexible and take less time	Administration techniques and score are more objective, resulting in findings that should be consistent from examiner to examiner
May be less costly to administer, requiring fewer materials, forms, or equipment	Results may be used for outcomes management purposes
Incorporates therapist's clinical reasoning and experience for interpretation	Results may be a more objective measurement by other professionals, clients, and third-party payers

Adapted from Lorch, A., & Herge, E. A. (2007). Using standardized assessments in practice. *OT Practice,* May 28, 17-22.

Nonstandardized assessments are used since they may require less time to learn to use, the administration of the test may be more flexible and take less time, and the tool may be less costly to administer than standardized tools (Lorch & Herge, 2007).

Standardized assessments may also include interview and observation, but tests that measure specific behavior, performance abilities, attitudes, skills, and traits are also options. Standardized assessments have established reliability and validity based on extensive research and can lend credibility to observations, provide consistent and factual information, enable evaluation of progress and outcomes, and support evidence-based evaluation and outcomes measurement (Lorch & Herge, 2007). The advantages and disadvantages of using standardized and nonstandardized assessments are summarized in Table 3-4.

Validity and Reliability of Assessments

Accurate measurements are essential to the development of intervention plans based on the goals and needs of the client, limitations in performance, and expected outcome. Accurate measurements are also used to document effective remediation that will ensure reimbursement of therapy services and become part of the legal record of these services. Accurate measurements are crucial in providing research data for treatment efficacy.

It is important that the evaluations used yield results that truly represent the client's function (validity) and that yield similar results through time and between testers (reliability). Multiple studies have been done to determine the reliability and validity of ROM assessments, but results vary based on the body part being measured, measurement error due to mass of body segments, inconsistent operational definitions, variety in instruments used and placement of tools, and variability in identification of bony landmarks (Awan, Smith, & Boon, 2002; Eckerson, Morton, Eckerson, & Grindstaff, 2012; Ellis & Bruton, 2002; Gajdosik & Bohannon, 1987; Hayes, Walton, Szomor, & Murrell, 2001; LaStayo & Wheeler, 1994; Madson, Youdas, & Suman, 1999; Naylor et al., 2011; Nussbaumer et al., 2010; Owen, Stephens, & Wright, 2007; Rothstein, Roy, Wolf, & Scalzitti, 2005; Sabari, Maltzev, Lubarsky, Liszkay, & Homel, 1998; Shin, Ro, Lee, Oh, & Kim, 2012; Somers, Hanson, Kedzierski, Nestor, & Quinlivan, 1997; Tajali, MacDermid, Grewal, & Young, 2016; Wakefield, Halls, Difilippo, & Cottrell, 2015; Walker et al., 2016).

Validity

There are different types of validity. Many assessments have face validity (items appear to address the purpose and variables to be measured) and content validity (items represent the domain or construct being measured). ROM evaluations have logical validity, in which the performance is clearly defined and the therapist directly observes the behavior. In a ROM assessment, the movement itself is being tested, not the ability to move (which would entail aspects of the central nervous system as well as muscle strength), length of the muscle, or flexibility of the structures. ROM assessments also have content validity because testing is based on knowledge of anatomy for proper placement of the goniometer, identification of bony landmarks, and the axis of rotation.

Difficulties in validity arise in using consistent explicit definitions of ROM. While normative data are available for the motion at each joint, the norms are not sensitive enough to reflect differences based on age, gender, occupation, or sociocultural considerations. However, in a study comparing radiographs (x-rays) with goniometric measurements, there was found to be a high correlation between these two types of measurements, indicating that this assessment has concurrent or congruent validity, which is a criterion-referenced measure. The goniometer is considered the gold standard by which other tools of joint measurement are compared (Flinn, Latham, & Podolski, 2008; Palmer & Epler, 1998). However, in a study comparing the use of a conventional goniometer and an electromagnetic tracking system in measuring hip flexion, abduction, adduction, and internal and external rotation, the goniometer measurement overestimated hip ROM, good concurrent validly was only achieved for hip abduction, and internal rotation was likely due to uncontrolled pelvic rotation and tilt and difficulties in placing the goniometer properly. Reliability did not differ between the two methods of measurement (Nussbaumer et al., 2010).

Reliability

Consistent results are also important. When a test is given to a client one time and the same test is given to the same client again by a different tester, this is known as *interrater reliability*. When the same tester assesses the same client at different times, this is called *intrarater reliability*. Intrarater reliability is consistently higher than interrater reliability (Boone, 1978; Flinn et al., 2008; Hamilton & Lachenbruch, 1969; Hellebrandt, Duvall, & Moore, 1949), and active ROM measurements have higher reliability than passive measurements (Sabari et al., 1998).

While some studies suggest that if reliability has been established among testers, there can be a high degree of accuracy, other authors recommend that examiners with little experience may want to take several measurements and record the mean of the values to increase reliability. Eckerson et al. (2012) used a variety of methods to measure ankle dorsiflexion with a novice rater and found that reliable measures could be obtained by a novice rater.

Somers and colleagues (1997) suggest that interrater reliability may be more dependent on training than on experience, and uniform training may be more of a determinant of interrater reliability.

Error estimates for ROM vary according to the specific joints tested. Awan et al. (2002) determined that intrarater reliability for internal and external rotation of the shoulder was good ($r = 0.58$ to 0.71) and interrater reliability was fair to good ($r = 0.41$ to 0.66). Walker et al. (2016) found acceptable interrater reliability for shoulder ROM with the exception of internal rotation. Rothstein and colleagues (2005) reported intrarater and interrater reliability values for specific joint motions, and the intraclass correlation coefficient (ICC) was used to assess the consistency of measurements made by multiple observers measuring the same quantity (Table 3-5). In measuring active lumbar spine and pelvic inclination, intrarater reliability was fair to poor for sagittal plane measurements and was reliable for lumbar lateral flexion and rotation (Madson et al., 1999). Measurement of knee ROM reliability using goniometry and photographic records yielded high validity for both methods and very high intrarater and interrater reliability (Naylor et al., 2011). In a study to determine the interrater reliability of ROM of the hip in children aged 4 to 10 years, goniometric measurement had low reliability (Owen et al., 2007)

In measuring ROM, there is equal reliability between readings of different goniometers for determining joint angles and between goniometers with different scale increments (Bear-Lehman & Abreu, 1989). Generally, ±5 degrees is considered the standard error of measurement for ROM. Reliability can be improved by using consistent and well-defined testing positions and anatomic landmarks to align the goniometer.

To avoid the problem with accuracy in landmarking anatomical structures, ROM was measured with a goniometer and using trigonometric techniques to measure hip length and vertical displacement. The trigonometric technique to measure hip extension ROM resulted in superior intrarater and interrater reliability when compared with the goniometric measurement (Wakefield et al., 2015).

Various measurement methods and tools have been used to assess ROM. Shin et al. (2012) cite the expense of digital inclinometers and instead used an inclinometer application on a smartphone and goniometric measurement to assess active and passive shoulder ROM for forward flexion, abduction, external rotation while the arms are at the sides, external rotation at 90 degrees abduction, and internal rotation at 90 degrees abduction. Both methods had satisfactory interrater reliability except for internal rotation at 90 degrees abduction, and intrarater reliability was excellent for most motions (Shin et al., 2012). When two experienced raters measured active wrist ROM, and active and passive index proximal interphalangeal (PIP) flexion using two digital goniometers, the intrarater and interrater reliabilities were high in most ROM measures (ICC range 0.64-0.97) for both types of electro-goniometers (Tajali et al., 2016). Measuring six different shoulder movements via visual estimation, goniometry, and photography was found to have fair to good reliability for all three methods (Hayes et al., 2001).

Assessment of Range of Motion

Assessment of ROM reflects the client factor aspect of the domain of occupational therapy. The various aspects of the occupational therapy domain (occupations, performance skills, performance patterns, client factors, and contexts and environments) are interrelated and limitations in one aspect can influence performance in other areas. Assessment of the body structures associated with movement and of the physiological functions of joint mobility and stability is important in understanding limitations in occupational performance, skilled activities, habits, routines, and roles within various contexts and environments.

Observation is an important initial part of the total assessment process where the therapist can look for symmetry between the limbs, use of compensatory motions, overall body posture, muscle contours, and color and temperature of the skin. This can be done while gathering information from the client for the occupational profile and even as the client enters the room. Noticing how the person moves and any pain or limitations may guide further assessments.

Limitations in ROM may be due to tissue changes (when passive ROM is less than normative values) or muscle weakness (where active ROM is less than passive). An understanding of why the joint is limited will direct the intervention. If the joint is limited due to shortened tissues, the goal would be to stretch the tissues to enable full or functional ROM. If the limitations are due to edema, pain, or spasticity, the goal of treatment would be to minimize these problems and then reassess joint movement. Long-standing limitations or contractures that are not able to be remediated would best be treated by the occupational therapist using compensatory or adaptation strategies.

Table 3-5

Intrarater and Interrater Reliability for Joint Motions

		Intrarater Reliability		Interrater Reliability	
Joint	**Motion**	**ICC**	**N**	**ICC**	**N**
Shoulder	Flexion	0.98	100	0.88	50
	Extension	0.94	100	0.27	50
	Abduction	0.98	100	0.85	50
	Horizontal abduction	0.91	100	0.29	50
	Horizontal adduction	0.96	100	0.37	50
		0.98	100	0.90	50
		0.94	100	0.48	50
Elbow	Flexion	0.95*	24	0.93*	12
	Extension	0.95*	24	0.94*	12
Knee	Flexion	0.98*	24	0.85*	12
	Extension	0.95*	24	0.70*	12
Ankle	Subtalar neutral	0.77	100	0.25	50
	Inversion	0.74**	100	0.32**	50
	Eversion	0.75**	100	0.17**	50
	Dorsiflexion	0.90	100	0.50	50
	Plantarflexion	0.86	100	0.72	50

*ICC values calculated using a less conservative form of the ICC than other values in the table.

** These measurements were not referenced back to the subtalar position.

Reprinted with permission from Rothstein, J. M., Roy, S. H., Wolf, S. L., & Scalzitti, D. A. (2005). *The rehabilitation specialist's handbook* (3rd ed.). Philadelphia, PA: F. A. Davis.

ROM limitations can result in physiologic changes in muscles and tissues. When a part is immobilized or normal movement does not occur, there may be a loss of muscle fibers, changes in the length and number of muscle sarcomeres, ligamental and tendon weakness, disorganized synthesis of new collagen, and shortening of muscle fibers. Disruptions in joint movement affect the synovial fluid, synovial membranes, and articular cartilage, further affecting joint movement and increasing the circumference of the joint. Increasing ROM is important physiologically to prevent muscle imbalance, minimize discomfort, avert skin breakdown, avoid hygiene problems, and enable people to care for the client or to enable the client to move actively.

ROM can be measured passively and actively with different information gleaned from each procedure. For clarification, the following abbreviations and terminology are defined:

- Passive range of motion (PROM): Arc of motion through which a joint passes when moved by an outside force
- Active range of motion (AROM): Arc of motion through which a joint passes when moved by muscles acting on a joint
- Active assistive ROM: Arc of motion through which a joint passes when moved initially by muscles then completed by an outside force
- Functional ROM: Amount of motion necessary to perform essential ADL tasks without adaptations or equipment. Another definition is the "minimum motion necessary to comfortably and effectively perform ADL" (Vasen, Lacey, Keith, & Shaffer, 1995, p. 291)
- Torque ROM: The external force (generally 200 g) is applied to the joint by an orthotic gauge or torque device to achieve objective and precise passive measurements (Flinn & DeMott, 2010)
- Total AROM: Total active motion is computed using AROM from metacarpophalangeal (MCP), PIP, and distal interphalangeal (DIP) of one digit minus the extension lag for that joint (Flinn & DeMott, 2010)
- Total PROM: Total AROM and total PROM are useful in identifying true progress in intervention and can identify a client who is making improvements in flexion at the expense of losing extension (Flinn & DeMott, 2010)

The assessment of ROM seems like a simple assessment of the movement of the joints, but an assessment of the mobility of the joint also includes an assessment of the physiological stability of the joint and its structural integrity. Many conditions limit ROM and joint stability (e.g., edema, adhesions, shortened tissues, decreased strength), and the assessment of joint motion may lead to the administration of other physical assessments. The ROM assessment would include understanding the client and his or her experiences and goals (i.e., the occupational profile), observing the way the client moves, palpating joint structures, and measuring the ROM.

Range of Motion Screening

Joint ROM can be assessed by means of a goniometer or by screening techniques. Screening tools are used as a rapid method of assessing multiple joint movements or combined movements to determine if more in-depth and standardized assessments are needed. Visual estimation of joint ROM is often used clinically as an informal screen for ROM. While some feel that this method is unreliable and deemed "not acceptable" (Demeter et al., 1996), others found fair to good reliability for visual estimation as compared with photography, hand goniometry, and radiographic goniometry (Hayes et al., 2001; Peters, Herbenick, Anloague, Markert, & Rubino, 2011).

Clinical ROM screens ask the client to move in a specified way, or the therapist passively moves the client. These can be done actively by the client, or the therapist moves the client into the positions. Table 3-6 provides AROM screening tests for the upper and lower extremities.

Functional motion tests or motion inventories often use observation to determine decreased motion or use of compensatory motions when achieving combined motions or simulated tasks. This might include tasks such as the following (Gutman & Schonfeld, 2003, p. 120):

- Placing an object behind the client and having him or her look for and retrieve the object while sitting and then standing
- Having the client reach overhead for an object
- Having the client don a button-up shirt or blouse
- Having the client pick up items off of the floor (can be done in sitting or standing)
- Observing the client comb/brush his or her hair
- Having the client cross his or her legs to don a pair of pants

Generally, a functional motion screening tool uses active motion and gives information about patterns of movement and about the client's willingness to move. Descriptions that are more detailed may minimize this problem but may also be more difficult for the client to understand. Scoring of functional motion tests often involves use of the following nominal scales:

- n = completes normally
- s = completes with substitution
- I = initiates movement but cannot complete
- u = unable to perform
- NT = not tested

Percentages are also used to indicate what part of range is limited, such as the following (Tan, 1998):

- 0 limitation = full ROM
- minimal limitation = 1% to 33% ROM
- moderate = 33% to 66% ROM
- maximal = 66% to 100% ROM

Some screening tools combine functional motion test items, such as picking up an object or turning a doorknob, with AROM screens of isolated joint motions (such as touching the top of the head for shoulder flexion). These tests may then be followed by simulated tasks such as using a hammer or screwdriver, throwing a ball, or threading a needle.

A disadvantage of functional motion screening tools is the variability of movements that can occur that satisfy the request for movement. For example, if asked to touch the top of the head, the humerus can be abducted or flexed with the elbow and wrist flexed to reach the hand to the head, or the elbow can be flexed with the neck and trunk flexed to reach the head to the hand.

Instrumentation

If deficits have been noted or a more detailed measurement of joint motion is desired, goniometric measurements are made. Goniometry is a commonly used measurement of joint motion. The word *goniometer* comes from two Greek words: *gonia*, which means angle, and *metron*, which means measure. A goniometer is a tool that is used to determine the amount of motion available at a specific joint.

There are various types of goniometers, but the most widely used is the universal goniometer. Universal goniometers have "good to excellent" reliability (Palmer & Epler, 1998). These are simple, uniplanar protractors commonly used in clinical practice. The goniometer has either 360- or 180-degree scales (or both), with two arms used to measure the motion. One arm follows the movement, and the other aligns with a stationary part of the body. These can be full-circle goniometers or half-moon (in the shape of half of a circle).

Gravity-dependent goniometers use gravity's effect on pointers and fluid levels. The device is strapped onto a distal leg segment with the proximal limb positioned vertically or horizontally. The pointer or bubble is read at the end of ROM. This type of goniometer does not need to be aligned with skeletal landmarks and makes the measurement of PROM easier. Disadvantages are that the gravity-dependent goniometer is bulkier, more expensive, not as readily available, and more difficult to use on small joints and for rotational movements than the universal goniometer.

An inclinometer is a pendulum-based device that has a 360-degree scale protractor with a counterweighted pointer. Electronic versions are available, and this type of goniometer is especially good for measurements of spinal ROM. A fluid goniometer (bubble goniometer or hydrogoniometer) also has a 360-degree scale with fluid in a tube with small air bubbles. An electrogoniometer is a potentiometer in which movement causes changes in resistance and voltage that can be calibrated to represent ROM. This tool is expensive and is often used in research (Tan, 1998).

Table 3-6

Active Range of Motion Screen

Position of Client	Motion Being Tested	Instructions to the Client/Ask the Client to ...
Sitting	• Scapular elevation	• Shrug shoulder toward ears and release.
	• Scapular retraction	• Squeeze shoulder blades back as if they are touching.
	• Shoulder abduction	• Raise right arm out to side, then as high up as possible; repeat left side.
	• Shoulder internal rotation	• Place hands behind their back as though fastening a bra or tucking in a shirt.
	• Shoulder abduction and lateral rotation	• Reach behind their head and touch the opposite shoulder blade, place hands behind their neck and push your elbows back (posteriorly).
	• Shoulder adduction and medial rotation	• Reach to their opposite shoulder and touch their shoulder blade on the opposite side, place both hands behind their back as high as possible.
	• Shoulder flexion and extension	• Raise arms in front of body and up as high as possible.
	• Elbow flexion and extension	• Bend and straighten elbows.
	• Supination and pronation	• Turn palm up and down with elbows bent to 90 degrees, and with arm at their side.
	• Wrist flexion and extension	• Bend their wrist up and down.
	• Radial and ulnar deviation	• Move wrist toward and away from the midline with palms down.
	• Finger flexion and extension	• Make a fist and then open up their fingers.
	• Finger abduction and adduction	• Spread their fingers apart and bring them together.
	• Thumb flexion and extension	• Bend their thumb across their palm and then out to the side.
	• Neck flexion and extension	• Place their chin on their chest and then tilt head back.
	• Neck rotation	• Turn their head to the right, left and then in a circle.
	• Hip flexion*	• March in place while seated.
	• Hip flexion, abduction and lateral rotation	• Uncross thighs and place the side of their foot on their opposite knee.
	• Ankle inversion	• Turn their foot in.
	• Ankle eversion	• Turn their foot out.
	• Hip abduction and adduction	• Spread legs apart and bring them back together.
Supine	• Hip flexion and knee flexion	• Bend the hips and knees.
Standing	• Trunk flexion	• Bend forward and reach for their toes with knees straight.
	• Trunk extension	• Bend backward while you stand beside them.
	• Trunk lateral bending	• Lean to the left, then right while you stabilize their pelvis.
	• Trunk rotation	• Turn to the right, then left while you stabilize their pelvis.
	• Ankle plantarflexion and toe extension	• Stand on their tiptoes.
	• Ankle dorsiflexion	• Stand on their heels.

Adapted from Palmer, M. L., & Epler, M. E. (1998). *Fundamentals of musculoskeletal assessment techniques* (2nd ed.). Philadelphia, PA: Lippincott Williams & Wilkins and Gutman, S. A., & Schonfeld, A. B. (2003). *Screening Adult Neurological Populations*. Bethesda, MD: American Occupational Therapy Association Press.

Other methods of measuring joint motion include the use of tape measures, photometric (video-based) motion analysis systems, radiographs, photocopies, freehand drawings or tracings, infrared light sources, electrogoniometry, roentgenography light-emitting diodes (or reflectors), or laser lights (which have good validity and reliability but are expensive; Tan, 1998). The type of goniometer chosen reflects the level of accuracy required, resources available, and convenience.

Smartphone applications (apps) are also available as an alternative to handheld goniometers. Milani et al. (2014) conducted a systematic review of apps for smartphones validated for body position measurement. The apps measured joint motion via accelerometer, magnetometer, and photography-based methods.

Accelerometers measure joint angles by comparing the inclination of the segment above and below the joint. The Simple Goniometer app (Ockendon) is an example of an accelerometer used to measure scoliosis and was found to be clinically equivalent to hump measurement in clients with spinal deformities (Izatt, Bateman, & Adam, 2012). The wGT3X-BT (ActiGraph) activity monitor is considered the gold standard in upper extremity accelerometry used to record continuous physical activity. When compared with the FixBit Flex, with similar mechanical systems, there was a significant correlation between the ActiGraph and FitBit, which can provide a less-expensive and readily acceptable tool for future studies (Rowe, Neville, & Melcher, 2016).

DrGoniometer (CDM) is an example of a photography-based app that validly measures flexion of both elbow and knee, active external rotation of the shoulder, and tibial external rotation angle (Ferriero et al., 2011, 2013; Mitchell, Gutierrez, Sutton, Morton, & Morgenthaler, 2014). In addition, DrGoniometer was ranked highest in userablity in a recent study when compared with Gonionmeter Record and Goniometer Pro apps (Calk, Stewart, Thomas, & Reichardt, 2016).

GetMyROM (Interactive Medical Productions) is an example of a bubble inclinometer. Unlike the study by Moran, Avena, Jooyandehnik, Pirak, and Zelig (2016) in which the GetMyROM app was not found to be reliable or valid, Mitchell et al. (2014) determined that this app had ICC scores of 0.79 to 0.81, with interrater reliability ranging from 0.92 to 0.94 and concurrent validity that ranged from 0.93 to 0.94.

Many of the apps reviewed in the Milani et al. (2014) systematic review had good to excellent intrarater and interrater reliability. Of those apps that were validated, two apps measured knee ROM (Angle [Smudge Apps] and Knee Goniometer [Ockendon]; Jenny, 2013; Ockendon & Gilbert, 2012); one measured shoulder ROM and cervical spine mobility (Clinometer [Plaincode]; Shin et al., 2012; Tousignant-Laflamme, Boutin, Dion, & Vallée, 2013); four measured the spine (CobbMeter [ALTAVI sarl], Compass [Apple], Scoliogauge [Ockendon], iHandy Level [iHandySoft]; Franko, Bray, & Newton, 2012; Izatt et al., 2012; Jacquot et al., 2012; Kolber, Pizzini, Robinson, Yanez, & Hanney, 2013; Qiao et al., 2012; Salamh & Kolber, 2014; Tousignant-Laflamme et al., 2013); one measured hallux valgus angle, intermetatarsal angle, and distal metatarsal articular angle (Hallux Valgus App [Ockendon]; Ege, Kose, Koca, Demiralp, & Basbozkurt, 2013); and one measured ankle ROM (TiltMeter [IntegraSoftHN]; Williams, Caserta, & Haines, 2013; Yoon et al., 2014).

Active Movement

It is important to distinguish whether the limitations in ROM occur during AROM or PROM. Combining the results of ROM and of contractile and noncontractile tissue assessments allows the therapist to determine what tissue or structure is affected. Treatment can then be directed to a specific tissue site. Optimally, AROM assessments are completed first. If AROM is less than PROM, this may be due to muscle weakness, pain, paralysis, spasm, tight or shortened tissues, changes in the length-tension relationships of the tissues, or modified neuromuscular factors or changes in the joint-muscle interaction (Magee, 2014).

Standardized ROM positioning for each joint motion have been developed. When using a goniometer to measure AROM, the testing position of the client and the goniometer placement are given for each joint. In consideration of the client's comfort, the client is seated in an armless chair that provides back support, although some tests can be done in the supine or standing positions. To ensure the most accurate results, make sure the client is comfortable and relaxed. Having established rapport during the initial interview, it is important to reassure the client that you are aware of motions that may be uncomfortable and to address any client concerns about being touched (due to fear of pain, cultural beliefs, etc.) prior to ROM testing initiation.

Tell the client exactly what you will be doing and why. State the purpose of the ROM simply, such as, "This test will provide information about the way your joints move, and this tool, a goniometer, will measure the arcs of motion of your joints." Then, have the client assume the starting position for the specific test, which is usually 0 degrees in the anatomical position (except for rotary movements). Stabilize the joint proximal to the joint being measured, which will help to minimize substitution movements, increase accuracy, and decrease client fatigue.

In aligning the goniometer to the joint, you need to consider the goniometer arm placement and identification of the joint axis. The goniometer is essentially a protractor used to measure joint angles. The axis of the goniometer is the rivet. This is aligned to the axis of movement of the joint. Often, this is a specific bony landmark, such as the acromion of the shoulder. Palpation is necessary to identify bony skeletal landmarks used as reference points when measuring the arc of motion. Because identification of joint axes involves bony landmarks, for the most precise ROM measurements, uncovering the joint will be necessary to palpate structures, avoid interference with motion, and for alignment of the goniometer axis.

Because joint movements are often a combination of movements at several joints simultaneously, the joint axis may appear to shift during movement. This occurs most notably during shoulder flexion and abduction. It is important in these cases to maintain the original orientation of the goniometer axis despite the shift in joint axis due to movement.

The two arms of the goniometer are then aligned to body segments. One arm of the goniometer (stationary arm) lies parallel to the longitudinal axis of a proximal segment or will point to a distal bony prominence. The other goniometer arm (considered the movable arm) follows the motion and lies parallel to the longitudinal axis of the moving distal joint or points to a distal bony prominence. To make sense of this, just remember you are measuring a part of the body that moves:

one part of the goniometer must be a reference (stationary arm); the other part has to follow the movement (moveable arm).

Demonstrate the motions you want the client to do first and how you would use the goniometer to measure the joint. Use as many sensory modalities as necessary to clearly convey to the client how you want him or her to move. You can verbally describe the motion, demonstrate the motion yourself so he or she can visually see the motion, and then have the client demonstrate the motion him- or herself so he or she can kinesthetically and proprioceptively feel the motion. You will have already asked if the client has any previous fractures or fused joints, which you will note on the recording form so you know in which joints to expect limitations. If performing PROM, hold the part securely but gently, and do not force any joints to move. During the joint movement, be aware of the client's comfort, and note any motions that produce pain. Record the number of degrees of motion at the initial and final positions.

Passive Movement

PROM gives the examiner information about the integrity of the articular surfaces and the extensibility of the joint capsule, ligaments, bursa, cartilage, nerves, nerve sheaths, and muscles. Passive movement is analogous to anatomical movements (as compared to active movements, which are seen to be physiologic movements).

PROM is tested in the same way that AROM is tested with the exception that the therapist is moving the part, rather than the client moving the part through volitional movement. Normally, PROM is greater than AROM due to accessory motions and joint play. Passive joint evaluations assess the "tensegrity" of a joint, which is a term denoting both tension and tissue integrity that occurs in normal structures. PROM assessments provide information about the status of the joint by evaluating normal limiting factors and patterns of limitation or restriction. PROM may be considered more objective than AROM because the motion is controlled by the examiner and is free of control by the subject (Demeter et al., 1996).

Normal Limiting Factors

Normal limiting factors of joint movement can be felt when passively moving a part to the extreme ends of ROM. This may be when a joint is in a close-packed position and the articular surfaces are in contact. The limited ligamental extensibility, due to the relative inelasticity of white fibrous collagen, restricts some motions, while limited muscle and tendon extensibility restricts other motions. In some joints, the normal limiting factor is due to the apposition of soft tissues. Structures that limit the amount of motion at a specific joint have a characteristic feel that is felt as resistance to further movement. This is known as *end feel*. End feel has been defined as the "subjective assessment of the quality of the feel when slight pressure is applied at the end of a joint's passive range of motion" (Lippert, 2006).

While there are some variations in the terminology used to describe an end feel, generally it is accepted that there are six types of end feel: three are descriptions of normal limiting factors, and three are pathological impediments to movement (Table 3-7).

Further motion in a joint with soft end feel is due to compression of soft tissue. This is a normal limiting factor and is seen in knee flexion when the soft tissue of the posterior leg contacts the posterior thigh. Firm normal end feel occurs when there is tension in the way the joint feels but also a slight "give" in the structures, comparable to pulling a rubber band or a strip of leather, depending on the structure limiting the motion.

Normal firm end feel can occur due to muscles, capsules, or ligaments. A firm muscular end feel occurs with hip flexion with the knee straight because there is passive elastic tension in the hamstring muscles. Extension of the MCP joints of the fingers creates tension in the anterior capsule and is an example of firm capsular end feel. Firm ligamental end feel is demonstrated in forearm supination with tension occurring in the palmar radioulnar ligament of the inferior radioulnar joint, interosseous membrane, and oblique cord. The third type of normal end feel is hard, in which there is an abrupt hard sensation at the extreme end of ROM. This is when a bone contacts another bone and can be felt in elbow extension (Cyriax, 1982).

Abnormal limitations in ROM may be due to any of the following (Trew & Everett, 2005):

- Destruction of bone and cartilage (osteoarthritis or rheumatoid arthritis)
- Bone fractures
- Foreign body in joint (Bankart lesion in shoulder; tearing of meniscus in knee)
- Tearing or displacement of intracapsular structures
- Adhesions or scar tissue
- Muscle atrophy or hypertrophy
- Muscle tear, rupture, or denervation
- Pain
- Psychological factors
- Edema
- Neurological impairment

These abnormal limitations would manifest as pathological end feels. Slight overpressure at the end of the ROM that reveals soft end feel in a joint that normally had a firm or hard end feel may be indicative of edema or synovitis of that joint. Other conditions may present with end feels different than the normal limiting factors or may present with the normal type of end feel, but the limitation occurs earlier in the ROM than in a normal joint. A hard end feel may occur in the cervical spine due to osteophytes, or empty end feel may occur due to acute bursitis or a tumor. Empty end feel is due to a lack of mechanical limitation of joint ROM and is where joint motion is limited by pain and complete disruption of soft tissue constraints (Lippert, 2006). If there is an abnormal hard end feel and limited but pain-free movement, this may be due to osteoarthritis where osteophytes restrict movement but are not compressing nerves or sensitive structures (Magee, 2014).

Other abnormal end feels include the following:

- Spasm that is felt as a "vibrant twang" (Marieb, 1998, p. 8; Cyriax, 1982) and is the result of a prolonged muscle contraction in response to circulatory and metabolic changes (Kisner & Holtgrefe, 2012; Lippert, 2006).
- Capsular end feel is similar to tissue stretch but occurs earlier in the ROM. Hard capsular end feel is more in chronic conditions or capsular abnormalities, and it comes

Table 3-7

Physiologic and Pathologic End Feel

	Physiologic (Normal)		Pathologic	
Type of End Feel	**Description of End Feel**	**Joint Examples**	**Description of End Feel**	**Possible Reasons**
Soft	• Soft tissue	• Knee flexion • Elbow flexion • CMC thumb flexion	• Occurs sooner or later in ROM • Occurs in a joint normally firm or hard • Feels boggy	• Synovitis • Edema
Firm	• Muscular stretch • Capsular stretch • Ligamentous stretch	• Scapular elevation • Scapular depression • Shoulder abduction • Shoulder adduction • Shoulder internal rotation • Shoulder external rotation • Shoulder extension • Shoulder horizontal abduction • Shoulder horizontal adduction • Forearm supination • Wrist flexion • Wrist extension • Wrist radial deviation • Wrist ulnar deviation • MCP extension • CMC extension • Thumb extension • Interphalangeal extension • DIP flexion • DIP extension • Hip flexion	• Occurs sooner or later in ROM • Occurs in joints normally soft or hard	• Increased tone • Shortening of capsules, muscles, or ligaments
Hard	• Bone against bone	• Elbow extension • Forearm pronation • PIP flexion • MCP flexion of thumb	• Occurs sooner or later in ROM • In joints normally soft or firm • Bony grating or block felt	• Osteoarthritis • Chondromalacia • Loose bodies in a joint • Myositis ossificans • Fractures • Frozen shoulder • Osteophyte formation

(continued)

Table 3-7 (continued)

PHYSIOLOGIC AND PATHOLOGIC END FEEL

Type of End Feel	Physiologic (Normal): Description of End Feel	Physiologic (Normal): Joint Examples	Pathologic: Description of End Feel	Pathologic: Possible Reasons
Empty			• ROM never reached due to pain • No resistance felt	• Acute joint inflammation • Bursitis • Abscesses • Fractures • Psychogenic

CMC = Carpometacarpal.

Adapted from Norkin, C., & White, D. (1985). *Measurement of joint motion: A guide to goniometry.* Philadelphia, PA: F. A. Davis.

on abruptly after smooth, friction-free movement. Soft capsular end feel is more common in acute conditions, with stiffness occurring early in the ROM and increasing to the end of the ROM. Soft capsular end feel presents as soft or boggy and may be the result of synovitis or soft-tissue edema. Major injuries to ligaments and capsule may cause soft end feel (Magee, 2014).

- Springy block is when a joint rebounds at the end of ROM due to internal articular derangement that may be indicative of intra-articular blocks, such as torn meniscus or articular cartilage.
- Muscle guarding is an involuntary muscle contraction in response to acute pain (Kisner & Holtgrefe, 2012; Lippert, 2006).

Patterns of Limitation

Joint play is the "give" or distensibility (or extensibility) of the joint capsule and soft tissues that can only be obtained passively. It is usually a motion less than 4 mm that must be tested in the loose-packed (resting) position because this is the position in which the joint is under the least amount of stress. The joint capsule works at its greatest capacity in this position, and there is minimal congruency between articular surfaces and the joint capsule. The ligaments are in a position of greatest laxity, which allows joint distraction via rolling, spinning, and sliding. The close-packed position should be avoided because, in this position, the two joint surfaces fit together perfectly, ligaments and tendons are maximally tight, and the joint is under maximal tension.

Assessing joint gliding requires an understanding of the convex-concave rule to successfully replicate the accessory motion. The direction of glide is in the same direction as the moving segment in joints that are concave, and the direction of glide is in an opposite direction to the bony segment in a convex joint.

Assessing the inert structures of the joint requires a passive stretch of these tissues to evaluate pain, laxity, or limitations in ROM. Normally, passive stretching or compression is painless, but if there is injury, immobilization, or inflammation resulting in abnormal tissues, the passive movement may be painful. Ligaments that are injured often result in a particular pattern of limitation that is found to be in a specific pattern in each particular joint. Noncapsular patterns are also possible. These are limitations that exist but do not correspond to the classic capsular patterns described for each joint (Magee, 2014). Local restriction (e.g., ligamentous adhesion), bursitis, internal derangement (as seen in knees, ankles, and elbows), intracapsular fragments, extra-articular lesions, and subluxations are possible reasons for noncapsular patterns (Magee, 2014). Capsular patterns are listed in Table 3-8. The value of assessing the inert structures is to identify the structures causing the limitation.

Recording Range of Motion Results

While the method of performing an ROM assessment is standardized, there are different methods of recording ROM results. There are three systems used in clinical practice: the 360-degree system, the 180-degree system, and the SFTR system. The 180-degree system is more commonly used (i.e., American Academy of Orthopaedic Surgeons) and accepted in clinical practice. In this system, the neutral zero or starting position is with the body in anatomical position with the zero position toward the feet. The body is in the plane in which the motion is to occur, with the axis of the joint acting as the arc of motion (Pedretti, 1996).

In the 360-degree system, the zero starting position is overhead with the arc of motion related to a full circle. In both systems, some motions do not readily lend themselves to movements around a semicircle or full circle. These are generally rotational movements such as pronation, supination, and internal and external rotation; radial and ulnar deviation; and thumb CMC flexion and extension. To illustrate the difference in recording between these two systems, consider the motion of shoulder flexion. The arc of motion for shoulder flexion is generally accepted to be 180 degrees, which would be recorded as 0 to 180 degrees in the 180-degree system. A separate

Table 3-8

Capsular Patterns of the Joints

Joint	Capsular Pattern (in Order of Limitation)
Glenohumeral	• Lateral rotation, abduction, medial rotation
Sternoclavicular	• Pain at extreme ROM
Acromioclavicular	• Pain at extreme ROM
Humeroulnar	• Flexion, extension
Radiohumeral	• Flexions more limited than extension • Supination and pronation equally limited
Proximal radioulnar	• Supination, pronation
Distal radioulnar	• Pain at extremes of rotation • Pronation and supination mildly limited at the distal radioulnar joint
Wrist	• Flexion and extension equally limited
Fingers	• Abduction more limited than adduction of the thumb CMC • Flexion more limited than extension of MCP and interphalangeal joints
Thoracic spine	• Side flexion and rotation equally limited, extension
Lumbar spine	• If a left facet is limited, forward bending produced a deviation to the left • Side-bending right is limited while side-bending left is unrestricted; rotation left is limited while rotation right is unrestricted
Cervical spine	• If left facet is limited, forward bending produces some deviation on the left • Side-bending right is unrestricted while side-bending left is comparatively unrestricted; rotation right is comparatively unrestricted and rotation right is most limited
Hip	• Flexion, abduction, medial rotation (order varies)
Knee	• Flexion more limited than extension
Foot and toes	• Extension more limited than flexion

movement of shoulder hyperextension (movement from the arm held at the side then moved in a posterior direction) would be recorded as 0 to 60 degrees. In the 360-degree system, this same arc of motion would include flexion and the additional movement of hyperextension. The total movement would be recorded as 0 to 240 degrees. It is clear that identification of the system of recording is vital to clear communication and documentation of ROM results.

Another method of recording is the SFTR system (Gerhardt, 1983). In this system, the measurement of ROM is completed as in either the 180- or 360-degree systems. The recording of the results is related directly to the cardinal planes, with S indicating the sagittal plane, F indicating the frontal, T indicating the transverse plane, and R indicating rotational movements. Neutral zero is the anatomical position with three numbers used to record the motion rather than an ROM. The first number indicates movements away from the body, such as abduction, flexion, or external rotation; the second number indicates the starting position (usually zero); and the third number represents movements toward the body, such as extension, adduction, and internal rotation. An SFTR recording of the shoulder movement of full flexion and hyperextension would be 180-0-60 degrees to indicate full flexion, starting position, and hyperextension. An elbow that can be hyperextended would be recorded as S 10-0-150 degrees.

Usually, in clinical practice, the recording of ROM uses the 180-degree system. The ROM results for shoulder flexion would be 0 to 180 degrees, and the 0 degrees signifies the starting position of full extension while the 180 degrees is indicative of the motion overhead into full forward flexion. This one ROM recording of two numbers describes both flexion and extension because the movement began in full extension and moved to full flexion. Other motions where one set of ROM values describes two motions are shoulder abduction and adduction, elbow and knee flexion and extension, and finger flexion and extension (PIP, DIP, MCP joints). Separate measurements are required for shoulder internal rotation, shoulder external rotation, pronation, supination, wrist flexion, wrist extension, ulnar deviation, radial deviation, hip adduction, hip abduction, hip flexion, hip extension, hip internal rotation, hip external rotation, dorsiflexion, plantarflexion, inversion, and eversion.

Regardless of whether the 360- or 180-degree system is used, it is important to record both numbers, as these signify the starting and ending positions. Limitations will be readily

Table 3-9

COMPARISON OF RANGE OF MOTION NORMATIVE VALUES (IN DEGREES)

	Ages 20 to 44 Years	
Motion	**Females**	**Males**
Hip extension	18.1 (17.0 to 19.2)	17.4 (16.3 to 18.5)
Hip flexion	133.8 (132.5 to 135.1)	130.4 (129.0 to 131.8)
Knee flexion	141.9 (140.9 to 142.9)	137.7 (136.5 to 138.9)
Knee extension	1.6 (1.1 to 2.1)	1.0 (0.6 to 1.4)
Ankle dorsiflexion	13.8 (12.9 to 14.7)	12.7 (11.6 to 13.8)
Ankle plantar flexion	62.1 (60.6 to 63.6)	54.6 (53.2 to 56.0)
Shoulder flexion	172.0 (170.9 to 173.1)	168.8 (167.3 to 170.3)
Elbow flexion	150.0 (149.1 to 150.9)	144.6 (143.6 to 145.6)
Elbow extension	4.7 (3.9 to 5.5)	0.8 (0.1 to 1.5)
Elbow pronation	82.0 (81.0 to 83.0)	76.9 (75.6 to 78.2)
Elbow supination	90.6 (89.2 to 92.0)	85.0 (83.8 to 86.2)

(continued)

apparent in the designation of these values. If normal shoulder ROM is 0 to 180 degrees, a value of 15 to 180 degrees would indicate a deficit in the ability to assume the zero starting position or an inability to assume full extension. Similarly, 0 to 165 degrees would indicate a 15-degree deficit in shoulder flexion. Familiarity with normative values is helpful in determining deficits in ROM. The standard error of measurement for ROM values is ±5 degrees (Radomski & Latham, 2014).

However, lack of achievement of the norms for a given motion does not necessarily signify this as an intervention goal because consideration of client goals and limitations in functional activities are the determinants of treatment planning as well as considering how imbalances in joint function might contribute to joint deformities.

The use of negative recordings leads to reporting of unclear data (Bear-Lehman & Abreu, 1989; Trombly, 1995). For example, if the client lacked 20 degrees of shoulder flexion, a negative recording would be -20 degrees. This lack of 20 degrees does not indicate the total ROM that occurred and can be easily misunderstood. Fused joints have the same start and end points, and results should state "fused at x degrees."

Interpreting Range of Motion Results

To interpret ROM, one needs to compare the client's values with established norms, compare uninvolved with involved sides (if applicable), and/or compare the client ROM values with the functional ROM limits required for most activities. It is not the ROM value per se that is of the greatest concern for the occupational therapist but how limitations in ROM will impact that client's ability to engage in meaningful occupations.

The client's ROM values give an indication of how the client's joint motion compares with normative values. In interpreting the results, it is important to recognize that these norms are not specific in regard to age, culture, or gender and that there is variability in what is considered normal based on environmental, occupational, methodological, individual, cultural, and skeletal factors (Table 3-9).

It is often suggested that if one extremity is impaired and the other is not, comparing the two sides is a way to interpret ROM differences. However, Günal, Köse, Erdogan, Goktürk, and Seber (1996) noted there are very significant differences between the right and left side and that the contralateral, normal side "may not always be a reliable control in the evaluation of restriction of motion of a joint" (p. 1401).

Full or "within normal limits" (WNL) values for ROM are not necessary for many daily tasks. Shampooing or combing hair requires only 115 degrees of active ROM, while the norms for shoulder flexion are 0 to 180 degrees. Table 3-10 compares normative ROM values with functional ROM for selected activities.

Precautions and Contraindications

Measurement of ROM is not always indicated or safe for clients. Measurement of AROM may be a safer method because there is voluntary cooperation of the client. Active motion assesses the physiologic movement of the joint as well as the degree of coordination, level of consciousness, length of the attention span, indications about pain, ability to follow directions, and skill in performance of functional activities. An unintended effect of AROM is that of self-limitation at the end ranges. The client may limit the amount of active movement for which he or she is capable due to pain or fear of pain, which may limit the usefulness of the movement to joint health.

Table 3-9 (continued)

Comparison of Range of Motion Normative Values (in Degrees)

Motion	Ages 45 to 69 Years Females	Males
Hip extension	16.7 (15.5 to 17.9)	13.5 (12.5 to 14.5)
Hip flexion	130.8 (129.2 to 132.4)	127.2 (125.7 to 128.7)
Knee flexion	137.8 (136.5 to 139.1)	132.9 (131.6 to 134.2)
Knee extension	1.2 (0.7 to 1.7)	0.5 (0.1 to 0.9)
Ankle dorsiflexion	11.6 (10.6 to 12.6)	11.9 (10.9 to 12.9)
Ankle plantar flexion	56.5 (55.0 to 58.0)	49.4 (47.7 to 51.1)
Shoulder flexion	168.1 (166.7 to 169.5)	164.0 (162.3 to 165.7)
Elbow flexion	148.3 (147.3 to 149.3)	143.5 (142.3 to 144.7)
Elbow extension	3.6 (2.6 to 4.6)	-0.7 (-1.5 to 0.1)
Elbow pronation	80.8 (79.7 to 81.9)	77.7 (76.5 to 78.9)
Elbow supination	87.2 (86.0 to 88.4)	82.4 (80.9 to 83.9)

Reference: Soucie, J. M., Wang C., Forsyth A., Funk S., Denney M., Roach K. E., Boone D., & the Hemophilia Treatment Center Network (2010). Range of motion measurements: Reference values and a database for comparison studies. *Haemophilia 2010*; e-pub November 11, 2010.

Reprinted with permission from the Centers for Disease Control and Prevention. Normal joint range of motion study. Retrieved from https://www.cdc.gov/ncbddd/jointrom/index.html

Table 3-10

Functional Range of Motion for Specific Activities

Functional Movement	Activity	Functional ROM (in Degrees)	Normative ROM (in Degrees)
Shoulder flexion	Shampoo or comb hair	115	0 to 180
Shoulder extension/ hyperextension	Reaching for surface when moving from stand to sit	20	0 to 60
Shoulder abduction	Placing a barrette in hair	80	0 to 180
Shoulder adduction	Washing contralateral side of the body	25	180 to 0
Shoulder internal rotation	Fastening a bra	80	0 to 90
Shoulder external rotation	Reaching behind body for shirtsleeve when dressing	80	0 to 90
Elbow flexion	Washing face; bringing hand to mouth	150	0 to 150
Elbow extension	Reaching to don/doff lower extremity clothes	Less than 0	150 to 0
Forearm supination	Brushing hair or teeth	15	0 to 90
Forearm pronation	Turning a key in a lock	15	0 to 90
Wrist extension	Pushing up from support surface	25	0 to 70
Wrist flexion	Pulling up on a car door handle to open it	30	0 to 80
Ulnar/radial deviation	Opening a door; wiping down a countertop	30	0 to 30/0 to 20

Precautions and contraindications to ROM assessment are included in Table 3-11.

Summary

- ROM is the arch of motion that occurs at a joint and is often measured with a tool called a *goniometer*.
- Individual factors such as genetic disposition, types of preferred activities, overall health of the person, age, and gender influence the amount of ROM at a joint. Anxiety and stress also influence joint mobility.
- The amount of movement that occurs in a joint is based on the types of tissue that make up the joint. Not only is the joint structure important for movement, but movement is also important to the joint structure for cartilage and bone nutrition and growth, and adequate functioning of ligaments and tendons.
- Structures limit the amount of motion at a joint, and these structures have a characteristic resistance called *end feel*. End feel can be firm, soft, or hard in normal joints, and these end feels also occur in joints with pathology. Other pathological end feels are springy blocks, spasms, muscle guarding, and muscle spasticity.
- Variations in ROM measurements occur due to different methods, devices, means of recording, and other variables that influence the reliability and validity of goniometric measurement. Goniometry measurements generally are seen to have better intrarater reliability than interrater, and measurement of the upper extremity is a more reliable measurement than lower extremity. Using consistent test procedures with the same client under the same environmental conditions enhances reliability and validity.

Table 3-11

Precautions and Contraindications for Range of Motion Assessment

Contraindications	Precautions
Dislocations	Infected joints
Unhealed fracture	Inflamed joints
Myositis ossificans	Client on pain medication
Immediately following surgery to tendons, ligaments, muscles, joint capsule, or skin	Client on muscle relaxants
	Marked osteoporosis
	Hypermobile joints
	Subluxed joints
	Hemophiliacs
	Regions of hematomas (especially elbow, hip, knee)
	Bony ankylosis

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4

Factors Influencing Strength

Melinda F. Rybski, PhD, MS, OTR/L

Muscular performance is the capacity of a muscle to do work, and included in this capacity are strength, power, and endurance (Kisner & Colby, 2012). The differentiation of strength, power, and endurance is necessary at this point.

One definition of strength is the force or torque produced by a muscle during maximal voluntary contraction based on the demands placed on the muscle (Levangie & Norkin, 2011; Neumann, 2010). Strength is a force that is directly related to the amount of tension a muscle can produce. Functional strength is the use of muscles in a smooth, coordinated manner during functional and real-world tasks and activities. While power and strength are quantitatively related, they remain separate physical parameters.

Muscle power is the product of force and velocity or the amount of work per unit of time. Power requires timing and coordination and is proportional to the speed at which you apply a maximal force. Muscle power declines earlier with advancing age than muscle strength and is seen as an important predictor of functional limitation in older adults (Reid & Fielding, 2012).

Endurance is the ability to maintain a force over time or for a set number of contractions or repetitions. Endurance requires low-intensity, sustained muscle contractions over long periods of time, which are the requirements of many activities of daily living (ADL). Taking a shower requires time engaged in the activity, not just short bursts of strength. Increasing endurance requires increased oxidative and metabolic capacities to deliver and use oxygen, which is not necessary in strength training (Kisner & Colby, 2012). Whether muscles contract for strength, power, or endurance, the development of active force comes from the muscles, and many factors contribute to this development of force in the muscles (Figure 4-1).

Factors Influencing Strength

Changes in muscle strength occur due to changes in muscle, the nervous system, and immunological changes as well as individual client factors, such as activity levels, health status, nutrition, age and gender, cognitive status, and individual responses to stress and pain.

Client Factors

Age and Gender

Developmentally, both genders develop the greatest strength capacities from birth through adolescence, with peak strength between 20 and 30 years of age. Both genders experience a decrease in strength with increasing age due to deterioration of muscle mass, decreased muscle fiber size and number, increases in connective tissue and fat, decreased vascularization, alterations in capacity to generate force, and decreased respiratory capacity of the muscle. Decreased muscle power also occurs with increased age due to declines in muscle mass, changes in muscle composition, reduced muscle strength per unit muscle mass, changes in individual muscle fiber contractile properties, and alterations in neuromuscular function (Reid & Fielding, 2012). Muscular endurance is maintained better than muscle strength or power throughout advanced age (Lan, Lai, Chen, & Wong, 2000).

Muscle and strength changes occur throughout the lifespan. At birth, muscle accounts for about 25% of the body weight, and the total number of muscle fibers is established prior to or

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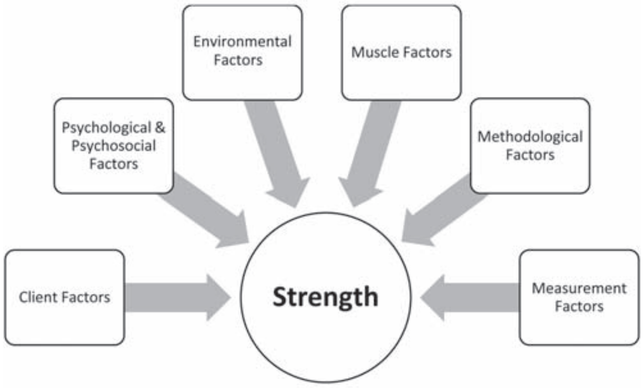


Figure 4-1. Factors influencing strength.

during early infancy. In puberty, there is a rapid acceleration in muscle fiber size and mass, and marked differences in strength levels develop between boys and girls. Muscle mass in women peaks between 16 and 20 years of age and between 18 and 25 years of age for men. By the third decade, strength declines between 8% and 10% per decade through the fifth or sixth decades.

Just how muscle strength decreases with age has been attributed to a variety of changes in the muscle. Muscle function changes due to muscle mass is one variable. Toji and Kaneko (2007) found that the decline in muscle force and shortening velocity was attributed to declining muscle function rather than a decrease in cross-sectional area of muscles, which was true in a study by Runnels, Bemben, Anderson, and Bemben (2005), in which decreases in both upper and lower extremity muscle function in the elderly occurred, independent of changes in muscle mass. In contrast to this finding, other studies indicate that muscle decline is due to decreased percentages of muscle fibers and loss of muscle mass (Doherty, 2001; Gaur, Shenoy, & Sandhu, 2007). Dalbo and colleagues (2009) identified the loss of type II muscle fibers and an increase in intramuscular fat storage as a change occurring with age, in which 20% to 30% of lean body mass is lost between the third and eighth decades of life.

Muscle fiber composition is another factor influencing muscle function with age. There is a shift in fiber composition, resulting in a greater percentage of type I fibers, enabling more prolonged contraction of muscle fibers as compared to type II fibers, which are involved in high-force, short-duration contractions (Dalbo et al., 2009). Anderson, Erzis, and Kryger (1999) suggest that, in the elderly, there are greater percentages of fibers that are a cross between type I and type II fiber types. Changes in muscle fiber types may affect the types of activities done and level of endurance in the elderly.

Gulde and Hermsdörfer (2017) studied the kinematic performance of basic motor tasks that show a clear decrease with advancing age. The elderly participants in their study took longer to complete a multistep ADL task (tea making), but there were no differences in bimanual performance. They concluded that age-dependent differences in kinematics between older and younger groups was due to the higher cognitive demands of the activity than on motor capability.

The decrease in type II fibers may be related to age-related loss of motor neurons, which occurs at a rate of 1% of the total number lost per year (Rice, 2000). Coupled with decreases in motor axon conduction velocity, decreased rates of protein synthesis, and increased muscle fatigability, muscle force generation is decreased (Bello-Haas, 2009). In addition, due to decreased strength, greater recruitment of other muscles is necessary to perform activities as a compensatory mechanism, which may lead to instability and structural deformities (Gaur et al., 2007).

Men, with bigger bones and larger muscles, are stronger than women. Generally, women are 40% to 50% weaker in the upper body and 20% to 30% weaker in the lower body (Tan, 1998). Women may experience strength losses earlier than men, but overall, age-associated decreases in strength are similar when controlling for muscle mass. The rate of isokinetic strength loss for women is 2% per decade, while it is 12% per decade for men (Frontera et al., 2000; Hughes et al., 2001). Older subjects demonstrated a greater rate of decline in strength. Men may experience greater losses of total muscle mass, but there are greater declines in muscle quality in older women (Doherty, 2001).

Many of the studies that compare strength by gender also compare strength based on the type of muscle action. Overall, isometric performance is the least affected type of muscle action (Runnels et al., 2005) and concentric is the most affected (Lindle et al., 1997; Lynch et al., 1999; Pousson, Lepers, & Hoecke, 2001). Muscle quality is affected by age and gender, but the magnitude of this effect depends on the muscle group studied and the type of muscle action (Lynch et al., 1999).

Individual Differences

Individual differences may be due to genetic factors, engagement in specific activities, lifestyle choices, cultural beliefs, gender roles, overall health and nutrition, and any preexisting comorbidities. Inheritable factors may result in differences in tissue anatomy, resulting in variations in rates of atrophy, the development of hypertrophy, and the physical capacity of tissues. Individuals also vary in their tissue physiology, affecting rates of healing and remodeling potential in one's response to chronic loading. This may be genetically determined or as the result of engaging in specific activities. Large variations occur in each gender due to diet, exercise, and level of activity.

While changes in muscle function are age-related, the amount of decreased strength is a function of training and regular exercise (Gaur et al., 2007; Rantanen, Guralnik et al., 1999). Decreased physical activity is associated with increased disability and loss of muscle strength, so continuation of valued occupations throughout life for our clients is a vital part of occupational therapy intervention.

Pain

Pain is a subject-related variable important in strength assessment. Pain is a multidimensional phenomenon with cognitive and affective components as well as physiologic properties that also have culturally determined values. How one perceives pain and reacts to it is part of a culturally sanctioned role that contributes to a person's ability to function in his or her environment. When assessing strength, indicators of the client's willingness to endure discomfort or pain can be observed. Pain invalidates the assessment of strength if the person is unable to provide a maximal voluntary contraction of the muscle being tested, so observation of discomfort and pain is important in the assessment of strength.

Muscle pain may be due to delayed-onset muscle soreness that occurs 1 or 2 days after injury. It may be possible to localize areas of palpable tenderness, and the client may experience loss of range of motion (ROM) and muscle stiffness. This type of pain is also characterized by reduced blood flow to the area, restricting oxygen to muscle tissues. Acute muscle soreness may occur immediately after exercise, especially if the activity required isometric contractions. The client may experience a burning sensation (Konin, 1999).

Cognitive Status and Perceptual Factors

When assessing a client's strength, the ability to follow directions, plan and execute the motor action, and pay attention are all factors influencing the test and can be observed. It is important to differentiate whether the client cannot complete the test motion due to motor planning problems (e.g., apraxia) or due to cognitive impairments (e.g., decreased attention). Language may be another reason a client is unable to follow directions, or there may be pathological reasons for lack of communication (as in aphasia).

Psychological/Psychosocial Factors

Often, clients want to perform well on tests of strength, and the link between muscle force and function often seems clearly linked. Motivation is related to accuracy in muscle testing and depends on the benefits of the client's performance to occupation, the ability to understand what is expected, fear of pain or injury, and anxiety about movement. Occasionally, true effort may not be demonstrated, which may be due to perceived benefits of secondary gains (e.g., discontinuation of work), parental or other roles, or depression.

Environmental Factors

Controlling environmental variables, such as noise and number of people, may facilitate better performance on tests of strength with clients. Temperature has a direct bearing on muscle activity. Muscle function is most efficient at around 101°F (38.5°C). A rise in muscle temperature causes an increase in conduction velocity and frequency of stimulation, thereby increasing the muscle force. Increased enzyme activity results and is related to greater efficiency in muscle contractions. Heat increases the elasticity of the collagen in the passive components (Nyland, 2006). These factors combined produce increased tension and a stronger muscular effort by the client. Additional environmental factors that might influence maximal muscle output are air quality, tasks with repetitive motion or excessive force, static exertion, awkward postures, and mechanical stress.

Muscular Factors

Muscles contribute to the production or control of skeletal movement, which is the primary focus of this chapter. However, muscles also assist in joint stability, maintenance of posture, support of visceral organs, protection of internal tissues from injury, continuation of pressure within body cavities, contribution to the maintenance of body temperature, and control of swallowing and bowel and bladder functions (Hamill, Knutzen, & Derrick, 2015; Levangie & Norkin, 2011; Nordin & Frankel, 2012).

Characteristics of Muscles

Of particular interest in the study of movement is the ability of the muscular system to stabilize and support the body and to allow movement. Muscle actions generate tension that is then transferred to bone. Muscles contribute significantly to joint stabilization when the muscle tension is generated and applied across joints via tendons. This is especially true in the shoulder and knee joints (Hamill et al., 2015). The tension developed by muscles applies a compression force to the joints, enhancing stability. Muscles could also pull segments apart and create instability depending on the line of pull of the muscle and the direction of movement.

Skeletal muscles are different from smooth and cardiac muscles in that each skeletal muscle receives a branch from a nerve cell called an *alpha motor neuron*, which is part of the somatic nervous system. These alpha motor neurons signal the muscle fibers to contract. Contraction of muscle fibers and not the muscle as a whole enables fine gradations of force to be produced by these muscles. Cardiac and smooth muscles are innervated by the autonomic nervous system, and muscle contraction is not determined directly by a single message from the nerve nor under voluntary control (Irion, 2000).

Irion (2000) states that "muscles act as a transducer to convert chemical energy into mechanical energy producing the force necessary to provide movement, support, and other mechanical functions" (p. 206). This being true, it is reasonable that skeletal muscles are the main energy-consuming tissues in the body. However, of the energy produced during a muscle contraction, only 20% of that energy is used to produce movement; the rest is lost as heat (Hamill et al., 2015).

Muscles are also the most abundant tissue in the body, making up 40% to 45% of the total body weight. While it is obvious that muscles contribute to joint movement and strength, muscles also add protection to the skeleton by distributing loads and acting as shock absorbers.

Skeletal muscles have four general characteristics. Contractility is the ability to produce tension between the ends of two bones to exert a pull, as when a muscle contracts. Irritability (excitability) is the ability of the muscle to respond to stimuli and transmit impulses. A muscle is distensible (or extensible) because it can be lengthened or stretched by a force outside the muscle itself, which is used therapeutically to increase ROM. Elasticity describes the ability of a muscle to recoil from a distended stretch. Not all parts of the muscle have each of these characteristics; some parts of the muscle contain the contractile elements, and other parts contain the elastic components (one of two major parts of connective tissue, with the other part being collagen).

Skeletal muscle contains muscle tissue and fibrous fascial connective tissue. The fascia wraps around muscle. The fascia also may extend beyond the muscle to create tendons, which attach to bones. The major component of fascia is collagen with only small amounts of elastin. The collagen provides strength to the fascia so that muscle contraction forces can be transferred to the bone (Muscolino, 2006).

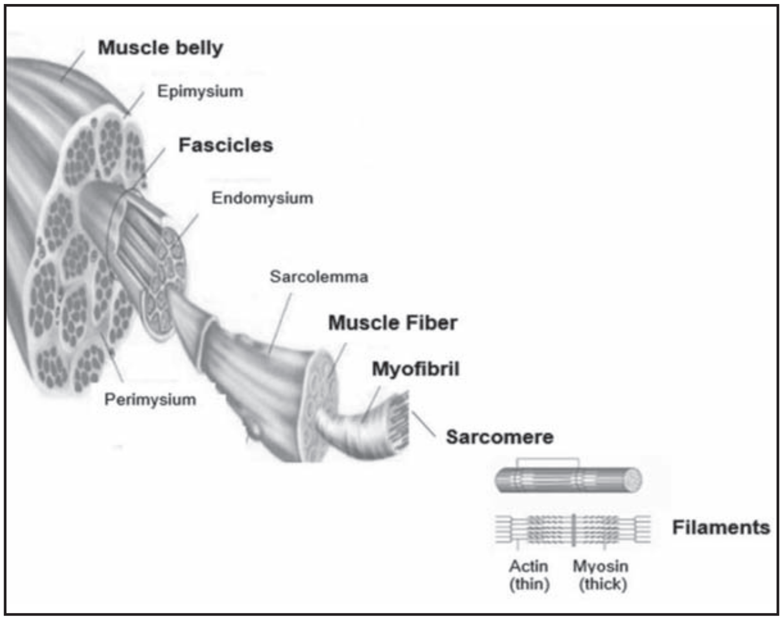


Figure 4-2. Organization of muscle fiber.

Structural Unit

The structural unit of skeletal muscle is the muscle fiber (Figure 4-2). Fibers range in thickness and length, and a skeletal muscle contains thousands of muscle fibers. Each muscle fiber is a single cell and is encased in a membrane (endomysium), which carries capillaries and nerves that innervate and nourish each muscle fiber. Fibers are organized into various-sized bundles called *fascicles*; there may be as many as 200 muscle fibers in one fascicle. Fascicles are encased in dense connective tissue (perimysium), which creates pathways for nerves and blood vessels in addition to organizing the muscle fibers and transmitting forces within the muscle. Perimysium is composed of collagen (giving the tissue strength) and elastin fibers (providing elasticity).

The entire muscle is wrapped in epimysium, which protects the muscle from friction during muscle contraction. Epimysium is continuous with the muscle fascia, endomysium and perimysium, and tendons. The connective tissue in the perimysium and epimysium gives the muscle the ability to be stretched. Perimysium is the focus of flexibility training because it can be stretched, which enables muscle elongation (Hamill et al., 2015). The function of the epimysium is to transfer muscular tension to tendons and then to bone.

Each muscle fiber is composed of many delicate strands called *myofibrils*. Each muscle fiber is filled with 80% myofibrils, and the remaining 20% is made up of mitochondria, sarcoplasm, reticulum, and T tubules (Hamill et al., 2015). Myofibrils are made up of filaments. One unit consists of thin, light bands of myofilaments and thick, dark bands and is called a *sarcomere*, which is the basic contractile unit of the muscle. The dark, thick bands are made up of myosin (tropomyosin) proteins, and the light, thin bands are actin proteins. The bands of light and dark myofilaments are what give skeletal muscles the characteristically striped (or striated) appearance. These two proteins, actin and myosin, create muscle fiber contraction due to the creeping action of actin protein along the thicker myosin protein.

Sarcomere Contraction

The sliding filament theory of muscle fiber contraction describes this creeping action of the thick and thin filaments as they increase or decrease their degree of overlap. Figure 4-3 illustrates the movement of the actin and myosin myofilaments. Once a muscle is stimulated to contract via neurochemical stimulation, calcium is released, which causes the sliding of actin to the center of the sarcomere. This stimulation of single muscle cells occurs in an all-or-none manner, where the cells either respond completely or they do not respond at all. The sarcomere, myofibril, and muscle fiber are all innervated by a single motor neuron that carries the message to either contract or not. This contraction does not extend to the entire muscle because there are many motor units in the entire muscle. This all-or-none property permits partial contraction of a muscle to create the right amount of force required for the muscle action.

If the stimulus is adequate, the myosin protein moves along the actin, forming cross-bridges between the head of the myosin and the actin filaments. Each cross-bridge acts independently. It is the simultaneous sliding of many filaments that creates a change in length and force in the whole muscle, which is proportional to the number of cross-bridges formed. The maximum number of cross-bridges between the actin and myosin proteins and the maximum contractile force in sarcomeres occurs when the full length of the actin at each end of sarcomere is in contract with myosin. This occurs when the muscle is in a lengthened position. The action of the myofibril cross-bridging is the active, contractile element of the muscle.

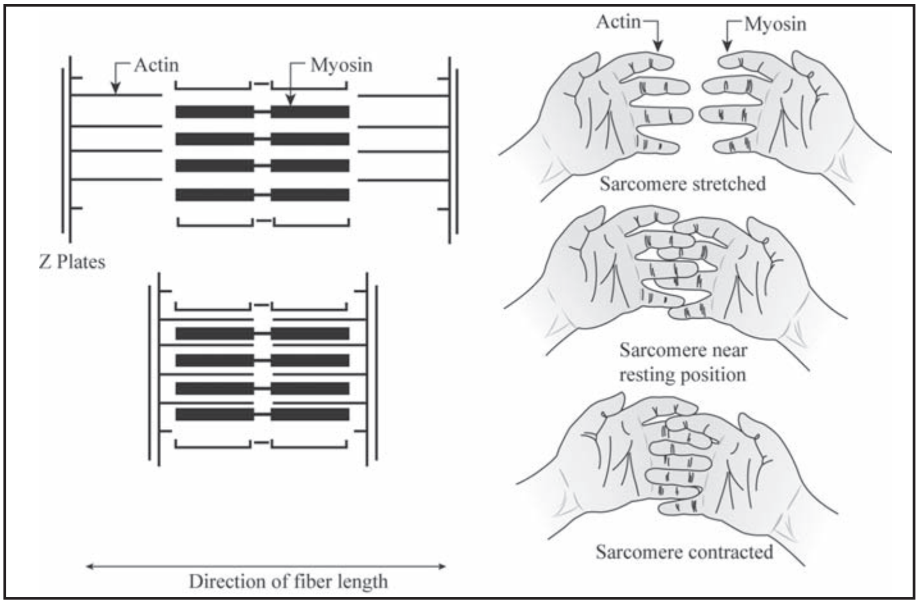


Figure 4-3. Myofilament movement of actin and myosin.

Active Components of Muscle Contraction

Voluntary contraction of a skeletal muscle requires the interaction of the contractile and elastic components of the muscle, intact nervous system input, and sufficient circulation and nutrition provided by the vascular system. The motor units and sensory receptors provide critical information about the status of the muscle and extent of the demand requiring a motor response. The vascular tissues provide the energy for muscle contraction. While the emphasis of this chapter is on the contractile tissues to produce skeletal movement, recognizing the importance of the neural and vascular structures is crucial to consider in the treatment of muscular limitations.

The contractile structures include the muscle body, musculotendinous junction, and tendon. A muscle contraction is a shortening of the fibers toward the center. This creates a pulling force on the bones attached to the muscle, ultimately resulting in movement of the body part (Muscolino, 2006). Contractile tissue has both passive and active components. Active muscle tension is produced by muscles, while passive tension occurs in connective tissue (epimysium, endomysium, perimysium, fascia) and tendons.

Passive Components of Muscle Contraction

Passive force is produced in the epimysium around the entire muscle; the perimysium around the fascicles; the endomysium around the individual fibers; and the sarcolemma penetrating between individual fibers and the tendon, aponeurosis, fascia, and other structures attaching the muscle to the bones. Two noncontractile (or inert) components of the muscle serve to absorb, transmit, and store energy: the series elastic component and parallel elastic component. Essentially, these passive structures are the fascial layers, which are unable to change the length of the muscle actively but conform with the muscle change in length (Houglum & Bertoti, 2012). The elastic components not only prevent overstretching of the muscle, but they also ensure that the contractile elements return to their resting length after a muscle contraction. The elastic components keep the muscle in readiness for contraction and ensure that muscle tension is produced and transmitted smoothly during contraction (Nordin & Frankel, 2012).

The series elastic components are found primarily in tendons (85%, with the remaining found in actin-myosin cross-bridges) that lie in series with muscle fibers. When the active contractile components shorten, this stretches the series elastic components, which act like a spring to maintain the tendon-muscle length and slow down the forces generated (Hamill et al., 2015). Series elastic components store energy and are converted to kinetic energy when stretched. Of the two passive components, the series elastic components are more important in the production of muscle tension.

The second passive element, the parallel elastic component, is found in the sarcolemma, epimysium, perimysium, and endomysium. Passive tension is created by lengthening the muscle beyond the resting length of the tissue that lies parallel to contractile component (muscle). These parallel components are important when a passive muscle is being elongated (when the contractile elements are active, the parallel elastic components do not function; Kisner & Colby, 2012). As the passive muscle is lengthened, the parallel component offers an opposing force and prevents the contractile elements from being torn apart by external forces.

Stretching a muscle elongates both passive structures, which generates a springy resistance in the muscle. Without a muscle contraction, the resistance to stretch increases as the stretch force continues due to the elastic recoil of the parallel elastic components and the slowing action of the series elastic components. This is passive muscle tension.

When a muscle is stretched prior to testing, it will have greater tension because the elastic energy stored in the noncontractile elastic elements is converted to kinetic energy when stretched. This passive tension helps prevent maximal elongation, and the viscosity of the stretched fibers helps protect muscles from being damaged by quick, forceful stretch due to prolonging the application of force to allow a more gradual elongation (Neumann, 2010).

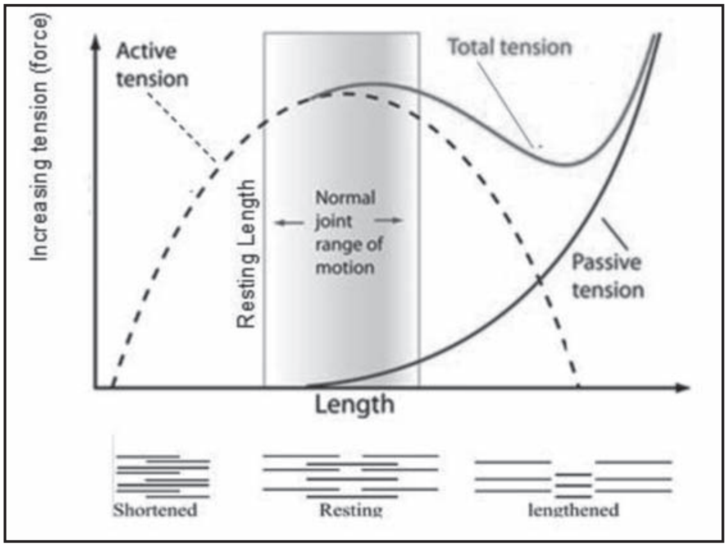


Figure 4-4. Total muscle tension: active and passive contributions.

The active and passive tension produced by muscle fibers follows a specific pattern, represented in Figure 4-4. The curve represents the relationship between the length of the sarcomere and the tension that it generates at that length (Muscolino, 2006). The dotted line represents active tension, where the strength of the sarcomere's contractions is greatest at the resting length because the greatest number of cross-bridges can be formed. While the active contractile contribution to muscle tension peaks in midrange of the stretch, passive components make an increasing contribution to force generation after midrange. As the tissues continue to be lengthened, active tension decreases, but passive tension increases. The passive tension force is generated when the sarcomere is stretched. When the muscle is stretched, the overlap area between actin and myosin decreases and the number of cross-bridges is less, resulting in a decrease in tension in the active components due to minimal overlap of actin and myosin. Continual stretch would result in tearing and failure of the sarcomere. The overall tension developed by a muscle is due to both the active (contractile) and passive (connective tissue) elements. Total tension is represented by the thin line at the top of the figure and represents the total pulling force of the sarcomere.

The length-tension relationship is based not only on the histological overlap of actin and myosin, but it is also related to biomechanical and neurophysiologic factors.

Biomechanically, the angle of muscle insertion into bone dictates where the greatest tension development will occur. The greatest moment arm for muscle force is when forces are perpendicular to the lever arm, which is seen in the length-tension curve at the apex of the active tension curve. Neurophysiologically, joint mechanoreceptors respond to muscle actions at joints. The least amount of power due to firing of the mechanoreceptors is at the beginning and end of the ROM, which is consistent with the active tension depicted in the length-tension curve (Cooper, 2007).

Factors Influencing Development of Muscle Force/Tension

In addition to the passive and active contributions to the development of muscle tension, there are many other factors that influence muscle tension. These include the number, size, and type of motor neurons recruited; fiber architecture; angle of pull of the muscle; type of muscle contraction; length of the muscle at time of contraction; cross-section of the muscle; velocity of contraction; and whether the muscle is a multijoint or single joint muscle.

Recruitment

Skeletal muscles as a whole are capable of responding with great variances of force, time, and speed rather than the all-or-none responses of muscle cells. This is due to the nerve-muscle functional unit, called the *motor unit*, which is composed of a single motor neuron and all of the muscle fibers innervated by it. Motor units affect the functioning of a muscle in (Nordin & Frankel, 2012):

- The number of muscle fibers, which affects the magnitude of the response
- The diameter of the axon, which determines the conduction velocity
- The number of motor units firing at any one time, which affects the total response of the muscle
- The frequency of the motor unit firing

The number of muscle fibers in a motor unit relates to the degree of control required of that muscle. Small muscles that perform fine movements may have less than a dozen muscle fibers so that the neuron controls only a few muscle fibers for greater control and precision. Fewer fibers mean more neural control per motor unit. Large muscles performing grosser movements may have several thousand fibers in one motor unit. An example of this is the gastrocnemius muscle, which may have 1720 fibers per motor unit, while the first lumbrical may have only 110 fibers per motor unit (Guyton, 1991). This innervation ratio has a direct bearing on the skill level achieved by the muscle.

The size of the motor unit is also related to muscle function. Smaller motor units produce contractions of a smaller number of muscle fibers, resulting in actions that are more precise. Smaller motor units, recruited first, produce less tension but require less energy and last longer than larger motor units. Larger motor units produce contractions of greater numbers of muscle fibers, so these produce larger, more powerful contractions. Based on the nature of the demand, large motor units may not be needed, which serves to conserve energy since small motor units require less energy. Each muscle generally has a mixture of small and large motor units (Muscolino, 2006).

The type of muscle fiber recruited also influences the amount of muscle tension produced. If a forceful or rapid muscle contraction is required, type II muscle fibers are recruited, whereas when a slow, continuous muscle contraction is needed (as in postural control), type I muscle fibers are engaged.

Recruiting more motor units to respond to resistance is another way muscles can generate gradations of force. Fibers of a motor unit are not contiguous but are interspersed throughout the muscle with other motor units. When stimulated, all fibers in the motor unit respond, but the muscle as a whole will not unless additional motor units are recruited.

A muscle as a whole contracts as larger numbers of motor units are added to contraction, which is called the *graded strength principle*. Graded muscle responses occur in two ways: by increasing the rapidity of stimulation, which produces a wave summation, and by recruiting more motor units to produce a multiple motor unit summation.

Wave summation or temporal summation occurs when more than one stimulus is received and the second contraction is induced before the muscle fully relaxes after the first contraction. Because the muscle was already partially contracted, the tension produced by the second contraction causes more shortening than the first by actually "summing" the contractions. If the stimulus is applied at a constant rate, the muscle is stimulated at faster rates, and relaxation time decreases. The summation becomes greater until a smooth, sustained contraction occurs, called *tetanus*. Because continuous, prolonged contraction cannot continue indefinitely, prolonged tetanus leads to muscle fatigue. The repetitive twitching of all recruited motor units of a muscle in an asynchronous manner ensures that every motor unit is not recruited at the same time, reducing the potential for fatigue while enabling smooth movement to occur (Nordin & Frankel, 2012). The excitatory input/rate coding principle states that increasing the frequency of stimulation of individual motor units increases the percentage of time that each active muscle fiber develops maximum tension (Houglum & Bertoti, 2012, p. 98).

Multiple motor unit summation serves to control the force of muscle contractions more precisely by neural activation of increasingly larger numbers of motor units. If weak and precise movements are required, few motor units are activated. When many motor units are stimulated, the muscle contracts more forcefully. The smallest motor units (with the fewest muscle fibers) are controlled by the most excitable motor neurons and are activated first. Larger motor units, activated by less excitable neurons, are activated only when stronger contractions are needed. This illustrates the size principle of recruitment, where small motor units are activated initially, and as the force of contraction increases, gradually larger motor neurons and larger numbers of motor units are required. Small motor neurons generally innervate the types of muscle fibers (type I/slow-twitch) that are required for sustained muscle actions and that fatigue slowly. This ensures weak but sustained postural contraction. By recruiting motor units controlling larger numbers of fibers, more cross-bridges are formed, so more tension is produced. Smooth movements occur because different motor units fire asynchronously; therefore, while one motor unit is firing, another is relaxing, ensuring that even weak contractions are smooth. While the size principle of motor unit recruitment has been demonstrated in some studies, it has not been demonstrated in human muscle (Nyland, 2006).

The Law of Parsimony states that the nervous system tends to activate the fewest muscles or muscle fibers to control a given joint action (Neumann, 2010). This means that smaller, one-joint muscles are activated first because they require less energy. If greater power is required, larger motor units are recruited, more motor units are added, and increased stimulation of motor units occurs to respond to the force. In this way, unnecessary fatigue is avoided, yet the necessary muscle force is generated to meet the resistance.

Muscle Fiber Types

There are three types of fibers based on varied physiologic features: type I, type IIB, and type IIA fibers. Each motor unit will have only one type of fiber (Table 4-1).

Type I/tonic (antigravity-postural)/red/slow-twitch oxidative are muscle fibers with a small diameter that are slow to fatigue. These muscle fibers have a good capillary supply so there is less build-up of lactate and metabolic waste. Tonic muscle fibers atrophy almost immediately when immobilized after injury because they depend on oxygen for metabolism (Cooper, 2007). Postural or tonic muscle fibers tend to become tight and hypertonic with pathology and develop contractures (Magee, 2014).

Type I fibers are recruited early but respond with weak contractions due to a small number of fibers activated. Type I fibers are generally involved in maintaining posture against gravity and are generally more deeply located and more medial. Examples of postural muscles are upper trapezius, levator scapulae, pectoralis major (upper part), pectoralis minor, scalenes, erector spinae, quadratus lumborum, tensor fascia latae, hamstrings, rectus femoris, short hip adductors, gastrocnemius, soleus, piriformis, iliopsoas, and tibialis posterior muscles.

Type IIB fibers/phasic/white/fast-twitch glycolic are basically anaerobic because the capillary supply is not as abundant as type I fibers. Type IIB fibers have large diameters and are recruited later to produce more powerful contractions of the muscle. Type IIB fibers are usually more numerous, producing sharp bursts of energy that enable quick postural changes or skilled movements. While type IIB fibers contract more readily than type I, these fibers also fatigue more readily.

Generally, type IIB muscles are more superficial and laterally located, are often longer muscles, and cross more than one joint. Phasic muscle fibers tend to become weak and inhibited with pathology (Magee, 2014). Examples of phasic muscles are tibialis anterior, trapezius (mid and lower), latissimus dorsi, rhomboids, serratus anterior, rectus abdominus, vastus medialis and lateralis, gluteus maximus, gluteus medius, gluteus minimus, and peroneals.

Table 4-1

Differentiation of Muscle Fiber Types

	Slow-Twitch Oxidative/ Heavy Work/Red/ Type-I	Fast-Twitch Glycolic/ Light Work/White/ Type-IIB	Fast-Twitch Oxidative/ Intermediate/Red/ Type-IIA
Diameter	Small	Large	Intermediate
Color	Red	White	Red
Capillary Supply	Dense	Sparse	Dense
Speed of Contraction	Slow	Fast	Fast
Rate of Fatigue	Slow	Fast	Intermediate
Motor Unit Size	Small	Large	Intermediate
Axon Conduction Velocity	Slow	Fast	Fast
Force Production	Low	High	Intermediate

Adapted from Norkin, C. C., & Levangie, P. K. (1992). *Joint structure and function: A comprehensive analysis* (2nd ed.). Philadelphia, PA: F. A. Davis.

Type IIA fast-twitch oxidative glycolic fibers tend to be intermediate in physiologic characteristics as compared to type I and type IIB fibers. Fast-twitch oxidative glycolic fibers have fast conduction rates and are able to engage in both aerobic and anaerobic muscle activities.

The ratio of muscle fiber types varies in each individual and is thought to be genetically determined. The ratio of muscle fiber types varies per each muscle, too. It is for this reason that some individuals, with presumed genetically preestablished ratios of specific fiber types, become sprinters (with a predominance of fast-twitch fibers) or marathon runners (with a predominance of slow-twitch fibers), each with a different percentage of fiber type in each muscle.

In terms of tension development, type IIB muscles are capable of the greatest tension, followed by type IIA and, finally, by type I fibers. In general, fast-twitch muscles are more affected by immobilization and disuse, which has implications for treatment. In addition, the fast-twitch muscles of the lower extremity (especially extensors) are more affected than muscles in the upper extremity. The differentiation of muscles by fiber type is an important consideration when developing an intervention that focuses on strengthening muscles because consideration of intensity and duration of muscle contraction will be variables directly linked to fiber type.

Fiber Architecture (Muscle Morphology)

Muscle fibers are arranged either in a parallel or an oblique manner within the muscle. Parallel or series fibers are longer muscles that are capable of producing greater ROM. Parallel fibers can be subdivided further (Table 4-2). Strap fibers are long and thin, running the entire length of the muscle, as is seen in the sartorius muscle. Fusiform fibers are spindle-shaped or wider at the middle, tapering off at each end (e.g., brachialis muscle, biceps muscle). Rhomboid fibers are four-sided, short fibers arranged in a flat, rectangular, or square shape (e.g., rhomboid muscle, pronator quadratus muscle). Triangular fibers are flat and fan-shaped, with fibers coming from a narrow attachment at one end and a broad attachment at the other (e.g., pectoralis major muscle; Snyder, Conner, & Lorenz, 2007).

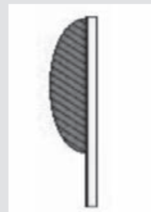
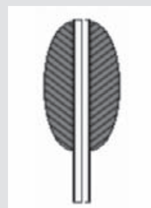
The parallel muscle fibers are arranged parallel to the line of pull in a longitudinal manner. The fiber length is greater than the tendon length, so these muscles have the potential for shortening through greater distances. Contraction occurs through the maximal distance allowed by the length of the muscle fibers so one can achieve maximum ROM but with limited power.

Oblique fibers can be seen in the tibialis posterior, flexor pollicis longus, and semimembranosus or extensor digitorum longus muscles. These muscles have a series of short fibers attaching diagonally along the length of a central tendon. These are unipennate fibers, which look like a one-sided feather. Bipennate oblique fibers obliquely attach to both sides of a central tendon (e.g., rectus femoris, gastrocnemius, solus, vastus medialis, vastus lateralis muscles). Many tendons with oblique fibers are multipennate fibers and include deltoid, gluteus maximus, and subscapularis muscles.

The oblique arrangement of the fibers makes a diagonal force to line of pull, and the muscle cannot shorten as much as parallel muscles can. However, due to the greater number of muscle fibers in the same area, oblique fibers are capable of greater power. Therefore, the arrangement of the fibers influences whether the muscle is primarily functioning for greater movement and mobility or whether it is more functional for strength and stability. Parallel muscle fibers produce greater ROM, and oblique fibers can generate greater force. As a comparison, biceps (with a parallel fiber arrangement) are capable of greater ROM than is possible with the triceps muscle (an oblique fiber arrangement), which is capable of larger force production.

Table 4-2

Fiber Architecture

	Parallel or Series Fibers			**Pennate/Oblique Fibers**	
	Strap	Sartorius muscle		Unipennate	Tibialis posterior, flexor pollicis longus, semimembranosus or extensor digitorum longus muscles
	Fusiform	Brachialis muscle			
	Rhomboid	Rhomboid muscle			
	Triangular	Pronator quadratus muscle		Bipennate	Rectus femoris, gastrocnemius, soleus, vastus medialis, vastus lateralis muscles
		Pectoralis major muscle			
				Multipennate	Deltoid, gluteus maximus, subscapularis muscles

Angle of Pull

A muscle's action is dependent on its line of pull relative to the joint that it crosses. Lines of pull of muscle fibers can be in a cardinal plane, in an oblique plane, or in more than one line of pull and can cross more than one joint. Brachialis is an example of a muscle with all fibers oriented parallel in the sagittal plane. There is only one muscle action, which is flexion of the forearm at the elbow. Coracobrachialis has muscle action in an oblique plane (or combination of sagittal and frontal planes). The motion produced is flexion in the sagittal plane and adduction in the frontal, and the arm is pulled diagonally in an anterior and medial direction. The deltoid muscle has fibers that run in anterior, posterior, and medial directions, so there are three lines of pull of the muscle fibers producing different muscle actions in each direction. Multijoint muscles have lines of pull on two or more joints. The flexor carpi ulnaris crosses the elbow with one line of pull in a cardinal plane and one in an oblique plane so that this muscle can flex the forearm at the elbow in the sagittal plane and flex the wrist in an ulnar direction at the wrist in the sagittal and frontal planes (Muscolino, 2006).

If the line of pull to the joint changes, the muscle action changes. For example, the clavicular head of pectoralis major is an adductor of the shoulder until the arm is adducted to more than 100 degrees and the clavicular head becomes an abductor. Clinical implications of this are that, if the supraspinatus and deltoid become weak, pectoralis major can contribute to adduction (Muscolino, 2006).

When a muscle contracts, it creates a force that causes the body segment in which it inserts to rotate around an axis of the joint. This turning effect, or torque, is the product of the muscle force and the perpendicular distance between the axis of rotation and the muscle force. Strength is the product of muscle force and the distance between the muscle's line of force and the axis of rotation. This length of the moment arm (or torque) changes through ROM. This is why muscle strength is greater in some positions and why, during a manual muscle test, minimal force can elicit maximal strength (Neumann, 2010).

The optimal angle of muscle pull occurs when the muscle is pulling at a 90-degree angle or perpendicular to the bony segment. It is at this point that all of the muscle force is acting to rotate the segment, and no force is used to distract or stabilize the limb. If the muscle is pulling at an optimal length or is perpendicular to the bony segment, then this will produce a stronger contraction.

The angles of pull and length-tension relationships interact to produce this force. Generally, there is a decrease in force production in the extreme outer and inner ranges, with greater force produced in the middle ROM. As a muscle begins contracting through its full range of shortening, it begins in a weakened condition, gradually becomes stronger, and then approaches its shortest length and becomes weakened again. The force resolution of the biceps muscle demonstrates that, mechanically, the biceps muscle reaches peak strength at 90 degrees of elbow flexion or in the middle of full ROM (Figure 4-5). There is a larger moment arm, and 100% of the muscle force is rotary movement. If the elbow is in full extension, the angle of the biceps insertion is small, and there is a long, stabilizing component that makes the biceps muscle less effective or forceful in this position. In elbow flexion greater than 90 degrees (i.e., when the angle of muscle attachment is less than 90 degrees), the resolution of forces yields an angular and a dislocating force that runs along the bone and away from

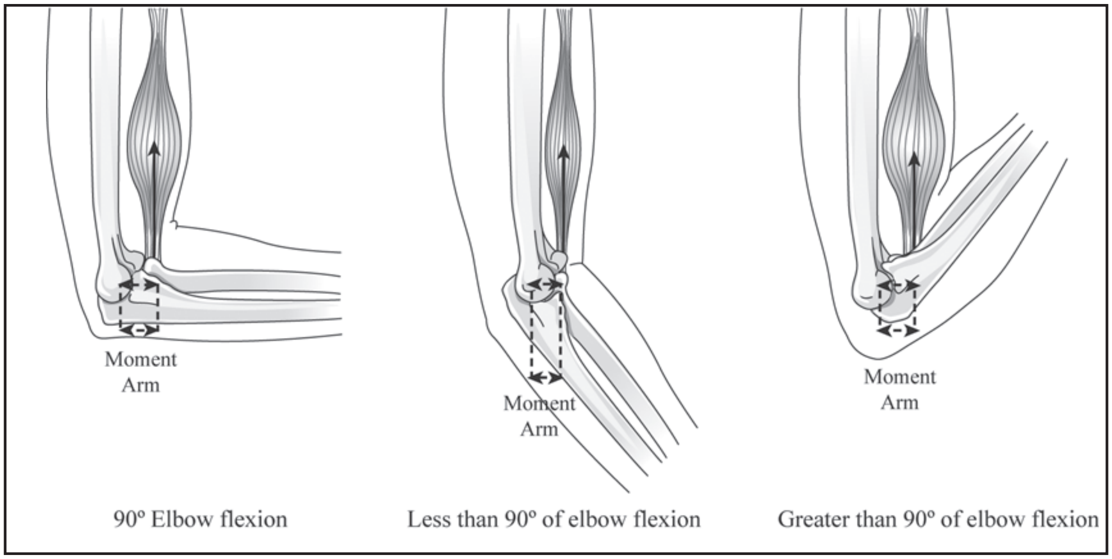


Figure 4-5. Effects of different angles of pull of muscle fibers.

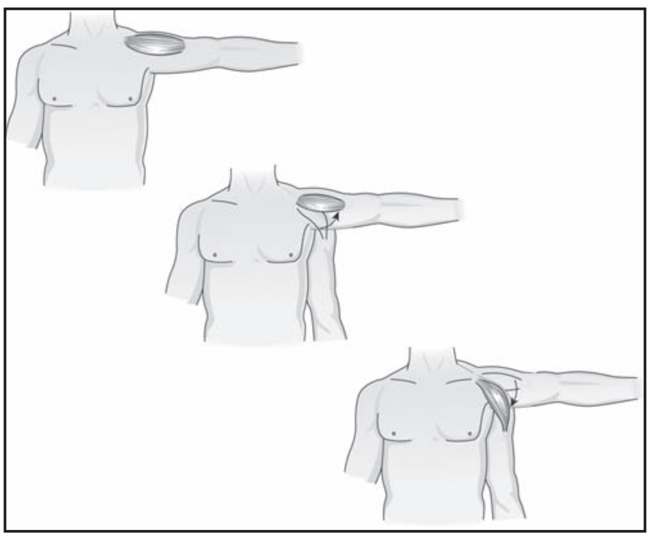


Figure 4-6. Types of muscle contractions.

the joint. These forces decrease the effectiveness of the biceps muscles as an elbow flexor because the forces are now directed toward dislocating the joint, not in force production.

Types of Muscle Contraction

When muscle fibers change in length, different forces are generated. In isotonic muscle contractions, internal forces result in movement of the joint, which may include lengthening (eccentric) or shortening (concentric; Figure 4-6).

Many texts refer to concentric and eccentric contractions as isotonic contractions, although some texts define muscle contractions not only in terms of tension/energy/length, but also in terms of the leverage effects at the joint (Richards, Olson, & Palmiter-Thomas, 1996). By strict definition, isotonic means "equal tension," and because the muscle force changes through ROM, muscle tension must also change. Norkin and Levangie (1992) add that "the tension generated in a muscle cannot be controlled or kept constant" and that the concept of equal or constant tension in a muscle is "unphysiologic" (p. 107). So, in the strictest sense, isotonic contractions do not exist in the production of joint motion. In general use, the term *isotonic* refers to a description of muscle length and not tension, and isotonic contractions may be one of two types: concentric or eccentric.

Concentric contractions occur when the internal force produced by a muscle is greater than the external force or resistance that produces a shortening of the muscle. An example of this is when one is walking up stairs. The quadriceps is demonstrating concentric contractions in the extending knee. Concentric muscle contractions produce the least force output compared with eccentric or isometric contractions.

Eccentric contractions produce a lengthening of the muscle as a whole because the internal force produced by the muscle is less than the external force or resistance. The antagonist muscle can eccentrically contract and lengthen, which serves as a braking action to motion. The antagonistic muscle can also relax and lengthen to allow movement.

Eccentric muscle contractions can develop the same force output as other types of muscle contractions at the level of the sarcomere but with fewer muscle fibers activated. This type of contraction is seen as more efficient and uses less oxygen consumption (Hamill et al., 2015). Eccentric contractions help to regulate movements caused by external forces, such as gravity, and can be seen when one lowers an object onto a table or eases into a chair. Eccentric contractions act as a brake to decelerate motion of the joint, as seen in the quadriceps muscles when one descends stairs. Muscle tension is less than gravity pulling the body down but sufficient to allow controlled movement.

Eccentric contractions occur in every movement in the direction of gravity. In eccentric contractions, active muscles are those that are antagonists of the same movement when it is made against gravity. Hamill and Knutzen (2003) state that "even the weakest individual may be able to perform controlled lowering of body part or small weight but not able to hold or raise the weight" (p. 73), so strengthening activities and exercise programs might start by using eccentric muscle contractions.

Table 4-3

Characteristics of Muscle Contractions

Type of Work	Type of Contraction	Mechanics of Contraction
Static	• Isometric	• No joint movement • Joint tension
Dynamic	• Concentric	• Internal muscle force greater than external force • Muscle shortens
	• Eccentric	• Internal muscle force less than external force • Muscle lengthens
	• Isokinetic	• Constant velocity of joint motion • Maximal muscle moment produced
	• Isoinertial	• Constant external load • Submaximal muscle moment produced

Eccentric muscle contractions are thought to be related to delayed-onset muscle soreness, which occurs 24 to 48 hours after exercise. This occurs because cross-bridges of myosin stay attached to the active sites while the resistance lowers, resulting in "tearing" away of cross-bridges when lowering against heavy resistance. Muscle swelling occurs, caused by damage to muscle and shifts in muscle length (Cooper, 2007; Donatelli & Wooden, 2010).

Also, since the word *contraction* means to draw together or shorten, it is more inaccurate and contradictory to say that an eccentric contraction is a lengthening contraction. While the use of the word *contraction* is used in this text in regard to muscle activity, the term *muscle action* would be more accurate (Levangie & Norkin, 2011).

Isometric contractions enable muscles to act in a restraining or holding action. Muscles acting as stabilizers and some synergists produce tension equal to the resistance that it needs to overcome. The tension produced against resistance is in equilibrium, and there will be no change in the external muscle length, no motion, and no mechanical work. The portion of the myosin filament that pulls the actin toward the center of the sarcomere is equal to resistive force (Cooper, 2007). There is static physiologic work being done (energy is expended), but no joint (mechanical) work is done. It is important to point out that all dynamic work involves an initial static (isometric) phase as the tension in the muscle develops.

An example of an isometric contraction is a contraction in which a constant external load is lifted at the extreme ends of motion. When you grasp the handle of a coffee cup, there is muscle tension but no movement. The sustained contraction helps to hold the cup. The types of muscle contractions are summarized in Table 4-3.

In terms of force production, eccentric muscle contractions produce the greatest force, followed by isometric. Eccentric muscle contractions produce two to three times the amount of force that a concentric contraction can produce (Donatelli & Wooden, 2010).

Length of Muscle

The tension developed within a muscle depends on the initial length of the muscle. A muscle is capable of generating maximal force at or near resting length because a maximal number of cross-bridges of actin and myosin can be formed. Moderate tension is produced when the muscle is lengthened, and minimal tension is possible in a shortened or contracted muscle. In a shortened state, the maximum number of possible cross-bridges has already been formed, and no additional tension can be produced.

In the shortened state, tension in muscle is equal to the tension in the series elastic components. When the muscle is lengthened, passive tension is generated. As the tension-developing characteristics of active components diminish with muscle elongation, tension in the total muscle increases due to the passive elements in muscle. As the series elastic component is stretched and tension develops in the tendon and cross-bridges, significant tension in the parallel component occurs as the connective tissue offers resistance to stretch. At extreme lengths, tension is almost exclusively elastic or passive tension (Hamill & Knutzen, 2003). This factor has implications not only for strengthening programs, but also for stretching of muscles and soft tissues.

Location of Muscle and Axis

Muscles that move a part usually do not lie over that part but are often proximal to the part moved. The distance of the origin and the insertion of the muscle to the joint axis have an influence on the type of movement produced. If the distance from the insertion to the joint axis is greater than the distance from the origin, this is considered a shunt muscle. Shunt muscles tend to have the line of pull along a bone, so the muscle tends to pull bones together, creating a more translatory effect, and the muscle acts as a stabilizer. Examples of shunt muscles are the sternocleidomastoid muscle and the brachioradialis muscle, where the origin is near the axis and the insertion is far.

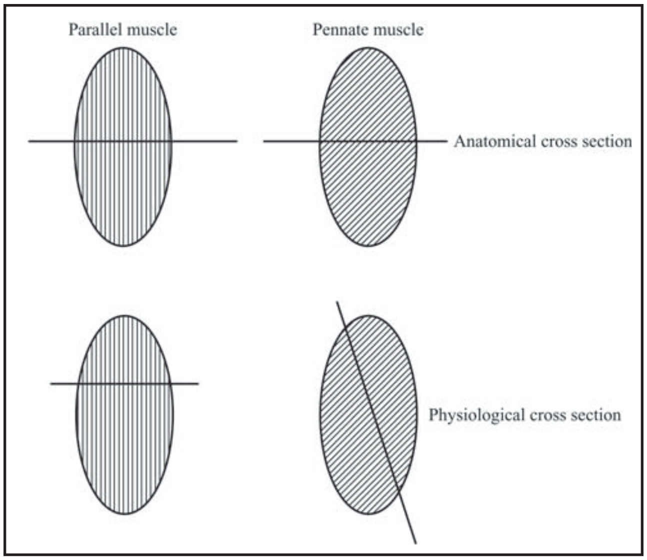


Figure 4-7. ACSA and physiologic cross-section area (PCSA) of muscle fibers.

A spurt muscle is one where the origin is farther from the joint axis and the insertion nearer. Spurt muscles have their line of pull across bones so that there is a larger rotary component to the movement produced. While shunt muscles act to stabilize joints, spurt muscles help to overcome inertia and produce rapid movements throughout a wide ROM. Two-joint muscles may possess spurt characteristics at one joint and shunt at the other joint. Spurt and shunt classifications are based on 19th century engineering terms, with spurt defined as a force that provides energy to impel a body into motion or keep it in motion, which basically is a restatement of Newton's Second Law.

The muscle's location or line of action in regard to the location of the joint axis determines what motion the muscle will perform. Muscles crossing anterior to the joint axis in the upper extremity, trunk, and hip are flexors, while muscles located posterior to the axis are extensors. Muscles located laterally and medially are abductors and adductors (Gench, Hinson, & Harvey, 1995; Nordin & Frankel, 2012). By applying knowledge about anatomy and muscle fiber arrangement, one can determine optimal angles of pull and locations of muscles to use muscles most advantageously in everyday occupations.

Cross-Section of the Muscle

Larger muscles with larger cross-sectional areas are capable of producing greater strength. This is what is known as *anatomical cross-section area (ACSA)*, which is the cross-section made at right angles to the longitudinal axis of the muscle at the widest point (Figure 4-7; Hamill et al., 2015). These typically refer to parallel muscle fibers. Different from the ACSA is the PCSA, which is the sum total of all of the cross-sections of fibers in the muscle, measuring the area perpendicular to the direction of the fibers. Pennate muscles are able to produce greater force due to larger PCSA than parallel muscles, and PCSA is larger than ASCA. In parallel muscles, the PCSA coincides with the ACSA. Muscles with shorter fibers and a larger cross-section produce force.

In parallel fibers, the ACSA and PCSA are the same, whereas in pennate fibers, the PCSA is greater than the ACSA. Because pennate muscles generally have more muscle fibers and shorter fibers that run diagonally into the tendon, pennate muscles have a much larger PCSA than parallel muscles, which enables greater force generation. The PCSA will give an indication of the maximum tensile force the muscle is capable of producing. The PCSA is directly proportional to the maximum tension that can be generated because it represents the sum of the cross-sectional areas of all of the muscle fibers within the muscle. Maximum muscle tension is not simply proportional to muscle mass (Lieber, 2002).

Velocity of Contraction

While muscle force is proportional to the PCSA of the muscle, muscle velocity is proportional to muscle fiber length. Muscles with longer fibers produce greater excursion and velocity. There is a direct relationship between the amount of force generated and velocity. As the velocity increases, the force decreases. The length-tension relationship describes muscle behavior at a constant length, but the force-velocity relationship involves movement (Lieber, 2002). This inverse relationship is shown in Figure 4-8 and illustrates the neuromuscular recruitment patterns of both type I and II fibers, which are activated together at lower speeds. However, as speed increases, there are fewer type I fibers recruited, and these eventually become inactive. At very high velocities, smaller and smaller fiber populations are recruited. Simply stated, this relationship indicates that high-velocity movement corresponds to low muscle force, and low-velocity movement corresponds to high muscle force (i.e., you can move a light load more quickly than a heavy load). This follows the same pattern as seen with tension production: eccentric muscle contractions, capable of the greatest force production, are strongest at slower velocities.

The greatest speed of shortening is when the external load is zero. As the load increases, the muscle shortens more slowly. Isometric contractions occur when the velocity is zero. Concentric contractions, the least in force production, occur when the velocity is greater than zero or at higher velocities. In concentric contractions, velocity is increased at the expense of a decrease in force. The maximum force is at zero velocity because a large number of cross-bridges are attached, and maximum velocity is achieved at the lightest load. As the velocity of the muscle shortening (concentric) increases, fewer cross-bridges are formed, so force production is negligible (Hamill et al., 2015). With increased speed, there is decreased tension. If a concentric muscle action (shortening) is preceded by an eccentric (lengthening) action, the resulting concentric action is capable of generating greater force. This pre-stretch condition changes a muscle's characteristics by increasing the tension through storage of potential elastic energy in the series elastic component. When a muscle is stretched, small changes occur in the muscle and tendon length and in the maximum accumulation of stored energy. When concentric muscle action follows, there is an enhanced recoil effect adding to the force output. Stored elastic energy in parallel components in connective tissue also contributes to high-force output at initial portions of concentric action as the tissue returns to a resting length. The parallel elastic contribution drops off as the muscle continues to shorten. If the stretch is held too long before shortening occurs, stored elastic energy is converted to heat and lost (Hamill et al., 2015; Irion, 2000).

The force-velocity relationship does not indicate that the muscle cannot generate a strong force at a fast speed because maximum strength can be generated either by recruitment of more motor units or by increased muscle length. The force-time relationship specifies that the force generated by a muscle is proportional to the contraction time. The longer the contraction time, the greater the force that is developed because this enables changes in length and in recruitment, allowing time for tension to be produced by the contractile elements and transmitted through the parallel elastic components to the tendon (Nordin & Frankel, 2012). Slow, steady contractions will produce the greatest force, which is important to remember when instructing clients how to perform activities using the most of their strength.

Number of Joints Crossed by the Muscle

Norkin and Levangie (1992) call muscles that cross more than one joint "economic" because they can produce motion at more than one joint (p. 116). However, one-joint muscles are recruited first for single joint motions because additional muscle fibers or motor units may be required to prevent unwanted motions of a two-joint muscle.

Two-joint or multijoint muscles are able to be stretched over a greater ROM. A multijoint muscle is most effective when shortened at one end and lengthened at the other so that the muscle works most effectively at one joint while being disadvantaged at the other. Manual muscle tests are designed to put one end of multijoint muscles "on slack" or lengthened so that the strength of the contracting muscle can be tested.

Muscle Insufficiency. Active insufficiency occurs when a multijoint muscle is unable to exert enough tension to shorten sufficiently to complete full ROM in both joints simultaneously. This occurs because of a decrease in myosin-actin cross-bridges because a shortened muscle is composed of shortened sarcomeres and, therefore, fewer cross-bridges can be formed. The agonist muscle cannot shorten any further because no further force can be produced. An example is the long head of the biceps. The long head of the biceps attaches to the superior portion of the glenoid, and the short head attaches to the coracoid. The biceps can assist the deltoid with shoulder flexion with the elbow in extension. When the elbow is fully flexed and the forearm is supinated, there is limited ability of the biceps to assist with shoulder flexion because it is actively insufficient. Other examples of active insufficiency occur with the triceps as it assists the posterior deltoid with glenohumeral extension, rectus femoris with hip and knee flexion, or the hamstrings as hip and knee extensors. A practical example of this is, if you are being attacked, grab the attacker's wrist and maximally flex it to reduce the attacker's ability to produce force in the hands (Konin, 1999).

Passive insufficiency occurs when an antagonist muscle cannot be elongated any further without damage. The antagonist muscle is passively stretched, and passive tension reaches the limit of extensibility. The passive tension that develops may be significant enough to cause joint movement, as in the tenodesis action of the wrist and fingers. The finger extensors become passively insufficient as they lengthen over the wrist during wrist flexion, causing passive tension to produce finger extension. The opposite occurs when the finger flexors develop passive tension when the wrist is extended. Passive insufficiency is usually felt as an uncomfortable or painful sensation and can be felt when one tries to simultaneously flex the wrist and fingers at the same time.

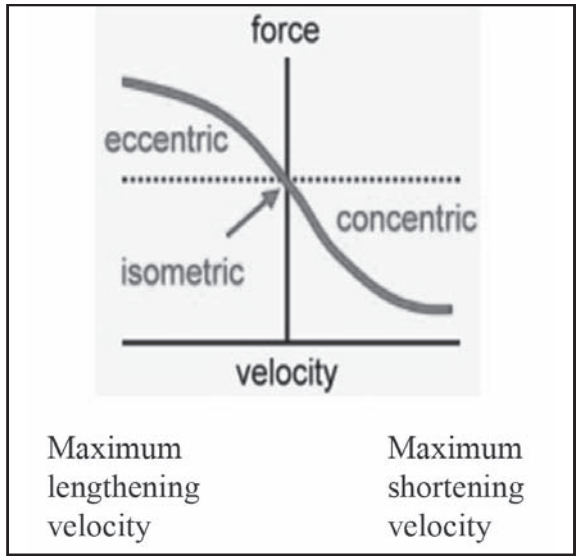


Figure 4-8. Force-velocity curve.

Passive insufficiency is related to the full stretch of the antagonist muscle when the agonist muscle is in active insufficiency, disallowing complete and full ROM in both joints simultaneously (Snyder et al., 2007). Both active and passive insufficiency result in incomplete movement of some or all of the joints crossed by the muscles. Muscles that become actively insufficient due to excessive shortening are likely to develop passive insufficiency in the opposite or antagonistic muscle group (Nordin & Frankel, 2012). The force generated by the position of the multijoint muscles can be seen by noting that the greatest isometric grip strength is achieved when the wrist is in slight extension. When the wrist is in full flexion, there is a combination of active insufficiency of the long finger flexors and passive insufficiency of the antagonistic long finger extensors (Houglum & Bertoti, 2012).

McGinnis (1999) proposes this self-experiment relative to muscle length and insufficiency:

> Consider the muscles that flex or extend your fingers. The finger flexor muscles are located in your anterior forearm, whereas the finger extensor muscles are located in your posterior forearm. Their tendons cross the wrist joint, the carpometacarpal joints, the metacarpophalangeal joints, and the interphalangeal joints. Flex your fingers, and grip a pencil as tightly as you can. Now, flex your wrist as far as you can. You may notice that you cannot flex your wrist as far with your fingers flexed as you can without your fingers flexed. You may also notice that your grip on the pencil weakened as you flexed your wrist (try to pull the pencil out in both positions). If you push on your hand and cause it to flex further, the pencil may even fall out of your grip. The finger flexor muscles were unable to produce much tension. The finger extensor tendons were lengthened at each joint they cross and were stretched by the extensor muscles beyond 160% of their resting length. Passive tension created by

the stretching of the connective tissue resulted in an extension of the fingers when you pushed your hand further into wrist flexion. (p. 272)

Methodological Factors

In testing the strength of muscles, you are assessing impaired muscle performance that might indicate muscle strain, neurologic injury (peripheral nerve or nerve root dysfunction), general weakness due to muscle imbalance of agonist/antagonist or due to immobilization, deconditioning or reduced force or torque production, altered length-tension relationships, or the presence of pain (Hall & Brady, 2005). Methods for muscle strength testing include strength screens, standardized manual muscle tests, functional motion tests, or observation of performance in daily activities. Handheld instruments may be used, but the external force often applied in the test is the force of the examiner. Palpation of muscles during testing ensures the evaluation of the correct muscle and adds to the test's validity.

Muscle Strength Screens

An occupation-based assessment would start first at assessing the client's ability to perform ADL. Occupational therapists often use daily activities to assess performance and function because the task performance involves more than muscle strength. Some inferences about muscle function can be made by observing and analyzing muscle performance during specific tasks that combine key muscle groups. This type of assessment enables the assessment of other factors that may also be interfering with successful performance in tasks, such as balance or cognition, as well as the dynamic interaction of muscles and observation of the complex interactions of musculoskeletal, neuromuscular, cardiopulmonary, and integumentary systems (Reese, 2005). Characteristics of the task itself are considered, such as the dynamics, complexity, context, and meaning of specific tasks to the individual client (Reese, 2005). If the client is observed to have difficulty performing these tasks, a muscle screen or standardized muscle test would then be done.

Screening for muscle weakness is appropriate for conditions where muscle weakness is not the primary symptom or the primary limiting factor in performance of daily activities. Screening tools are designed to provide a general estimate of strength, and if deficits are indicated, further discrete testing may be done. Often, these quick muscle strength screens place clients in positions of convenience rather than specific positions (e.g., against gravity or in gravity-eliminated positions; Reese, 2005). Muscle screens can be as simple as asking a client to hold a position while the therapist applies resistance to the muscle. An example would be to have the client shrug the shoulders, hold that position, and the therapist applies resistance downward for a test of the strength of the scapular elevators.

Functional motion tests vary in what they assess and how the assessment is done. Some tests look at the active movement of a client as an assessment of joint ROM and active, volitional movement patterns. The Zimmerman functional motion test screens for strength, ROM, and coordination for the upper extremity (Zimmerman, 1969). In some tests, the part being tested is passively placed, and the client is asked to hold the part in that position while resistance is applied. In other tests, active movement into the test position is required. Some tests describe first and second positions designed to take into account the effect of gravity on the part during testing, while others do not. Functional tasks might include asking the client to rise from a chair, ascend steps without assistance, and move from a seated to a standing position as an assessment of lower extremity strength, and placing a garment in a closet, drinking from a glass, or squeezing toothpaste as an assessment of upper extremity strength and grasp.

Gutman and Schonfeld (2003) describe functional muscle strength testing as the amount of resistance a joint can sustain during movement. They associate muscle groups with specific activities and the functional muscle grade required to perform the activity. For example, drinking from a glass requires fair plus functional muscle grades of elbow flexors, while pulling up knee-high socks requires poor plus strength of elbow extensors. This can be a helpful guide when deciding intervention strategies for desired activities based on muscle strength.

Manual Muscle Testing

More discrete testing of muscle strength is actually a measurement of impairment rather than function (Van Deusen & Brunt, 1997). Consider not only the weak muscle, but the distribution of weakness and significance of the limitation to performance of occupational tasks. Patterns of weakness may be generalized or may indicate nerve innervation patterns. Observe for muscle imbalances between agonist and antagonist muscles where strengthening and positioning may also be considerations for intervention.

Tan (1998) describes the potential uses of strength testing:

- For physical medicine and rehabilitation:
  - Prescribing treatment and establishing a baseline
  - Monitoring progress
  - Evaluating level of impairment
- Medical-legal:
  - Test effort consistency
  - Determine maximal exertion
  - Assess disability
- Industry:
  - Provide ergonomic and rehabilitation guidelines
  - Screen for job placement and return to work
  - Compliance with The Americans with Disabilities Act

Other purposes for strength testing are to determine how muscle weakness limits performance; prevent deformities caused by muscle imbalance; establish the need for assistive or technological devices; and aid in the selection of appropriate activities. Results are useful in establishing differential diagnoses and prognoses.

Manual muscle testing is appropriate for those clients who are able to voluntarily contract muscles, which excludes those with central nervous system dysfunction and those with tone problems or stereotypic, automatic movements. Manual muscle testing is often not performed with children younger than 3 years of age, and the elderly may not be able to assume and/or tolerate some testing positions. Manual muscle testing is contraindicated for those with dislocations. Extra care and attention in testing should be taken for clients with cardiovascular and chronic respiratory diseases (e.g., chronic obstructive pulmonary disease, chronic obstructive lung disease), as well as those clients just recovering from abdominal surgery. It is possible to tear muscle fibers if excess application of resistance is applied, and muscle cramping can occur if resistance is applied for too long.

Strength testing can be done in various ways. Manual testing would involve the active contraction of the muscle by the client with the application of resistance by the tester. Several muscles can be tested as a group that produces a particular motion. For example, the anterior deltoid, coracobrachialis, pectoralis major, and biceps muscles might be tested as a group of muscles that produce shoulder flexion. Individual muscles can be isolated and tested separately.

Manual muscle testing grades the level of strength in a muscle or muscle group's voluntary maximum contraction based on the ability of the muscle to maintain a position against the application of resistance by the tester or by the force of gravity. This can be done by means of isotonic, isokinetic, or isometric force application. This can be done by means of isotonic, isokinetic, or isometric force application.

In isotonic testing, muscle strength is tested by using a constant external force, often applied by weights or machines. Isotonic dynamometers, which are force-measuring devices, use a constant weight or resistance to measure muscle contractions at an accommodating speed and at an accommodating resistance. An example of a commercially available isotonic dynamometer at an accommodating speed would be the Ariel Computerized Exercise System (Ariel Dynamics Worldwide). Some disadvantages to this type of muscle testing are that the repetition maximum, determined largely by trial and error, is determined for each muscle group and may be overtaxing for some clients; the testing can be time-consuming; and the equipment may not be portable (Tan, 1998).

Isokinetic resistance is provided by machines, which provide the resistance through a specific ROM at a constant velocity. This provides a peak torque at one point in the ROM, and this measurement has high reliability. Disadvantages are portability and high cost of the equipment (Tan, 1998). Isokinetic instruments include Cybex (Cybex International), and active isokinetic tools include Biodex (Biodex Medical Systems, Inc.) and Kin-Com (Chattecx Corp). Isokinetic dynamometers can be used to assess both muscle strength (tension development at a constant speed) and muscle endurance (endurance at fixed speeds).

Resisted isometric movements are done to determine the function of the contractile tissues. The muscle is usually tested in a position of optimum length so maximum force can be generated. In most of the manual muscle testing done in clinical settings, isometric muscle testing is done. Muscles generate force against an immovable resistance (either the therapist or a handheld dynamometer [HHD]), so muscle length remains the same throughout the test. By testing using isometric muscle contractions, variability in muscle length and velocity of joint motion are eliminated. Because little or no equipment is needed, isometric manual muscle tests or HHDs are portable and inexpensive (Magee, 2014).

Isometric resistive tests can be used to assess strength and for the provocation of pain. Cyriax (1982) recommends specific test positions to evoke varying levels of pain indicative of underlying dysfunction. For example, resisting shoulder abduction may produce pain during muscle contraction, which may be indicative of a lesion within a muscle belly. If the pain occurs once the contraction is completed, this may indicate a lesion within a tendon. Strong and painless resisted contractions are normal. If the resisted action resulted in a strong contraction that was painful, this might be a minor muscle dysfunction. Gross trauma or partial rupture of muscle or tendon may occur when there is a weak muscle contraction accompanied by a painful response. If the contraction is weak and pain free, this might indicate a muscle or tendon lesion or a neurological dysfunction.

Tester Requirements

Those performing manual muscle tests need a thorough knowledge of the location and directional line of pull of muscles and of the structural anatomy of the parts being tested. This is especially true when palpating muscles to determine muscle grades of zero and trace. Knowledge of muscles with the same innervation can help in identifying patterns of weakness or those that may be related to specific diagnostic categories. The function of participating muscles (synergist, prime mover, etc.) is important, as is familiarity with patterns of substitution. Experience and adherence to standardized positioning and stabilization required in the specific muscle tests enables more accurate test results. Sensitivity to differences in normal muscle contours and joint laxity is invaluable to the assessment of muscles. The effects of fatigue and sensory loss on the ability to move also cannot be disregarded. Manual muscle testing requires attention to detail, knowledge of normal movement and anatomy, and time.

Manual muscle tests might need to be modified when testing older clients due to pain, joint deformities, or limitations in endurance and flexibility, and extra caution is advised in the presence of osteoporosis (Bonder & Bello-Haas, 2009).

Make Versus Break Tests

In manual muscle testing advocated by Daniels and Worthingham (1986), motions using agonists and synergists are the focus of assessment. Group muscle testing is seen as more functional than individual muscle testing, and the assessment occurs through the full test ROM. The client performs a concentric contraction or holds the test position at the end of the available ROM while the muscle is in a shortened position. Not as objective as individualized muscle testing, group strength testing can help to identify where in the range weakness exists.

Testing at the end of the range with the muscle or muscles providing the isometric hold is referred to as the *break test* or *method*. Manual muscle testing follows muscle length-tension relationships and joint mechanics in the positioning of the client for assessment. One-joint muscles often have external force applied at the end of the range, whereas two-joint muscles often have the point of maximum resistance at or near the midrange. In the break test, the primary movers of the joint are positioned so that they have mechanical advantage or when the muscle or muscles are at resting length or slightly more than resting length. In this position, the prime movers are at their strongest and the actions of the synergistic muscles are reduced (Radomski & Latham, 2013). In a study to determine interrater reliability of manual muscle testing using both isometric (break) and through-range (make) techniques, the

Table 4-4

Manual Muscle Test Procedure (Break Test Against Gravity)

1. Ensure that the client is comfortable, warm, and rested.
2. Arrange the environment to ensure that it is quiet, well lit, and warm.
3. Explain what you will be doing, how the test will be done, the purpose of the test, how the results will be used, and who will see the results.
4. Place the client (or have the client move) into the described test position.
5. Provide fixation (stabilization, support, or counterpressure) as specified in the test procedure.
6. Tell the client to "hold this position and don't let me move you."
7. Apply resistance slowly and for 4 to 5 seconds, paying attention to signs of exertion or discomfort.
8. Palpate the contracting muscle.
9. Determine the muscle grade.
10. Record the results and any additional information from observations during the test.

isometric technique had the highest reliability and agreement (El-Ansary et al., 2015). Kim, Lim, and Cho (2016) analyzed the intrarater and interrater reliabilities of the make test and concluded that the make test was a reliable manual muscle testing method with intraclass correlation coefficient (ICC) correlations of 0.992 for intrarater reliability and 0.949 for interrater reliability.

Kendall, McCreary, Provance, Rogers, and Romani (2005) proposed methods for testing specific, individual muscles rather than testing muscle groups. This type of manual muscle testing requires a greater knowledge of anatomy and kinesiology. While seen as more accurate, this type of testing is also more time-consuming to perform and fatiguing for the clients. The test is performed while the client contracts isometrically with the segment aligned in the direction of the muscle fibers in a midrange position. The client is then asked to "hold" this position against resistance. Similarly, the Medical Research Council Scale uses resistance as an isometric hold at the end of the test range, and this group advocates using numbers rather than words for muscle grades (i.e, a "good" muscle grade is a 4/5).

Resistance that is applied throughout the test range in a direction opposite to the muscle's rotary component is known as *make test*. This method is done while the muscle is performing a concentric contraction (Palmer & Epler, 1998). The make test is especially useful for quantifying muscle grades fair plus to normal (Radomski & Latham, 2013). The make test is the preferred method when using HHDs (Reese, 2005).

Test Procedure

Making sure the client is comfortable, warm, and rested is important not only to elicit optimal muscle contractions by controlling environmental factors, but it is vital to the establishment of therapist-client trust and the development of the therapeutic relationship. Be aware of cultural and personal boundaries when performing assessments because you will be touching clients, sometimes asking them to expose parts of their body so that skeletal landmarks can be identified and palpation of structures can occur (Table 4-4).

The test is standardized so that it can be given in the same manner every time and by different testers. The test protocols specify the starting position of the client, where stabilization is needed, instructions to give to the client, and the direction of the applied resistance. Two test positions are given: one against gravity and one with gravity eliminated. Common substitution movements and where to palpate specific muscles are also given to ensure testing of the correct muscle or muscle action.

Client positioning in the specified positions is essential to prevent substitution movements and to ensure that the appropriate muscle is being tested. In general, the distal joint segment is placed in relation to pull of gravity, and the proximal segment of the joint is stabilized. The origin of the muscle is fixed so that a maximal contraction against the insertion can occur. Inadequate stabilization may cause an underestimation of strength because the client will be less able to produce optimal force. Be aware, too, of your own body mechanics when performing a manual muscle test. Position yourself so that you can use your muscles in the most mechanically advantaged position while still maintaining the test protocols. The proper positioning of the client in the specific tests not only elicits the strongest muscle contraction from the client, but also optimizes the examiners' body mechanics when proper stabilization and application of resistance are applied.

Controlling for environmental factors can elicit the client's best response. Make sure the client is comfortable, warm, and rested, and make sure the room is quiet, well lit, and warm. Reassure the client that the test should not cause pain and explain what you will be doing and why. Explain the purpose of the test, how it will be performed, who will see the results, and what the results will be used for. Simply tell the client that this is a test to assess the strength of muscles and that you will be positioning him or her in specific ways to test specific muscles. You will also be applying some resistance to that muscle to test its strength, but the resistance will be applied slowly.

Tell the client to inform you if he or she is uncomfortable at any time during the testing. This is important for the rapport, trust, and therapeutic relationship, but can also help to identify at what point in the range limitations or pain may occur.

When applying resistance in the against-gravity position, apply the resistance slowly. This will enable recruitment of larger and more motor units to respond to the force you are

Table 4-5

Factors Related to Muscle Grades (Contraction, Gravity, Resistance)

Evidence of Contraction	• Zero (0): or 0/5	• No muscle contraction felt
	• Trace (T): or 1/5	• Evidence of contractility on palpation • No joint motion
Gravity	• Poor (P): or 2/5	• Movement with gravity eliminated but not against gravity or complete ROM with gravity eliminated
	• Fair (F): or 3/5	• Can raise part against gravity or complete ROM against gravity
Resistance	• Good (G): or 4/5	• Can raise part against outside resistance and against gravity or complete ROM against gravity with some resistance
	• Normal (N): or 5/5	• Can overcome a greater amount of resistance than a good muscle or complete ROM against gravity with full resistance

applying. The subjective part of the manual muscle test is when resistance is applied. Nicholas, Sapega, Kraus, and Webb (1978) studied whether it was the duration or amount of force that was applied that enabled the clinician to make the muscle grade determination. In this study, it was the clinician's perceptions of both the time required to move the limb through certain ranges of motion and the average force that was involved in the mental process of the evaluation (Nicholas et al., 1978).

While resistance is often applied at end of the gravity-resisted ROM (which is frequently not the strongest point in the ROM for the muscle being tested), this provides a consistent point for application of resistance and may prevent overestimating strength (Reese, 2005). Table 4-4 outlines the steps of the break test against gravity test.

Muscle Grades

The definition of manual muscle testing that was provided earlier identifies three variables that are used in determining the grade of the muscle: voluntary maximum muscle contraction, gravity, and resistance. Table 4-5 summarizes these three factors. Muscle grades can be identified as a number (1 to 5) or as a letter to identify zero, trace, poor, fair, good, and normal.

Contractility is the first variable, and the client's ability to volitionally contract a muscle determines the muscle grades of zero and trace. Contractility is determined by palpation of the muscle. When palpating a muscle, move slowly, avoid excessive pressure, and focus on what you are feeling (Biel, 2001). You need to be sure you are locating the correct structure and if you feel tension as the muscle contracts.

If the client is unable to contract a muscle and no muscle tension is felt with palpation, the muscle grade is zero. Palpation is best performed by using the middle finger, which is the most sensitive finger, to identify muscle tension. Every muscle tested must be palpated to be sure the correct muscle is being tested and to minimize substitution actions by synergists or other muscles. If the client is able to contract by volitional control, then the muscle grade would be at least a trace or 1/5.

Gravity, the second variable, affects the muscle's ability to contract by adding an external force. Muscles that can contract volitionally in a gravity-eliminated situation would be considered a poor muscle (or 2/5). If the person can move the extremity in a position against gravity, the muscle grade is fair (or 3/5). Manual muscle testing positions are against gravity (to test for fair, good, and normal muscles) and gravity-eliminated (to test for zero, trace, and poor muscles). In a gravity-eliminated muscle test, the best muscle grade possible is a poor because a fair muscle is one that can contract against gravity.

The third variable, resistance, is used to differentiate the good muscle (4/5) from the normal muscle (5/5). The application of manual resistance is seen as a subjective variable, which may account for the poor reliability and validity of muscle grading above the fair muscle grade. The amount of resistance is dependent on the muscle being tested. Less resistance should be applied to muscles with a predominance of type II fibers or those of parallel arrangement because they are less likely to be as strong as those that are type I or pennate. Less resistance should be applied to smaller muscles such as the hand muscles as compared to larger shoulder and hip muscles. Consideration of the individual characteristics of the client, such as age and gender, also affect the amount of resistance used.

Generally, if a client has good to normal muscle strength and good to normal endurance, the person will be able to perform all work, play, and self-care tasks without undue fatigue, but it may depend on the occupation task. Those clients with fair plus strength will have low endurance for tasks, will fatigue more easily, and may need frequent rests. A client with fair muscle strength can move against gravity and perform light tasks with little or no resistance and with decreased endurance. A muscle grade of poor is considered below the functional range, but the client can perform some light ADL with adaptive equipment and assistance.

Muscle grades can be further defined by adding a + or - to further quantify the muscle grade (Table 4-6). Muscle grades of good minus (4-) or below are considered weak and, therefore, a possible focus of remediation (Flinn, Latham, & Podolski, 2008; Whalen, 2014). Others consider muscle grades of good and below as the point at which to consider intervention (Reese, 2005).

Instruments for Muscle Strength

HHD devices can be easily used. Dynamometry is a method of strength testing using sophisticated strength measuring

Table 4-6

Comparison of Gravity-Resisted Manual Muscle Test Grading Criteria

Lovett and Daniels and Worthingham	Kendall and McCreary	Medical Research Council
N (Normal): Subject completes range of motion against gravity, against maximal resistance.	100%: Subject moves into and holds test position against gravity, against maximal resistance.	5
G+ (Good Plus): Subject completes range of motion against gravity, against nearly maximal resistance.		4+
G (Good): Subject completes range of motion against gravity, against moderate resistance.	80%: Subject moves into and holds test position against gravity, against less than maximal resistance.	4
G- (Good Minus): Subject completes range of motion against gravity, against less than moderate resistance.		4-
F+ (Fair Plus): Subject completes range of motion against gravity, against minimal resistance.		3+
F (Fair): Subject completes range of motion against gravity with no manual resistance.	50%: Subject moves into and holds a test position against gravity.	3
F- (Fair Minus): Subject does not complete range against gravity but does complete more than half the range.		3-
P+ (Poor Plus): Subject initiates range of motion against gravity or completes range with gravity minimized against slight resistance.		2+
P (Poor): Subject completes range of motion with gravity minimized.	20%: Subject moves through small motion with gravity minimized.	2
P- (Poor Minus): Subject does not complete range of motion with gravity minimized.		2-
T (Trace): Subject's muscle can be palpated, but there is no joint motion.	5%: Contraction is palpable with no joint motion.	1
0 (Zero): Subject exhibits no palpable contraction.	0%: No contraction is palpable.	0

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devices (e.g., hand-grip, handheld, fixed, and isokinetic dynamometry). HHDs are portable force-measuring devices that the examiner holds while the client exerts maximal force. Some HHDs that are commercially available include Lafayette Hand Dynamometer, Lafayette Pediatric Hand Dynamometer, Nicholas Manual Muscle Tester (Lafayette manual muscle test system), Rolyan Hydraulic Dynamometer [Smith & Nephew], Jamar Dynamometer (Lafayette Instrument Company), JTech Power-Track II (JTech Medical), and MicroFet Dynamometer (Hoggan Scientific).

The key features of HHD vary according to instrument type and units of measurement, with each type possessing advantages and disadvantages in the measurement of grip strength. Hydraulic dynamometers (e.g., Jamar Dynamometer) enable grip strength to be read from a gauge dial and are measured in kilograms or pounds. Hydraulic HHDs are portable, are economical, and have normative data available. A disadvantage is that the use of the hydraulic HHD can cause stress to fragile tissues. Pneumatic HHDs (e.g., Martin Vigorimeter [Gebrüder Martin]) measure pressure in millimeters of mercury (mmHg) or in pounds and are tolerated better for weak or fragile tissues. Since pneumatic HHDs measure pressure, the surface area in which force is applied can influence the measurement. Mechanical HHDs (e.g., Harpenden Dynamometer [British Indicators Ltd.]) measure grip strength via the amount of tension produced by a spring. There is little evidence to support the use of this device in clinical practice. Grip force can also be measured in multiple planes by isometric strength testing units using newtons as the unit of measurement (MicroFet is an example of an isometric strength testing units). However, these can be very expensive (Roberts et al., 2011). The differences between instruments may be related to the different means of transmission to measure grip strength (mechanical, hydraulic, and electric), in addition to the different shapes of the handles (Amaral, Mancin, & Júnior, 2012).

Using a hydraulic or pneumatic HHD is noninvasive, relatively quick, inexpensive, and applicable to a wide range of applications (Reese, 2005). As with manual muscle testing, the clients need to be able to follow directions in order to assume the test positions and maintain muscle contractions against gravity. Strength testing done with dynamometers is generally regarded as more reliable and valid than with manual resistance (Jackson, Cheng, Smith, & Kolber, 2017). Using an HHD for strength testing yielded a greater than 0.84 test-retest value when performed by an experienced therapist (Trombly, 1995a). Jackson et al. (2017) found good intrarater reliability (ICC = 0.93 to 0.98) of an HHD used with a portable stabilization device for lower extremity muscle force production in an athletic population.

Isometric dynamometers can be used to assess muscle strength via handgrip dynamometer or leg and back dynamometers to assess limb muscle groups and measure peak and average force, reaction time, rate of motor recruitment of motor units, and maximal voluntary exertion and fatigue. In this test, the muscle length is held constant, which is a preferred method in conditions where joint motion causes pain. Buckinx et al. (2017) used the MicroFET2 (Hoggan Scientific) device to assess the isometric strength of eight different muscle groups among nursing home residents. They found high relative and moderate absolute reliability was observed for all but ankle muscle groups. The disadvantage to this type of testing using strain gauges is that the movements are not well-correlated with real-life dynamic activities (Tan, 1998). Isometric dynamometers can also assess muscle endurance where one begins at maximal strength, and the dynamometer measures the percentage of decline in strength over a one minute interval or measures the time the client can maintain 50% of the maximal voluntary strength.

When considering whether to use an HHD or a manual muscle test, consider the client's overall strength. If the client has significant weakness, muscle strength is best assessed using manual muscle testing or functional motion testing, which are more sensitive to low levels of muscle strength. If your client has a muscle grade of good or better, the HHD is a better choice of an assessment because manual muscle testing does not clearly discriminate between higher muscle grades (Reese, 2005).

Grasp and Pinch Assessment

Grip strength is important in many of the activities in which we engage every day. The assessment of grip strength was found to be a good predictor of overall strength (Bohannon, 1998), of whole body strength and disability (Bassey & Harries, 1993; Davis, Ross, Preston, Nevitt, & Wasnich, 1998; Giampaoli et al., 1999), and of mortality (Bassey & Harries, 1993; Milne & Maule, 1984; Philips, 1990; Warburton, Katzmarzyk, Rhodes, & Shephard, 2007), and midlife grip strength is predictive of functional limitations and disability 25 years later (Rantanen et al., 1999). Strength testing can assess nutrition (Harries, 1985) and the risk of mortality in people with acute illness (Philips, 1990), can be a prognostic factor (Sunderland, Tinson, Bradley, & Hewer, 1989), is associated with hospital outcome, and can be used to identify intensive care unit–acquired paresis (Ali et al., 2008). Because hand grip dynamometry is easy to perform and sensitive, El-Ansary et al. (2015) recommend a two-tier approach to diagnosing intensive care unit–acquired paresis that first tests handgrip strength followed by an isometric strength assessment.

The loss of muscle strength, including grip, is associated with the development of physical disability in diabetes (Park et al., 2006; Redmond, Bain, Laslett, & McNeil, 2009; Sayer et al., 2005), and decreased hand grip and key pinch power have been found to be decreased in people with type 2 diabetes mellitus (Cetinus, Buyukbese, Uzel, Ekerbicer, & Karaoguz, 2005). In addition, Redmond and colleagues (2009) state that there is an interrelationship between hands, obesity, and physical functioning in women.

Factors affecting grip and pinch include gender (Balogun, Akomolafe, & Amusa, 1991; Crosby, Wehbe, & Mawr, 1994; Mathiowetz, Volland, Weber, Dowe, & Rogers, 1985; Mathiowetz, Wiemer, & Federman, 1986; Petersen, Petrick, Connor, & Conklin, 1989); age (Ager, Olivett, & Johnson, 1984; Bear-Lehman, Kafko, Mah, Mosquera, & Reilly, 2002; Bohannon, Wang, Bubela, & Gershon, 2017; Butterfield, Lehnhard, Loovis, Coladarci, & Saucier, 2000; Crosby et al., 1994; De Smet & Vercammen, 2001; Imrhan & Loo, 1989; Lee-Valkov, Aaron, Eladoumikdachi, Thornby, & Netscher, 2003; Mathiowetz et al., 1985, 1986; Molenaar, Zuidam, Selles, Stam, & Hovius, 2008; Petersen et al., 1989; Yim, Cho, & Lee, 2003); hand dominance (Crosby et al., 1994; Josty, Tyler, Shewell, & Roberts, 1997; Mathiowetz et al., 1985; Petersen et al., 1989); occupation (Josty et al., 1997); body weight and height (Balogun et al., 1991; Chau et al., 1997; Peolsson, Hedulnd, & Obert, 2001); position of the wrist, shoulder, and elbow (Balogun et al., 1991; Chau et al., 1997; Crosby et al., 1994; O'Driscoll et al., 1992; Peolsson et al., 2001; Pryce, 1980; Su, Lin, Chien, Cheng, & Sung, 1994); interest and cooperation of the client; experience and tone of the tester (Johannson, Kent, & Shepard, 1983); posture; fatigue; ability to understand directions; ability to understand various grades and test positions (Kendall et al., 2005); and culture (Massy-Westropp, Gill, Taylor, Bohannon, & Hill, 2011).

As with body strength, age and gender are factors in the assessment of grasp and pinch. In one study (Alaniz, Galit, Necesito, & Rosario, 2015), there was no difference between boys and girls aged 4 to 10 years in pinch and grip strength scores, but this is debated in the literature (Ager et al., 1984; Bear-Lehman et al., 2002; De Smet & Decramer, 2006; Imrhan & Loo, 1989; Mathiowetz et al., 1986; Molenaar et al., 2008; Yim et al., 2003). Bohannon et al. (2017) conducted a study to provide normative values for grip strength obtained from a cross-sectional population-based sample of individuals 3 to 17 years of age. Normative data can be useful for assessing physical maturation in this age group. In this group, the dominant hand was significantly stronger than the nondominant hand ($F = 298.8$, $P < .0001$), boys were significantly stronger than girls ($F = 354.8$, $P < .0001$), and older children were significantly stronger than younger children ($F = 794.1$, $P < .0001$). There were significant interaction effects on grip strength between side and age ($F = 12.9$, $P < .001$) and between sex and age ($F = 48.2$, $P < .001$).

Men are stronger than women, and this is true throughout adult life. Men have higher grasp values in all postures and joint angles (Gutierrez & Shechtman, 2003). While men are stronger, some studies suggest that women are more dexterous (Durward, Baer, & Rowe, 1999; Rice, Leonard, & Carter, 1998; Richards et al., 1996). There are also significant differences between men and women for grip endurance, which is the number of seconds one can sustain maximal grip or the level of strength output after repetitive or sustained contraction for a predetermined time (Wallström & Nordenskiöld, 2001). Differences in gender were revealed in a study where the purpose was to identify questions that could estimate grip strength. Two questions (opening a bottle and wringing out a towel) were found to be correlated with grip strength for the women only (and not for the men), and one question (self-rated strength compared to 10 years ago) was correlated only to the men (and not to the women; Simard et al., 2012).

For both genders, grip strength increases curvilinearly until age 20 years, peaks between 19 and 50 years, then declines (Schechtman, Mann, Justis, & Tomita, 2004). With females, the strength increases until age 13 years, then remains constant until 20 to 29 years. Males demonstrate linear increases before peaking at ages 30 to 39 years, after which decline in strength occurs (Durward et al., 1999). Shiffman (1992) found a significant effect of aging on functional performance, with statistically significant differences with age on grip strength, prehension, and time to perform tasks (Durward et al., 1999). Desrosiers, Bravo, Hebert, and Dutil (1995) state that "grip strength in persons aged 60 years and older varies negatively and curvilinearly with age and that the loss seems more marked across older subjects" (p. 641). These authors propose that reductions in the number and size of muscle fibers (especially fast-twitch fibers) decreased ability to achieve maximum tension levels, and that normal age-related changes in the nervous, vascular, and circulatory systems account for decreased grip strength with increased age.

Grip scores may be meaningless when tested in cognitively impaired clients, as seen in a study comparing grip strength between minimally impaired, visually impaired, motor impaired, and cognitively impaired clients (Schechtman et al., 2004). Age and gender are not the only determining factors of grip strength in the frail elderly.

Hand dominance differences in strength are discrepant. Some studies indicate no statistically significant differences in grip strength between right and left hands (Bear-Lehman & Abreu, 1989; Mathiowetz et al., 1985; Peolsson et al., 2001; Peters et al., 2011; Richards et al., 1996), while others found that the dominant hand is 10% to 13% stronger than the nondominant hand (Crosby et al., 1994; Desrosiers et al., 1995; Petersen et al., 1989; Richards et al., 1996; Schechtman et al., 2004). Many studies resulting in normative values for grip strength reflect the greater grip strength values for the preferred hand.

Grip Strength

The measurement of grip strength has been the focus of many studies that consider the position of the shoulder, elbow, forearm, and wrist; type and complexity of directions; position of the body (sitting, standing); instruments used to measure grasp; terminology; and protocols of testing. Grip strength is influenced by various factors such as morbidity and nutritional status (Mohd Hairi, Mackenbach, Andersen-Ranberg, & Avendano, 2010), socioeconomic and financial circumstances in old age (Mohd Hairi et al., 2010), lifestyle and culture (Wu, Wu, Liang, Wu, & Huang, 2009), as well as anthropometric variables (Desrosiers et al., 1995; Li, Hewson, Duchêne, & Hogrel, 2010; Simard et al., 2012).

Grip and pinch strength is measured isometrically and statically, but, interestingly, most activities are done dynamically. An assessment of grasp and pinch is only a small part of the evaluation of the client's ability to use and manipulate objects with the hands. Observation of the use of the hands during activities is also needed to understand the client's occupational performance. Since most daily tasks require a combination of static and dynamic movement, there is a need to study motor performance during hybrid tasks in addition to static force tasks (Joshi & Keenan, 2016).

In a study by Alaniz et. al. (2015), grip strength and lateral, palmar, and tip pinch strength correlated with functional activities when examining the sample, which included typically developing children and children with autism aged 4 to 10 years. Grip and pinch strength were strongly correlated with independence in functional activities in both groups. The functional activities most significantly correlated with grip strength included tasks related to feeding (tears open a small snack, opens twist-off bottle top with closed seal, cuts food with knife, puts straw in juice box), hygiene (takes cap off toothpaste, squeezes toothpaste on toothbrush) and accessibility (turns key to unlock door, turns doorknob to open door). Grip strength also correlates with handwriting quality and processes (Engel-Yeger & Rosenblum, 2010; Falk, Tam, Schwellnus, & Chau, 2010). However, in a study by Li-Tsang (2003), it was found that dexterity, not hand strength, correlated with functional deficits and fine motor delays in children with neurological motor disorders.

Nunes et al. (2014) assessed the correlation between strength and function of the hand and deficits in motor control. A strong correlation between the Moberg pickup test (used to assess hand function) and parameters of grip force control (latency and force) was found in clients with hand osteoarthritis, a strong correlation was found between the Disabilities of the arm, shoulder, and hand outcome measure and visual analog scale, and a weak to moderate correlation was found between the Moberg pickup test and visual analog scale in clients with hand osteoarthritis.

A grip force of 9 kg (or 20 pounds [lb]) has been considered necessary and functional for most ADL (Nalebuff & Philips, 1990, p. 292; Philips, 1990), although Rice et al. (1998) found that it took less than 20 lb of grip force to open and manipulate common objects such as an aerosol spray can, medicine bottles, or dual-pinch safety squeeze bottles.

Grasp values are considered abnormal when associated with functional limitation and/or if the value is ±3 standard deviations from normative values. Normative values for the Jamar HHD are based on the mean of three trials by gender, age, and hand preference, as listed in Table 4-7. The results from various instruments (Jamar, Rolyan, Grippit [Catell AB], Dexter Evaluation System [Cedaron Medical Inc.], and Baltimore Therapeutic Equipment [BTE]-Primus models) can be compared to the norms established by Mathiowetz and colleagues (1985; Bellace, Healy, Bryon, & Hohman, 2000; Mathiowetz, 2002; Schechtman, Davenport, Malcolm, & Nabavi, 2003; Wallström & Nordenskiöld, 2001). Revised normative values for the Jamar dynamometer using statistical techniques that capture the non-Gaussian distribution of the grip strength values appropriate for continuous data are available (Peters et al., 2011).

Table 4-7

Descriptive Statistics and Comparisons of the Values for Hand Grip and Pinch Grip Strength for the Dominant and Nondominant Hands of Male and Female Participants in the Different Age Groups

		Dominant Hand			**Nondominant Hand**				
	Age Group (Years)	**Male**		**Female**	**Male**		**Female**	**Dominant versus**	**Nondominant**
Hand Grip (kg)	20 to 34	51.2 ± 9.4		31.8 ± 5.0	49.1 ± 3.5		29.3 ± 4.8	$P<0.001$	$r=0.95$
	35 to 49	54.9 ± 8.4		30.3 ± 5.8	51.6 ± 4.1		29.3 ± 5.9		
	50 to 64	45.5 ± 11.2		28.5 ± 4.9	44.7 ± 4.3		26.2 ± 4.4		
	65 to 79	35.4 ± 8.5		22.5 ± 6.6	33.9 ± 2.4		20.2 ± 5.7		
P for effect of		Sex < 0.0001	Age < 0.0001	Int. 0.0006	Sex < 0.0001	Age < 0.0001	Int. 0.027		
Tip Pinch (kg)	20 to 34	10.5 ± 1.8		8.3 ± 1.2	10.2 ± 2.1		7.9 ± 1.5	$P<0.001$	$r=0.90$
	35 to 49	11.2 ± 1.8		7.7 ± 1.5	11.2 ± 2.1		7.4 ± 1.2		
	50 to 64	9.5 ± 2.2		7.5 ± 1.3	9.3 ± 2.8		7.0 ± 1.6		
	65 to 79	8.5 ± 1.5		6.1 ± 1.1	8.3 ± 1.8		5.5 ± 1.0		
P for effect of		Sex < 0.0001	Age < 0.0001	Int. 0.065	Sex < 0.0001	Age < 0.0001	Int. 0.133		
Key Pinch (kg)	20 to 34	13.2 ± 2.1		9.5 ± 1.1	12.8 ± 2.2		9.2 ± 1.1	$P<0.001$	$r=0.93$
	35 to 49	14.1 ± 2.3		10.1 ± 1.3	13.8 ± 2.2		9.7 ± 1.6		
	50 to 64	12.7 ± 3.4		9.2 ± 1.3	12.3 ± 3.2		8.4 ± 1.1		
	65 to 79	11.1 ± 2.2		7.8 ± 1.4	10.6 ± 2.6		8.2 ± 1.2		
P for effect of		Sex < 0.0001	Age < 0.0001	Int. 0.851	Sex < 0.0001	Age < 0.0001	Int. 0.700		
Palmaar Pinch (kg)	20 to 34	11.7 ± 1.3		9.0 ± 1.3	11.8 ± 2.2		9.0 ± 2.8	$P=0.021$	$r=0.91$
	35 to 49	13.2 ± 3.0		8.7 ± 0.9	13.0 ± 2.6		8.4 ± 0.9		
	50 to 64	10.6 ± 2.6		8.3 ± 1.3	10.8 ± 2.8		7.6 ± 1.2		
	65 to 79	9.2 ± 1.7		6.8 ± 1.0	9.0 ± 1.9		6.4 ± 1.0		
P for effect of		Sex < 0.0001	Age < 0.0001	Int. 0.0006	Sex < 0.0001	Age < 0.0001	Int. 0.046		

Int. = interaction of sex and age.

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In a study by Lindstrom-Hazel, Kratt, and Bix (2009), occupational therapy students expressed concern about using norms established in 1985, especially since many occupations have changed since then and now include greater use of computers and handheld devices. However, the ICC scores from this study were consistent with the findings from Mathiowetz, Weber, Volland, and Kashman's (1984) reliability study using similar gauges (Lindstrom-Hazel et al., 2009). To ensure the most accurate results, the same model should be used consistently with any one client (Cadenas-Sanchez et al., 2016; King, 2013).

The American Society of Hand Therapists suggests that grip be measured with the client seated in a straight chair with the feet flat on the floor. The shoulder should be adducted against the body in neutral rotation with the elbow flexed to 90 degrees and the forearm in neutral rotation (Fess, 1992). Reporting the mean of three consecutive trials is recommended. Other studies support this positioning during grasp and pinch testing (Richards et al., 1996), while performing the handgrip strength test with the elbow extended appeared the most appropriate protocol to evaluate maximal handgrip strength in adolescents when using the TKK dynamometer (Espana-Romero et al., 2009). Grip strength tests are only valid and reliable when the client is exerting maximal voluntary effort and are not a test of sincerity of effort (Gutierrez & Shechtman, 2003).

Several instruments are used in clinical practice to evaluate grasp and pinch. The Jamar dynamometer is considered the gold standard for grip measurement with ICC of 0.98 to 0.99 (Gerodimos, 2012; Härkönen, Harju, & Alaranta, 1993; King, 2013; Lindstrom-Hazel et al., 2009; Mathiowetz, 2002; Mathiowetz et al., 1985; Peolsson et al., 2001; Savva, Giakas, Efstathiou, & Karagiannis, 2014; van den Beld et al., 2006). In a review of 18 studies, Bohannon (1998) found the majority of reliability coefficients for HHD to be above 0.7. However, there have been studies that found other types of dynamometers (TKK, DynEx [MD Systems], and BTE-Primus) have higher reliability and validity than the Jamar (Amaral et al., 2012; Shechtman et al., 2003; Shechtman, Gestewitz, & Kimble, 2005). Recently, norms were established by gender and age for digital Baseline dynamometers and pinchmeters (Gilbert, Jepsen Thomas, & Pinardo, 2016).

The Jamar HHD is a sealed hydraulic strain gauge system that measures force exerted on the device in pounds or kilograms. Calibration accuracy is important to validity, and calibration accuracy of the Jamar dynamometer is ±3% to 5% (Richards et al., 1996). This means that if one scored 50 lb using the Jamar dynamometer, the actual value is somewhere between 47.5 and 52.5 lb.

Using the second handle position yielded high interrater reliability with a correlation coefficient of 0.97 or above for all tests; test-retest reliability using the mean of three tests was most consistent with a correlation coefficient of 0.80 or better. Lowest correlations occurred when only one trial was done. Measurements taken at a single standard handle position are sufficiently accurate to assess grip strengths (Trampisch, Franke, Jedamzik, Hinrichs, & Platen, 2012). The Jamar dynamometer is considered the most precise of the instruments used to measure grasp (Desrosiers et al., 1995).

The Jamar dynamometer measures strength in pounds with norms based on age and gender. The procedure for use is as follows:

- Adjust the handle to fit the client's hand size and to allow metacarpophalangeal flexion. It was found that, with the handle in the second position, the grasp values were the strongest, and values obtained in each of the five handle positions would represent a bell-shaped curve (Palmer & Epler, 1998).
- The client is permitted to rest the forearm on a table if desired but not any part of the dynamometer. The elbow should be flexed to 90 degrees.
- Three trials with each hand are performed with the mean value recorded.

An alternate method is to perform two separate trials where the person exerts maximum pressure (two times with hand), and the higher score is recorded. In each method, both hands are tested alternately, with care taken not to fatigue the client.

The Martin Vigorimeter is an air-filled bulb connected to a pressure gauge (Durward et al., 1999) with three different-sized bulbs for testing grip and pinch. Measurements are expressed in kilopascals and, unlike the Jamar dynamometer, involve an isotonic contraction due to the movement necessary to compress the bulb (Desrosiers et al., 1995). The Vigorimeter measures grasp with high test-retest reliability with coefficients of 0.96 for the mean of three measures on the dominant hand and 0.98 for the nondominant hand and good interobserver and intraobserver agreements (analysis of variance, $r = 0.95$ to 0.97) and high responsiveness (standardized response mean scores > 0.8) were demonstrated for the Vigorimeter in clients with immune-mediated polyneuropathies (Merkies et al., 2000). Norms are available for age and gender (Fike & Rouseau, 1982; Merkies et al., 2000). In a comparison study between two devices to measure grip strength, the Vigorimeter was recommended for clients with immune-mediated neuropathies based on client preference (Draak et al., 2015). When comparing the reliability of grip strength measurements using the Jamar dynamometer and the Martin Vigorimeter with children under age 12 years, it was found that both instruments were reliable for this population and that the dynamometer was a more accurate tool (Molenaar et al., 2008). Merkies et al. (2000) report that the Vigorimeter is particularly used in Europe, while the Jamar HHD is used in the United States.

The third instrument, a sphygmomanometer or modified sphygmomanometer (blood pressure cuff), is often used for clients with fragile hands. The sphygmomanometer ratings had a strong and linear relationship to Jamar, with $r = 0.83$ for the right hand and $r = 0.84$ for the left hand (Flinn et al., 2008). The sphygmomanometer measurement is in mmHg. The following is the procedure for the use of the sphygmomanometer in measuring hand strength:

- Roll the cuff into a cylinder shape and inflate to 100 mmHg.
- Deflate to 30 mmHg to establish the baseline.
- Record as maximum vs. baseline average (x mmHg/30 mmHg).

A value of 300 mmHg/30 mmHg is considered within normal limits, and conversion tables have been developed that compare the sphygmomanometer results with Jamar results. Hamilton, McDonald, and Chenier (1992) showed that the sphygmomanometer and Jamar dynamometer exhibit good within-instrument reliability, and the sphygmomanometer can be seen as essentially equal to the Jamar for grip strength measurement.

The BTE power grip attachment has also been used to assess grasp and pinch. The BTE values had a test-retest value of > 0.98 on the right dominant hand in clients aged 20 to 45 years with a day-to-day variability of 5% for right and 3% for left. The BTE is a valid measure of grip strength (ICC = 0.978; Beaton, O'Driscoll, & Richards, 1995).

Innovations in grip strength measurement are being developed. An innovative device called the *grip-ball* is also designed to measure grip strength and contains a pressure sensor and Bluetooth communication system. The best results for force prediction were in the range in which frailty is typically detected, useful with fragile hands (Chkeir, Jaber, Hewson, & Duchêne, 2013). An additional system to measure total grip force is the manugraphy system. In addition to grip force, this tool identifies load distribution patterns of each single finger and the hand. In this device, cylinders are gripped, which are wrapped with sensor mats. When comparing the Jamar dynamometer and the manugraphy system, there were positive correlations between the two measurement methods ($P < .001$) and both systems allow valid and constant grip force measurement (Mühldorfer-Fodor et al., 2014).

The Grippit, a dynamic writing aid that provides support for children and adults who have difficulty holding a pen, was evaluated to determine the reliability of peak and sustained grip strength children within 6-, 10- and 14-year-old groups. The Grippit demonstrated good test-retest reliability and was good for both peak and sustained grip strength using the mean of three test trials (Svensson, Waling, & Häger-Ross, 2008)

When accuracy and reliability of the Jamar dynamometer, Takei dynamometer [Takei Scientific Instruments], and EMG System Manual Transducer with modified handle were compared with volunteers aged 20.0 ± 1.3 years, statistically significant differences were found in the female group between the Jamar and the Takei dynamometers (females $P < .001$ and males $P = .022$) and the EMG System Manual Transducer (female $P < .001$ and males $P = .007$), while the Takei dynamometer and the EMG System Manual Transducer were similar for both female ($P = .161$) and male groups ($P = .850$). Acceptable values of ICC between measurements were identified, but low agreement between the Jamar dynamometer and the other instruments was found (Amaral et al., 2012).

The difficulty in comparing grasp values and determining reliability and validity is that there is such an array of methods and protocols used. Different instruments use different units of measurement, different hand configurations, and different force transmission. For example, the modified sphygmomanometer measures pressure produced within the sphygmomanometer cuff, and the Jamar dynamometer measures force exerted on the handle. These tools use different joint and muscle mechanics. Even when the same tools are used, the use of different testing procedures and positions and the lack of standardization in terms of description and testing protocols make comparison of results difficult (Durward et al., 1999; Roberts et al., 2011).

Pinch Assessment

Assessment of pinch generally involves testing of tip, lateral, and palmar pinches, although there is much variety in the description of pinch and in the terminology used. Different tasks require different types of pinch and grasp. In one study, 17 healthy participants performed three different tasks, each requiring different functional prehension patterns assessing the force required to perform ADL. With the cylindrical objects (grasping small and large glass bottles with a cylindrical power grasp), the greatest forces were at the fingertips and thumb. Untwisting and returning the lid of a coffee tin with a diameter of 90 mm by a spherical grasp to its original position using only the distal finger pads, which were in contact with the tin lid, required contributions of the thumb, ring, and small fingers. The highest forces were when the zipper was closed with tip pinch (using the pad of the thumb and the index finger to open and close a zipper as on a large backpack or book bag with the zipper oriented vertically on the lap; Pylatiuk, Kargov, Schulz, & Döderlein, 2006).

The B&L Pinchmeter (B&L Engineering) is often used for testing pinch. Using these tools, the client squeezes the pinch gauge using the various pinches. One to three trials are used to test tip, lateral, and palmar pinches, and usually three trials are taken with the mean calculated. Pinchmeter values are accurate to within +1%, interrater reliability is > 0.979, and test-retest reliability is > 0.81 (Lindstrom-Hazel et al., 2009; Mathiowetz, Vizenor, & Melander, 2000).

Client results are compared to norms that are based on age and gender (see Table 4-7). The pinch norms can be used with most of the different pinchmeters because of demonstrated reliability (MacDermid, Evenhuis, & Louzon, 2001). Other ways of assessing pinch and grasp would be observation of hand use during functional activities and by using standardized coordination tests and timed tests of hand function. MacDermid, Kramer, Woodbury, McFarlane, and Roth (1994) found the ICC of interrater reliabilities of grip, lateral pinch, and tripod pinch measurements in clients with cumulative trauma disorders to be above 0.87 using hand therapists as raters.

Measurement Factors

Manual muscle testing, while used extensively clinically, has not demonstrated consistent reliability and validity. The break test is considered inaccurate in testing strength greater than fair muscle grades (or 3/5; Sisto & Dyson-Hudson, 2007) and is insensitive to change (Van Deusen & Brunt, 1997). There is a tendency to overestimate the normalcy of muscle strength, and manual muscle testing has been inadequate in determining functional capacity (Tan, 1998). However, there is no other method for evaluating muscle weakness that has the reliability, validity, and ease of use of manual muscle testing (Hall, Lewith, Brien, & Little, 2008). Manual muscle testing is a valid and reliable method to measure muscle strength (Herbison, Isaac, Cohne, & Ditunno, 1996; Marx, Bombadier, & Wright, 1999; Swartz, Cohen, Herbison, & Shah, 1992).

Reliability

In a study of occupational therapy students who were given adequate training and testing for competency, novel raters demonstrated ICC for interrater reliability, with the

Jamar dynamometer ranging from 0.996 to .0998 ($P < .05$) and with the pinch gauge ranging from 0.949 to 0.990 ($P < .05$; Lindstrom-Hazel et al., 2009).

A review of the reliability and validity of the Jamar dynamometer in comparison with other grip devices concluded that excellent inter-instrument reliability exists between the Jamar, Dexter, Rolyan, MicroFET 4 (Hoggan Scientific), DynEx, and Baseline dynamometers and moderate to excellent reliability between the Jamar, BTE Work Simulator, BTE Primus, and Martin Vigorimeter. However, low inter-instrument reliability scores were reported between the Jamar, sphygmomanometer, and Vigorimeter (Mathiowetz, 2002; Roberts et al., 2011).

Manual muscle testing has interrater reliability within one muscle grade 60% to 75% of the time (Frese, Brown, & Norton, 1987; Williams, 1956), and others have found that results do not vary more than one-half of a muscle grade (Palmer & Epler, 1998; Van Deusen & Brunt, 1997). Further, there is approximately 50% complete agreement on muscle grades, including the addition of + and -, 66% agreement within + or -, and 90% agreement within one full grade (Iddings, Smith, & Spencer, 1961; Palmer & Epler, 1998). Brandsma, Schreuders, Birke, Piefer, and Oostendorp (1985) found that there was a range of 0.71 to 0.96 for intrarater reliability and 0.72 to 0.93 for interrater reliability when testing intrinsic hand muscles. Savic, Bergstrom, Frankel, Jamous, and Jones (2007) found overall agreement of assigning muscle grades was 82% on the right and 84% on the left, with strongest agreement for zero muscle grades and the weakest for fair muscle grades.

There is poor interrater reliability in muscle grades below fair (Beasley, 1961; Frese et al., 1987; Palmer & Epler, 1998; Rothstein, Roy, Wolf, & Scalzitti, 2005; Tan, 1998), but Florence and colleagues (1992) found that reliability ranged from 0.80 to 0.99, with the muscle grades for the gravity-eliminated positions (poor, zero, trace) having the highest reliability values.

Muscle grades of good and normal are seen as subjective and inaccurate (Stuberg & Metcalf, 1988) because they involve the application of force by the examiner, which will vary from person to person and by age and gender of the examiner. To overcome this problem, the use of HHDs might be considered for these muscle grades. HHDs can achieve ICC values ranging from 0.91 to 0.99 for intrarater, interrater, intrasession, and intersession comparisons (Lu, Hsu, Chang, & Chen, 2007). HHDs are seen as reliable and valid (Kolber & Cleland, 2005; Li et al., 2006). Clinically, there are fewer adaptations that need to be made to activities or exercises at the good and normal range, and the discrepancies in accuracy do not limit functional performance as much as with lower muscle grades.

It is essential to follow procedures, provide clear directions, demonstrate and explain movements, and passively move the client to facilitate understanding of required motions. Following the standardized procedures produces reliable results even if the tester is inexperienced (Pollard, Lakay, Tucker, Watson, & Bablis, 2005), but more experience leads to greater reliability. Other factors that need to be considered to improve reliability include the following (Trombly, 1995b):

- Cooperation of the client
- Experience of the tester
- Tone of voice of the tester
- Ambient temperature
- Temperature of the limb
- Distractions to the client and tester or other environmental conditions
- Posture
- Fatigue
- Operational definitions of muscle grades

Validity

It is generally accepted that manual muscle testing has face and content validity because the testing is based on anatomic and physiologic structures (Lamb, 1985; Palmer & Epler, 1998; Payton, 1979), but there is little credence placed on the ability to generalize the results to immediate and future behavior of clients (Palmer & Epler, 1998). Validity is improved by palpating each muscle being tested, stabilizing proximal segments during testing, and preventing substitution movements and muscle actions.

Summary

- Muscle strength is the amount of tension that a muscle can produce. Power is the product of force and velocity. Endurance is the ability to maintain a force over time.
- Many factors influence muscle strength. Skeletal muscles have the properties of contractility, elasticity, irritability, and distensibility.
- The sliding filament theory is used to explain the contraction of single muscle cells in an all-or-none fashion, where the myosin and actin filaments increase or decrease the amount of overlap.
- Total tension a muscle can develop depends on the amount of tension developed by each fiber, the number of fibers contracting at any time, the number of fibers in each motor unit, and the number of active motor units.
- Tension in a muscle depends on the initial length of the muscle, innervation ratio of muscle fibers to motor units, fiber arrangement and cross-section, type of contraction, location of the muscle in relation to the joint axis, type of fiber, number of joints crossed by the muscle, and level of fatigue. Finer control of muscle tension is possible in muscles with small motor unit size.
- The greatest tension can be produced in fast-twitch glycolic fibers and by shorter muscle fibers that are able to generate higher levels of passive tension and higher peak tension. Muscles with greater cross-sectional areas are able to produce greater tension. Muscles stretched prior to testing are stronger because passive elastic energy in the noncontractile elements is converted to kinetic energy when stretched.
- Tension in muscles can also be increased by increasing the frequency of the firing of motor units and by increasing the number and size of motor units participating.
- Subject-related factors (age, gender, activity level) and psychological factors also influence strength and muscle testing.
- Strength testing can be done by manually applying resistance to a part (manual muscle testing) or by using

instruments to measure peak strength. Screening for muscle weakness may precede strength testing where muscle weakness is not the primary limiting factor in performance.

- Manual muscle testing has face and content validity but variable reliability. Reliability is enhanced when using dynamometers or instruments.
- Pinch and grasp strength are affected by client factors, hand dominance, position of the arm and body, devices used for measurement, and variances in testing protocols.

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Section II

Normal Joint Movement

5

The Shoulder

Melinda F. Rybski, PhD, MS, OTR/L and Kim Szucs, PhD, OTR/L

The shoulder is a complex joint made up of many articulations capable of a wide variety of motions. It is widely accepted that the shoulder joint complex consists of four major joints, and other sources cite at least one and as many as three additional articulations that allow the wide variances of movement at the shoulder (Houglum & Bertoti, 2012; Kisner & Colby, 2012; Ludewig & Borstad, 2011). The connections of the thorax with the humerus and scapula enable the positioning of the arm and hand in functional positions. The shoulder functions to position the hand, provides stability for hand use, lifts, pushes, elevates the body, and assists with forced inspiration and expiration and even weightbearing as in crutch-walking (Smith, Weiss, & Lehmkuhl, 1996, p. 223).

The bones and articulations of the shoulder form a kinematic chain. The chain starts with the trunk (sternum), where forces are transmitted to the sternoclavicular (SC) joint. From there, force is transmitted from the clavicle to the acromioclavicular (AC) joint. The scapula is next in the chain, incorporating the glenohumeral (GH) joint and, finally, the humerus. Each part of the chain is essential for normal shoulder function. Figure 5-1 shows the shoulder in action. This kinematic chain of the upper extremity, trunk, and lower extremity works in wondrous synchrony to accomplish the activity of raising the arm over the head with the rope. The weight is shifted to the right to free up the left arm to move freely. The shoulder acts as a stable base to enable elbow extension to reach closer to the target while the hands hold onto the rope. This same action is repeated every day as we reach into cupboards, comb the back of our hair, and bend down to tie a shoelace.

Functional activities also require coordination between the visual field and use of the arms and hands. Because of the scapula's position on the anterior aspect of the thorax, this facilitates the use of the hands working in front of the body, where we can see what we are doing. The position of the scapula enables the shoulder muscles to work in their stronger, middle ranges. The slight medial rotation of the humerus at the GH joint helps bring the hand to the mouth rather than to the anterior aspect of the shoulder (Trew & Everett, 2005).

The human shoulder, with the laterally directed glenoid cavity and longer, laterally twisted clavicle, allows much mobility and enables overhead action, which may have had a role in evolution by enabling vertical climbing. Because humans can carry objects, this may have been an incentive for bipedal locomotion (Veeger & vanderHelm, 2007).

Bones of the Shoulder and Palpable Structures

The shoulder connects with the axial skeleton at the sternum (manubrium) and clavicle and muscles originating from the axial skeleton. Since the shoulder girdle does not have any bony connection posteriorly, the manubrium and left and right clavicles and the scapulae form an incomplete girdle (Houglum & Bertoti, 2012).

The shoulder complex is made up of the clavicle, humerus, sternum, scapula, ribs, and vertebral column (Figure 5-2). Many skeletal landmarks and bony characteristics can be palpated.

Rybski, M. F.
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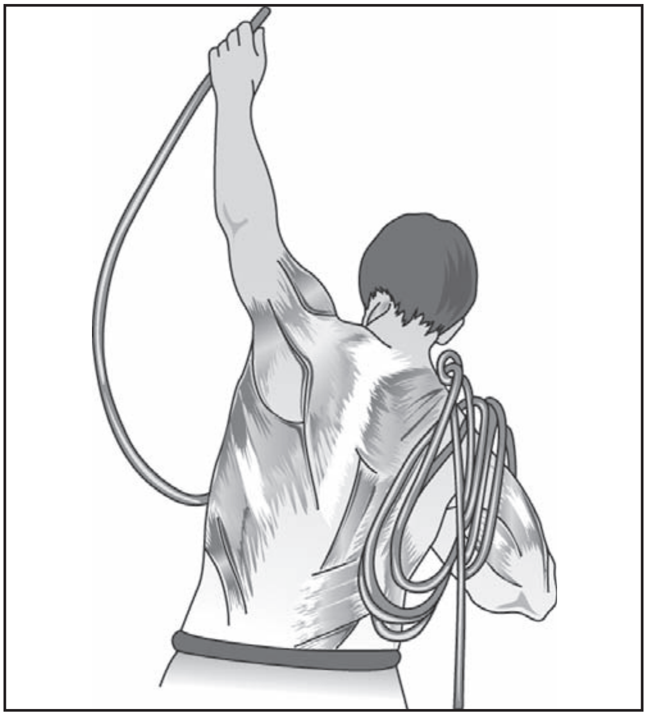


Figure 5-1. The shoulder in action.

Clavicle

The clavicle provides the connection between the sternum and the scapula and not only enables movement of the shoulder, but also protects the underlying brachial plexus and vascular structures (Nordin & Frankel, 2012). It lies horizontally across the upper chest and has an S shape (Biel, 2016). The S-shaped bone helps to hold the scapula in the proper position for abduction by means of suspensory ligaments that help to produce maximum range of motion (ROM) at the GH joint. The clavicle increases the mobility of the GH joint to permit reaching and climbing activities. The clavicle may rotate as much as 50 degrees with the shoulder in abduction and may elevate as much as 40 degrees, primarily at the AC.

Lateral/Acromial End

The lateral end of the clavicle, which articulates with the acromion process of the scapula and projects above it, is easily palpable. It is relatively flat and rises slightly above the acromion (Biel, 2016).

Medial/Sternal End

Palpate the rounded projection above the superior aspect of the manubrium sterni. The line of the SC joint can be identified, and movement of the clavicle can be felt by abducting the humerus. The sternal end curves inferiorly.

Shaft

It is possible to palpate the anterior and superior surfaces from the medial to lateral ends of the clavicle. Note that the anterior surface is convex medially and concave laterally.

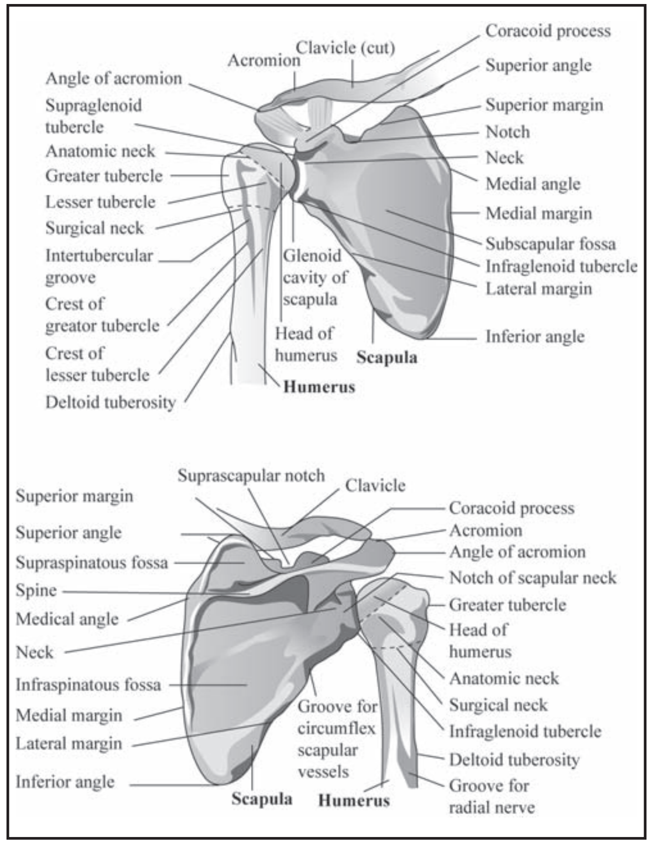


Figure 5-2. Bones of the shoulder.

Humerus

The humerus is the only bone of the upper arm and is positioned by the closed chain formed by the thorax, scapula, and clavicle (Veeger & vanderHelm, 2007). In the frontal plane, the humeral head sits at an angle of 135 degrees (angle of inclination) to the axis of the humeral shaft, and the resting position of the humeral head is in a posterior direction (about 30 degrees) relative to the distal condyles of the humerus. This posterior position, called *retroversion*, allows the humeral head to be aligned in the scapular plane and still maintain elbow joint alignment (Houglum & Bertoti, 2012).

Humeral Head

The humeral head is located medially and superiorly in the frontal plane and rotated posteriorly in the transverse plane.

Greater Tubercle

The greater tubercle of the humerus is located inferior and lateral to the acromion on the neck of the humerus. With the arm in internal rotation, palpate just distal to the anterior portion of the acromion process. As your subject internally rotates the arm, you will feel it move under your fingers (Esch, 1989). The significance of the greater tubercle is that this is where supraspinatus, infraspinatus, and teres minor muscles insert. This is often a site of impingement.

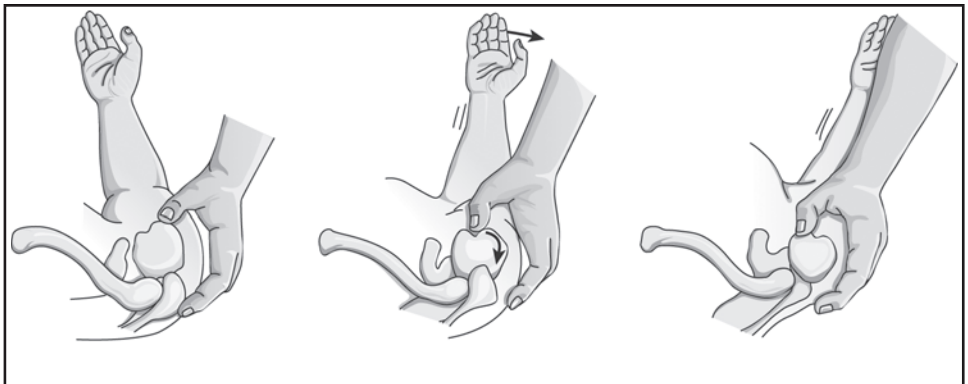


Figure 5-3. Palpation of the greater and lesser tubercles and the intertubercular groove.

Lesser Tubercle

This small mound is the attachment site for the fourth rotator cuff muscle, subscapularis. With the humerus in external rotation, palpate anterior to the greater tubercle. The lesser tubercle is smaller and lies more medially than the greater tubercle.

Intertubercular (Bicipital) Groove

This indentation is felt between the greater and lesser tubercles. Palpate this area while the subject alternately internally and externally rotates the humerus. The long head of the biceps lies in this groove and can be tender with palpation (Figure 5-3).

Sternum

The sternum is made up of the manubrium, the body, and the xiphisternum. The manubrium is where the left and right clavicles attach the upper limb to the axial skeleton. The manubrium and body are palpable as is the suprasternal (or jugular) notch, which is located on the superior aspect of the manubrium. The xiphisternum is less easily palpated.

Scapula

The scapula acts as a platform on which movements of the humerus are based. It is a flat surface that allows for smooth gliding of the scapula on the posterior thoracic wall and provides a large surface for muscle attachments. Motions of scapula are constrained by the medial border of scapula, which is pressed against thorax by the serratus anterior and rhomboid muscles and by external loads of the arm. Scapular motions are also constrained by clavicle, which allows the acromion to move on a sphere around the SC joint (Veeger & vanderHelm, 2007). The scapula provides muscle attachment sites and also provides a stable base from which the GH joint can function (Houglum & Bertoti, 2012).

Medial (Vertebral) Border

This border is easily palpated about 1.5 inches lateral and parallel to the vertebral column.

Inferior Angle

The inferior angle is superficial and located on the scapula at the medial border's lower end (Biel, 2016). Glide your fingers inferiorly along the medial border and palpate the lowest portion of the scapula (i.e., the junction of the medial and lateral borders of the scapula). If your subject consciously relaxes the shoulder girdle musculature, the angle will be more easily palpated.

Glenoid Fossa

This is the superior lateral aspect of the scapula that forms the GH joint.

Acromion Process

This structure is located at the top of the shoulder and the lateral aspect of the spine of the scapula. Palpate this flat process at the lateral point of the shoulder where it forms a shelf over the GH joint. This is the origin of the middle fibers of the deltoid muscle and the insertion of the trapezius muscle.

Spine of the Scapula

This is the superficial ridge that ends at the top of the shoulder and runs at an oblique angle to the medial border of the scapula (Biel, 2016). Palpate from the acromion process to its base on the vertebral border.

Infraspinous Fossa

Located inferior to the spine of scapula (Figure 5-4), this triangular depression can be felt above the inferior angle and between the medial and lateral borders (Biel, 2016).

Supraspinous Fossa

This small yet deep depression is located superior to the spine of the scapula. It is difficult to access directly because it is covered by trapezius and supraspinatus muscles (Figure 5-5).

Subscapular Fossa

Because of its location on the scapula's anterior (underside) next to the rib cage, it is difficult to palpate.

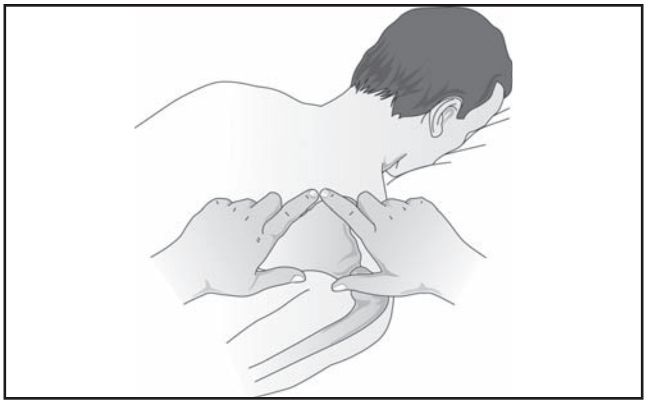


Figure 5-4. Palpation of the infraspinous fossa.

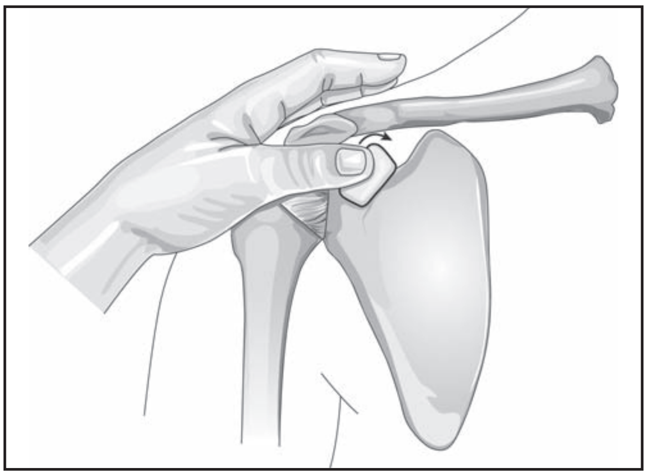


Figure 5-6. Palpation of the coracoid process

Coracoid Process

This pointed projection is found inferior to the shaft of the clavicle and often is tender when palpated, so use care. Palpate with deep pressure through the medial border of the anterior deltoid muscle, just inferior to the clavicular concavity. It may be palpated approximately 2.5 cm below the junction of the lateral one-third and the medial two-thirds of the clavicle. If you have difficulty, ask your subject to protract the shoulder slightly. The coracoid process provides the origin for the coracobrachialis muscle and insertion for pectoralis minor muscle. It is the only hard, bony surface in this area (Figure 5-6).

Ribs and Vertebrae

These bones and their articulations are presented in greater detail in Chapter 9, related to the spine and neck.

Articulations of the Shoulder

The shoulder is capable of a wide variety of movements at as many as six articulations, as shown in Figure 5-7. It is generally accepted that there are three synovial joints (GH, AC, and SC) and two functional joints (scapulothoracic and suprahumeral). The additional movement that occurs during

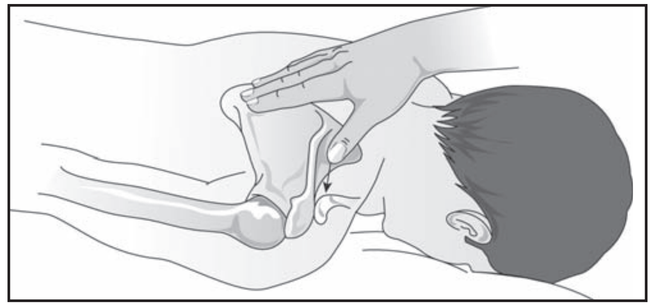


Figure 5-5. Palpation of the supraspinous fossa.

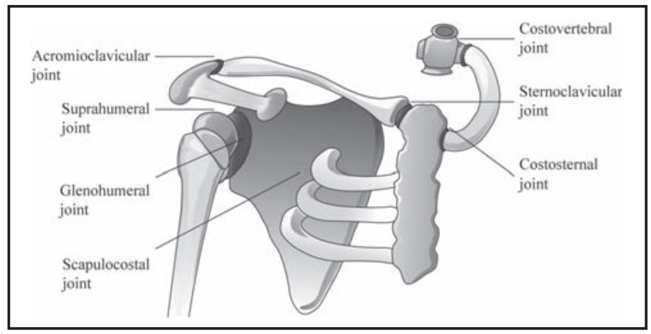


Figure 5-7. Articulations of the shoulder.

shoulder motions occurs between the ribs and the sternum (costosternal) and between the ribs and vertebral column (costovertebral).

Glenohumeral Joint

The GH joint is the major joint of the shoulder complex. The joint includes the glenoid fossa of the scapula articulating with the head of the humerus.

The glenoid is positioned with a 5 degree superior inclination and 7 degree retroversion in resting position, and the humeral head is retroverted an average of 33 degrees with an upward or medial inclination of 45 degrees (Magee, 2014; Nordin & Frankel, 2012).

The GH joint is considered an incongruous joint because the articulating surfaces are not in direct contact. The greatest amount of articular contact is in mid-elevation between 60 and 120 degrees of motion (Wilk, Arrigo, & Andrews, 1997b). As a way of visualizing the incongruence, the GH joint has been compared to a ball on a plate. In fact, two-thirds of the humeral head are not covered by the glenoid fossa of the scapula, which creates a marked discrepancy between the curvature of the glenoid fossa and the convex surface of the humeral head, as shown in Figure 5-8. This lack of congruence can be worsened by reduced humeral retroversion, by decreased curvature of glenoid fossa, or by an anteriorly tilted glenoid fossa, which was found in 80% of unstable shoulders as compared with 27% of normal shoulders (Jordan, Jazrawi, & Zuckerman, 2012).

The location of the head of the humerus in the glenoid provides a wide ROM and shock-absorbing capability for the joint (Matsen, Harryman, & Sidles, 1991). The position of the humerus in the glenoid also helps to resist inferior subluxation or dislocation. However, the humeral head is particularly incongruent when the shoulder is (1) adducted, flexed, and

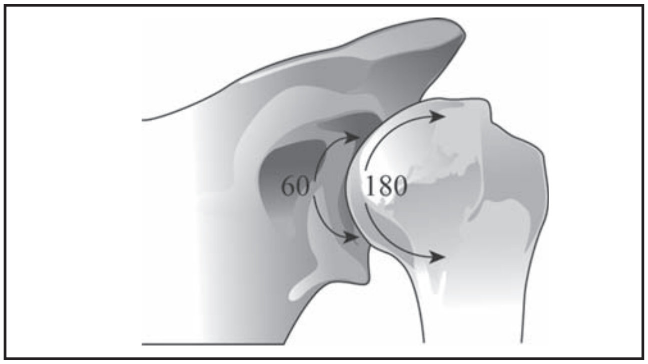


Figure 5-8. Incongruence of GH bony articulation.

internally rotated; (2) abducted and elevated; or (3) adducted at the side with the scapula rotated downward (Saidoff & McDonough, 1997, p. 196).

Matsen et al. (1991) noted that:

> It is amazing that this seemingly unstable joint can center itself to resist the gravitational pull on the arm hanging at the side for long periods, to permit lifting of large loads, to permit throwing a baseball at speeds approaching 100 miles an hour, and to hold together during the application of an almost infinite variety of forces of differing magnitude, direction, duration, and abruptness. (p. 783)

The glenoid concavity is formed by a combination of the shape of the bone, overlying cartilage, and labrum. The effective glenoid arc, or the deformable rim under load, may be compromised due to congenital deficiencies (glenoid hypoplasia), excessive compliance, traumatic lesion, or wear.

The glenoid fossa is deepened somewhat by the glenoid labrum, which provides 50% of depth to the GH joint (Figure 5-9; Nordin & Frankel, 2012). The labrum is composed of dense fibrous tissue with few elastic fibers. The labrum joins with the GH joint capsule, GH ligaments, long head of the biceps, and rotator cuff muscles, but the glenoid is still shallow, allowing only a small surface area of bone-to-bone contact.

The superior attachment of the labrum is loose while the inferior attachment is firm and unmoving (Wilk et al., 1997b). The role of the labrum as a passive stabilizer of the GH joint is debated (Hess, 2000; Veeger & vanderHelm, 2007). It appears to aid in controlling GH translations, act as a load-bearing structure, protect the edges of the bones, assist in joint lubrication, provide an attachment for GH ligaments, and increase the contact area between articular surfaces (Hess, 2000; Ludewig & Borstad, 2011; Wilk et al., 1997b). The intact labrum resists tangential forces of approximately 60% of compressive loads placed on the shoulder (Jordan et al., 2012). Damage to the superior labrum may occur with anteroposterior extension (e.g., a SLAP lesion), repetitive overhead activities, a sudden pull on the arm, and compression (e.g., a fall on an outstretched arm) and may result in pain and shoulder instability (Jordan et al., 2012).

The subacromial space (also referred to as *subdeltoid* or *suprahumeral*) articulation is a functional joint (as opposed to an anatomic joint) serving in a protective capacity. It is part of the GH joint and not seen as a separate joint (Levangie & Norkin, 2011). This is the articulation between the acromion and the coracoacromial ligament and arch. The head of the humerus slides beneath the acromion, and the tendon of the long head of the biceps muscle slides in the bicipital groove. Tendons of the rotator cuff muscles (supraspinatus, infraspinatus, teres minor, and subscapularis), long head of the biceps, joint capsule, capsular ligaments, subdeltoid, and subacromial bursae lie in this area and may be susceptible to impingement or compression syndromes. This articulation prevents trauma from above, prevents upward dislocation of the humerus, and mechanically limits abduction of the humerus.

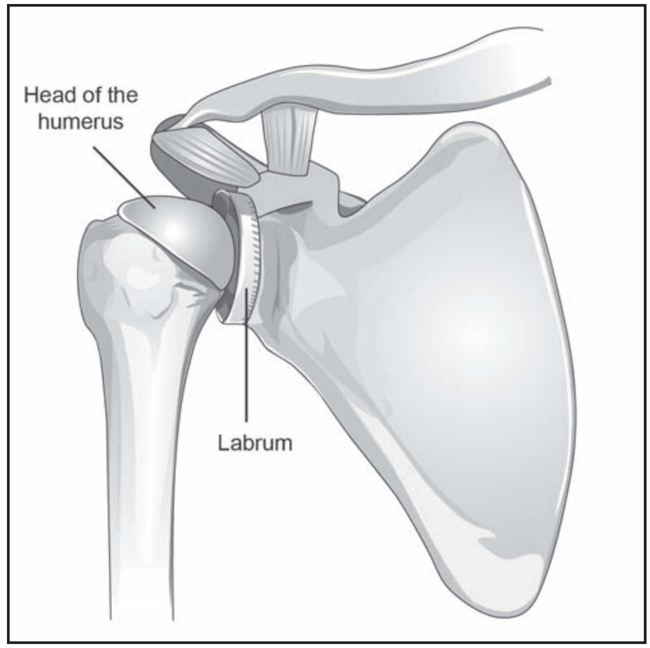


Figure 5-9. Labrum of the GH joint.

Osteokinematics

The GH joint is a ball-and-socket, freely movable, synovial joint with three degrees of freedom or motion in all planes. The GH joint permits rotation around all three axes, all of which pass through the head of the humerus. Since there is such an incongruence between the size of the large convex humeral head and the shallow concave glenoid fossa and rotation around the three axes, pure spin does not occur; instead there are changing centers of rotation.

GH flexion and extension move the humerus in a sagittal plane around a coronal axis, GH abduction and adduction move the humerus in a coronal plane around a sagittal axis, and internal and external rotation of the humerus moves the humerus in a horizontal plane around a vertical axis. Accessory motions (e.g., rolling, spinning, gliding, and combinations of these movements) help to produce the diverse mobility seen at this joint.

Because this ball-and-socket joint is a synovial joint with a joint capsule and synovial fluid, friction is decreased. There are a number of bursae in the capsule that aid joint mobility. These include the subdeltoid, subcoracoid, coracobrachial, subacromial, and subscapular bursae. The bursae are formed by the synovial membrane of the joint capsule and function to decrease friction between two bony surfaces at points where muscles, ligaments, and tendons glide over bones. The

Table 5-1

Osteokinematics of the Glenohumeral Joint

Functional Joint	• Diarthrotic, multiaxial
Structural Joint	• Synovial, ball and socket
Close-Packed Position	• Horizontal abduction with external rotation (Hertling & Kessler, 1996) • Flexion and internal rotation (Culham & Peat, 1993)
Resting Position	• 55 degrees abduction, 30 degrees horizontal adduction (scapular plane)
Capsular Pattern	• External rotation, abduction, internal rotation

Primary Muscles	• External rotators
	  ◦ Supraspinatus
	  ◦ Infraspinatus
	  ◦ Teres minor
	• Internal rotators
	  ◦ Teres major
	  ◦ Subscapularis
	• Elevators
	  ◦ Upper trapezius
	  ◦ Levator scapulae
	  ◦ Rhomboids
	• Depressors
	  ◦ Lower trapezius
	  ◦ Latissimus dorsi
	  ◦ Pectoralis minor
	• Retractors
	  ◦ Rhomboids
	  ◦ Middle trapezius
	• Protractors
	  ◦ Pectoralis major
	  ◦ Serratus anterior
	• Upward rotators
	  ◦ Trapezius (upper and lower)
	  ◦ Serratus anterior
	• Downward rotators
	  ◦ Rhomboids
	  ◦ Levator scapulae
	  ◦ Pectoralis minor
	  ◦ Latissimus dorsi
	• Flexors
	  ◦ Biceps
	  ◦ Deltoid (anterior)
	• Extensors
	  ◦ Triceps
	  ◦ Deltoid (posterior)
	• Abductors
	  ◦ Deltoid (middle)
	• Adductors
	  ◦ Pectoralis major
	  ◦ Triceps

subacromial bursa, which comprises the subacromial and subdeltoid bursae, allow small motions between the rotator cuff muscles and the acromion and AC joints. The subscapular bursae protect the tendon of the subscapularis muscle and go under the coracoid and the neck of the humerus.

The close-packed position of the joint in which the bones have the greatest congruency is in maximum abduction and external rotation. Accessory movements of the GH joint are possible in the loose-packed position of 55 degrees of abduction and 30 degrees of horizontal adduction. Table 5-1 summarizes the osteokinematics of the GH joint.

Flexion and Extension

Flexion and extension of the GH joint, defined as the rotation of the humerus in the sagittal plane around a medial-lateral (frontal or coronal) axis of rotation (Neumann, 2010, p. 112), is primarily a spinning motion that occurs around a fixed point on the glenoid.

The anterior deltoid, pectoralis major, and coracobrachialis muscles flex the humerus, and the inferior GH capsule tightens. As this occurs, the humeral head slides posteriorly and rolls anteriorly. In a normal GH joint, passive flexion produces about 4 mm of anterior translation of the humeral head on the glenoid while extension produces approximately 4 mm of posterior translation (Uhl, Kibler, Gecewich, & Tripp, 2009).

In full extension, the anterior capsule becomes slightly tight, causing an anterior tilt of the scapula to complete full extension. Capsular tightness causes slight lateral rotation in extension and slight medial rotation in full flexion (Houglum & Bertoti, 2012).

Abduction and Adduction

For abduction and adduction, defined as the rotation of the humerus in the frontal plane around an anterior-posterior axis (sagittal), the middle deltoid muscle and supraspinatus are active, and the physiologic motions of the humeral head include sliding inferiorly and rolling superiorly. The convex humeral head rolls upward and slides downward on the scapula's concave glenoid fossa. Without sufficient inferior slide during abduction, the rolling action of the humeral head would impinge on the supraspinatus muscle on the coracoacromial arch, which is painful and limits abduction (Neumann, 2010).

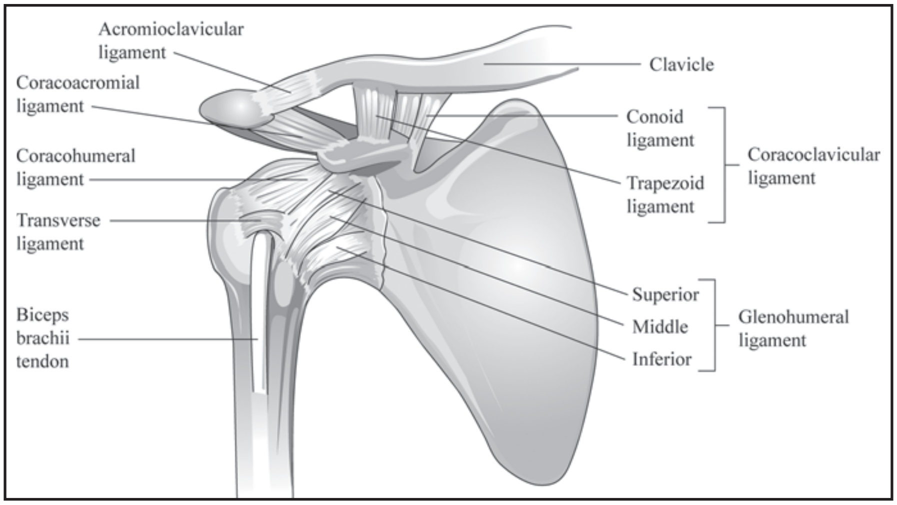


Figure 5-10. Anterior shoulder ligaments.

The amount of abduction is dependent on the rotation of the GH joint. In full medial rotation, abduction is limited to 60 degrees since the greater tubercle contacts the acromial process and AC ligament. In 90 degrees of abduction, the greater tubercle rotates, allowing additional abduction (Houglum & Bertoti, 2012). The humeral flexors and abductors do not act without the rotator cuff muscles and the long head of the biceps because this would cause compression of the subacromial space and there would be very little abduction or flexion. This information is invaluable to the therapist who is trying to provide mobilization to the shoulder by means of passive range of motion (PROM) or soft tissue stretching (Uhl et al., 2009).

Elevation in the Plane of the Scapula

When asked to raise the arm up, most people do not elevate their arms precisely in the sagittal plane and frontal axis as occurs in forward flexion, nor do they purely abduct the arm in a frontal plane and sagittal axis. Instead, the movement is more likely to be elevation in the plane of the scapula. This movement is approximately 30 to 45 degrees anterior to the coronal or frontal plane and is sometimes called *scaption*. The forward elevation of the plane of the scapula is considered a more functional movement because the inferior portion of capsule is not twisted and the musculature of the shoulder is optimally aligned for elevation of the arm (Jordan et al., 2012). The center of the humeral head remains centered in the glenoid cavity throughout the arc of motion except during initiation of elevation. Movement in this plane enables upward rotation of the scapula, posterior tilt, and external rotation with clavicular elevation and retraction (McClure, Michener, Sennett, & Karduna, 2001).

The plane of the scapula is clinically significant because the length-tension relationship among the shoulder abductors, rotators, and posterior rotator cuff muscles is at an optimum length as compared with function in the coronal plane. With the shoulder in this plane, bony impingement of the greater tuberosity against acromion does not occur because of the alignment of the tuberosity and acromion. There is optimal bony congruence in this position, which decreases anterior capsular stress (Ellenbecker & Ballie, 2010).

The amount of abduction that occurs in the frontal plane depends on rotation of the humerus. If the humerus is in internal rotation, there is 60 to 90 degrees of abduction, while if in external rotation, 90 to 120 degrees abduction is possible (not accounting for scapulothoracic contributions). Abduction in the scapular plane is not dependent on humeral rotation, and there is less restriction of motion. Average maximal ROM for abduction in the scapular plane is 107 to 112 degrees (McClure et al., 2001; Zatsiorsky, 1998).

External and Internal Rotation

External rotation occurs when the humeral head simultaneously rolls posteriorly and slides anteriorly on the glenoid fossa (Neumann, 2010). If external rotation occurs by posterior roll without anterior slide, this amount of translation of joint surfaces can disarticulate the joint (Neumann, 2010). Internal rotation occurs when the humeral head simultaneously rolls anteriorly and slides posteriorly on the glenoid fossa. To isolate internal and external rotation from pronation and supination of the forearm, rotate the humerus with the elbow in 90 degrees of flexion.

Greater lateral rotation occurs with the arm elevated rather than at the side. When the arm is at the side, the coracohumeral and anterior humeral ligaments are taut and limit lateral rotation; when the arm is elevated, these ligaments are lax (Figure 5-10; Houglum & Bertoti, 2012). Internal rotation with the arm at the side produces only about 2 mm of anterior translation, with external rotation producing the same amount in a posterior direction (Uhl et al., 2009).

An approach called the *globe system* has been developed by Pearl et al. (1992) to describe positions of the shoulder unambiguously. This system has been used in several three-dimensional (3D) studies of activities involving the shoulder (Aizawa et al., 2013; Doorenbosch, Harlaar, & Veeger, 2003; Gates, Walters, Cowley, Wilken, & Resnik, 2016; Harryman, Clark, McQuade, Gibb, & Matsen, 1990; Magermans, Chadwick, Veeger, & vanderHelm, 2005; Matsen, Lippitt, Sidles, & Harryman, 1994; van Andel, Wolterbeek, Doorenbosch, Veeger, & Harlaar, 2008; Veeger, Magermans, Nagels, Chadwick, & vanderHelm, 2006). Rather than describing humerothoracic motion as degrees of humeral elevation in the sagittal plane (flexion) and in the coronal plane (abduction), a globe with latitudinal and longitudinal lines is used as a reference in a specified sequence. The first reference in the sequence is the plane of elevation,

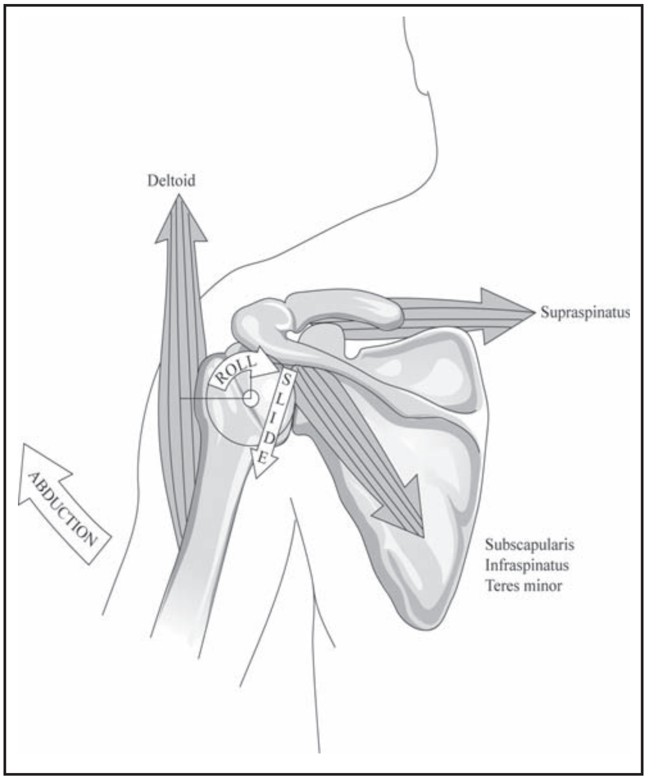


Figure 5-11. GH arthrokinematics for abduction.

which corresponds with the longitudinal lines on the globe. This includes both flexion and abduction and can describe movements outside of the pure sagittal or coronal planes. Second in the sequence is the angle of elevation, which is defined as the angle between the unelevated and the elevated humerus measured in the plane of elevation (Pearl et al., 1992). The angle of elevation corresponds with the latitudinal lines on the globe. The final reference in the sequence is angle of rotation. Rotation is defined by the angle between the forearm (elbow flexed to 90 degrees) and a line perpendicular to the plane of elevation (the latitude). This method of describing motion at the shoulder is seen to be less ambivalent than using principle planes and can describe the complexity of movements at the shoulder and during daily activities.

Arthrokinematics

Passive motion of the GH joint produces rolling of the convex humeral head and downward gliding on the scapula's concave glenoid fossa, as seen in Figure 5-11. This means that the motions of the distal and proximal humerus are reciprocally opposite during GH movement. For example, during shoulder abduction, when the humerus moves up, the head of the humerus slides inferiorly. Likewise, during adduction, as the arm comes to rest at the side of the body, the humeral head slides upward or superiorly. However, when the humerus is stabilized and the scapula moves, the concave glenoid fossa slides in the same direction as the scapula (Kisner & Colby, 2012). Because the convex head of the humerus is not parallel to the concave glenoid fossa, rotation of the joint cannot take place as pure spin but requires that motions of the humerus be accompanied by combined rolling and gliding of the head of the humerus on the glenoid fossa in a direction opposite to the movement of the shaft of the humerus (Ludewig & Borstad, 2011). This prevents impaction of the humeral head on either the acromion or the coracoacromial ligament in the normal GH joint. In flexion and extension, the humeral head spins in the glenoid fossa with no roll or slide until higher elevation, where there is an anterior slide of the humeral head on the glenoid fossa in flexion and a posterior slide during hyperextension.

To elevate the humerus, either in flexion or abduction, the muscles must accommodate the spin, roll, and glide of the head of the humerus. The forces that guide the arthrokinematics are the rotator cuff muscles and the GH ligaments.

The concave-convex rule states that the humeral head slides inferiorly during abduction, anteriorly during external rotation, and posteriorly during internal rotation. However, other research has shown that, during the initial 30 to 60 degrees of elevation in the scapular plane, the humeral head moves superiorly 3 mm then stays centered within 1 mm. During horizontal plane movement, the humeral head stays centered until maximal extension and external rotation occurs (such as the cocking phase of pitching), when 4 mm of posterior translation occurs (Howell, Galinat, Renzi, & Marone, 1988). These studies suggest that movement of the humeral head is related to tightness in the joint capsule, supporting the importance of joint mobility testing. Joint mobilization techniques need to consider the direction of force rather than just the convex-concave rule (Kisner & Colby, 2012). Kirby, Showalter, and Cook (2007) add that, because support for the convex-concave rule for the GH joint is poor, joint mobilization techniques based solely on this rule may not yield outcomes any better than other GH movement patterns. The arthrokinematics of the GH joint are summarized in Table 5-2

Supporting Structures

Unlike the hip joint (the other ball-and-socket joint in the body), the stability of the GH joint is not accomplished due to the articulation of bony segments, but is achieved instead by capsular, ligamentous, and, particularly, muscular structures. Zuckerman and Matsen (1984) identified five factors that are important for the stability of the GH joint:

1. Adequate size of the glenoid fossa
2. Posterior tilt of the glenoid fossa
3. Humeral head retroversion
4. Intact capsule and glenoid labrum
5. Function of muscles that control the anteroposterior position of the humeral head

The first four factors are considered passive supporting structures, while the function of muscles is the dynamic support for the GH joint. The forces of the synovial fluid and joint pressure hold GH joint surfaces together, and gravity is also a passive stabilizing force.

Gravity acts in static stability by pulling the humeral head downward in a direction parallel to the humeral shaft, moving the humerus into adduction. Gravity is offset by the superior joint capsule, superior and middle portions of the GH ligaments, and coracohumeral ligaments, which are tight when the arm is adducted. This provides stabilization as well as limits external rotation in the lower ranges of abduction. If there are additional loads to the limb in addition to the force of gravity, dynamic stabilizers provide the additional stabilization.

Table 5-2

Arthrokinematics of the Glenohumeral Joint

Movement of Convex Head on Concave Glenoid Fossa	**Roll**	**Slide**	**Resultant Movement**
Flexion	Minimal	Anterior at higher elevation	Opposite
Horizontal adduction	Anterior	Posterior	Opposite
Internal rotation	Anterior	Posterior	Opposite
Extension	Posterior	Anterior (posterior at higher elevation)	Opposite
Horizontal abduction	Posterior	Anterior	Opposite
External rotation	Posterior	Anterior	Opposite
Abduction	Superior	Inferior	Opposite

Adapted from Kisner, C., & Colby, L. A. (2007). *Therapeutic exercise: Foundations and techniques* (5th ed.). Philadelphia, PA: F. A. Davis.

Supraspinatus contracts to aid with stabilization and may be assisted by the posterior deltoid muscle, which also helps to prevent downward displacement of the humerus (Kisner & Colby, 2012; Matsen et al., 1991; Wilk, Arrigo, & Andrews, 1997a).

Passive Structures

The passive structures that aid in GH stability include the bony geometry and the GH joint capsule-ligamentous complex.

Bony Support. Kibler (1998) and Kibler and McMullen (2003) identified five roles that the scapula assumes in the function of the GH joint. Several of these contribute to GH stability. First, the scapula is considered the stable portion of the joint. The humerus and scapula move so that the center of rotation of the joint is constrained within a physiologic pattern throughout the full ROM (Kibler, 1998, p. 325). This allows compression of the humeral head into the glenoid fossa. In addition, the weight of the upper extremity creates a downward and forward tipping of the scapula (Kisner & Colby, 2012), creating a cohesive force of the subscapular bursa.

Second, the scapula permits protraction and retraction along the thoracic wall, without which there would not be full humeral elevation. The third role of the scapula is to enable elevation of the acromion. The scapula must rotate and be tilted to avoid impingement of the rotator cuff muscles. The scapula also provides a base for muscle attachments as the fourth important role. The scapular muscles attach to the medial, superior, and inferior borders and are intrinsically aligned so they are most efficient between 70 and 100 degrees of abduction, acting as a compressor cuff (Kibler, 1998). The final role of the scapula is as a link in the proximal-to-distal sequencing of velocity, energy, and force transmission (Kibler, 1998). Kibler and McMullen (2003) add that:

> The scapula is thus pivotal in transferring large forces and high energy from the legs, back and trunk to the delivery point, the arm and hand, allowing more force to be generated in activities such as throwing than could be done by the arm musculature alone. The scapula, serving as a link, also stabilizes the arm to more effectively absorb loads that may be generated through the long lever of the extended or elevated arm. (p. 143)

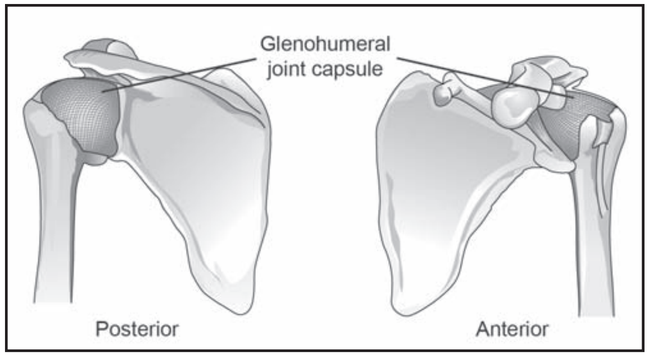


Figure 5-12. GH joint capsule.

Glenohumeral Capsuloligamentous Complex. The GH joint capsule and ligaments of the joint provide both static and dynamic stabilization for the GH joint. The superior structures provide static stability by preventing inferior slide of the humeral head at rest, while the dynamic stabilization occurs when the capsuloligamentous complex structures are taut and center the humeral head in the glenoid fossa.

The GH joint capsule (Figure 5-12) is a large, loose structure enabling much motion at the GH joint. It is a lax structure, and anterior, superior, and posterior aspects of the capsule are reinforced by the tendons of the rotator cuff and by coracohumeral and superior GH ligaments, but there is no reinforcement inferiorly, so this is an area of weakness. The posterior capsule is crucial to GH stability since it is the primary posterior stabilizing structure and also assists with restraint to anterior dislocation (Nordin & Frankel, 2012).

The capsule has multilayered collagen fiber bundles, and the anteroinferior portion is the thickest and strongest, with densely organized fibers. Fiber arrangement varies and serves different stabilizing functions. With the radially oriented collagen fibers, rotational forces produce tension within these fibers, which leads to compression of joint surfaces and a centering of the joint. Circular fiber bundles appear to contribute to absorption of stress and tension, and spiral-shaped, cross-linked collagen fibers assist with joint stability (Wilk et al., 1997a, p. 369).

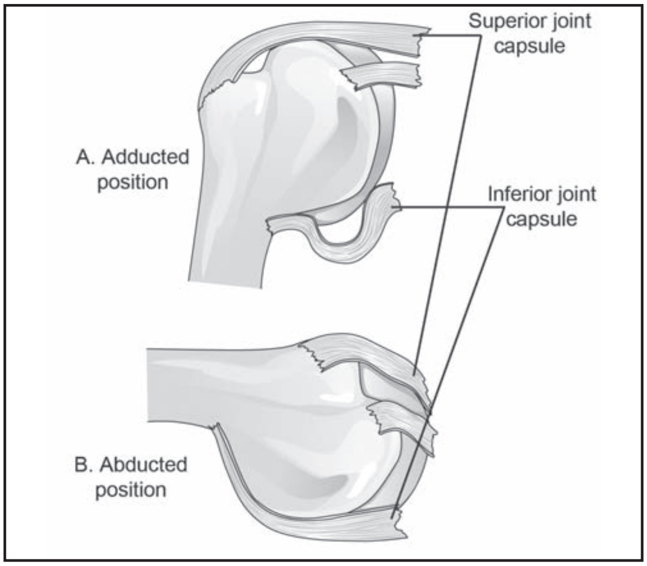


Figure 5-13. Capsular support at the GH joint.

With the arm in adduction, the capsule is taut superiorly and slack inferiorly (Figure 5-13). The inferior portion lies in folds with the arm adducted so it can adhere to itself, possibly leading to adhesive capsulitis when disease or trauma is present. With increasing abduction, the capsule becomes tight inferiorly and lax superiorly. This provides passive joint stability because the capsule holds the humeral head to the glenoid. Abduction is accompanied by external rotation in the normal shoulder joint. When abducting the humerus, a twist occurs on the joint capsule and tension develops in the joint capsule. This tension increases with abduction, pulling the humerus into external rotation and allowing greater ROM into abduction because the greater tubercle can clear the coracoacromial arch (Hertling & Kessler, 1996).

There is a similar taut/loose pattern with internal and external rotation and the joint capsule. When the arm is in external rotation, the anterior capsule tightens. Conversely, in internal rotation, the capsule tenses posteriorly, resisting anterior translation of the humeral head. The passive restraints act not only to restrict movement, but also to reverse the humeral head movement (Wilk et al., 1997a, p. 366).

As a rule, the superior capsular structures have a role in joint stability when the arm is adducted, and inferior capsular structures assist with joint stability from 90 degrees abduction or forward humeral flexion. The posterior capsule is seen as crucial to maintaining GH stability as a secondary restraint to anterior dislocation and is seen as a primary posterior stabilizing structure (Jordan et al., 2012). With pathologic shortening of the GH structures, the humerus moves to the position of least restriction. For example, if there was shortening of the posterior capsule, the humerus would move to an anterior position. Capsular adhesions and patterns for the GH joint are in abduction and internal and external rotation. Abnormal tightness of the joint capsule can greatly impair the normal biomechanical motion of the shoulder. Patterns of capsular mechanics contributing to GH stability are summarized in Table 5-3.

An additional function of the GH joint capsule is that, because the capsule is sealed tight, this creates a relative vacuum that resists large GH joint translations. Small translations are possible and can be balanced by fluid flow in the opposite direction. Negative joint pressure pulls the capsule inward toward the joint space, creating a suction effect of the glenoid labrum with the humeral head and an adhesion-cohesion relationship of the synovial surfaces (Kisner & Colby, 2012; Matsen et al., 1991). Even though the magnitude of the pressure is small, when the joint capsule is punctured, the humeral head tends to sublux, regardless of where puncture occurs, resulting in loss of GH stability (Wilk et al., 1997b). The joint volume effect can be compromised in clients with capsular defects, joint effusion, and in excessively compliant joint capsules (Matsen et al., 1991; Wilk et al., 1997b).

Table 5-3

CAPSULAR MECHANICS FOR THE GLENOHUMERAL JOINT

Capsule Portion	**Taut Position**
Superior	Adduction or resting position
Inferior	90 degrees abduction
Anterior	External rotation
Posterior	Internal rotation
Posteroinferior	Restraint to posterior dislocation

Ligaments resist tension in one direction and serve to connect bone-to-bone, which adds to the stabilization of the joint. Ligaments are as strong as tendons with many collagen fibers, but also with fibroelastic tissues providing some elasticity to these structures. The primary ligaments adding support to the GH joint are the coracohumeral and GH ligaments.

The GH ligament is part of the glenoid labrum and has three parts: superior, inferior, and middle. There is much variability in size and attachment of the GH ligaments, and the clinical significance of these structures is yet to be fully explained (Muscolino, 2006). The GH ligaments are the thickenings of the anterior and inferior joint capsules, which help to prevent dislocation of the humeral head anteriorly and inferiorly. Essentially, as a group, the GH ligaments serve to limit extremes in GH motions. The ligament is lax enough to permit motion, so the ligament cannot prevent GH translation when the joint is moving through most of its ROM. The ligament exerts an effect only when it is under tension, usually at the extremes of range (Matsen et al., 1991).

The superior GH ligament (Figure 5-14) is the smallest of the GH ligaments, with fibers running from an inferior-medial to superior-lateral orientation. It originates from the upper part of glenoid cavity and the base of coracoids and attaches to the middle GH ligament, biceps tendon, and labrum, inserting just superior to the lesser tuberosity in the region of the bicipital groove. The primary role of the superior GH ligament is to limit inferior translation of the humeral head in adduction and act as a restraint to anterior translation of the humeral head when the humerus is in adduction (Magee, 2014; Matsen et al., 1991). The superior GH ligament, together with the

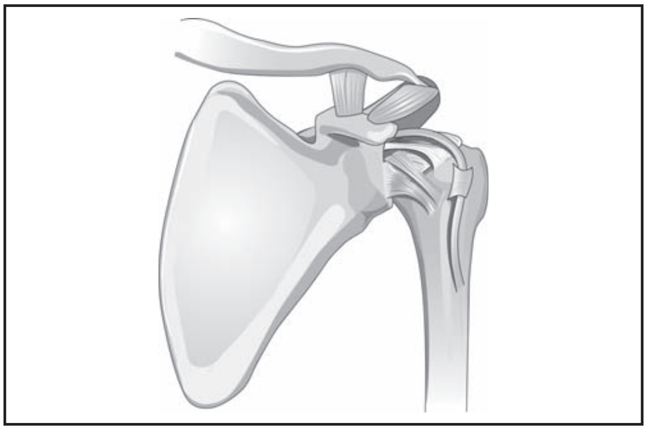


Figure 5-14. GH ligament.

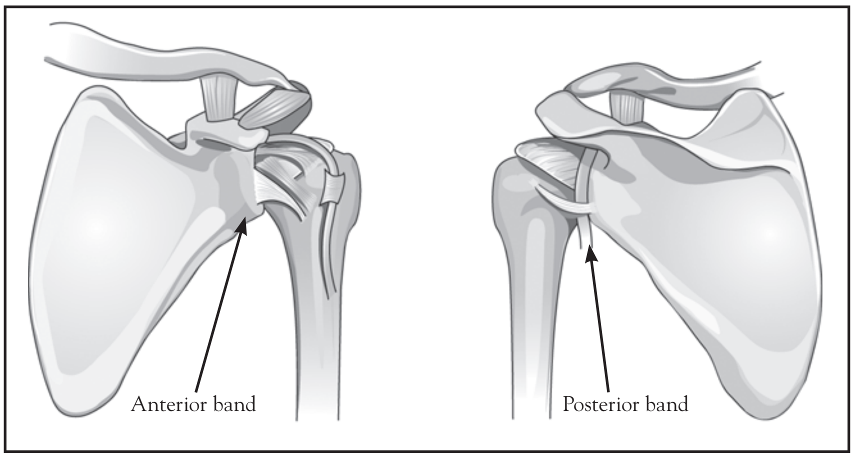


Figure 5-15. Inferior GH ligament's anterior and posterior bands.

coracohumeral ligament and supraspinatus muscle, aids in prevention of downward displacement of the humeral head and limits external rotation between 0 and 60 degrees (Wilk et al., 1997a).

The middle GH ligament (see Figure 5-13) is dense but variable in size and thickness. It is poorly defined or absent in 30% of normal shoulders (Matsen et al., 1991). The middle GH ligament attaches to the anterior aspect of the anatomic neck of the humerus, just medial to the lesser tuberosity of the humerus, and it arises from glenoid via the labrum. The middle GH ligament acts as a restraint to inferior translation with the arm adducted and in external rotation. In addition, the middle GH ligament can act to restrain anterior movement, with the maximal effectiveness between 45 and 90 degrees of abduction (Magee, 2014; Wilk et al., 1997b).

The inferior GH ligament (Figure 5-15) is the largest and most important of the GH ligaments. It consists of three parts: anterior, posterior, and the axillary pouch. The anterior and posterior portions contribute to the anterior and posterior labrum, and the axillary pouch is located between the anterior and posterior bands and attaches to the inferior two-thirds of the glenoid via labrum. The axillary pouch acts like a sling: supporting the humeral head above 90 degrees of abduction; limiting inferior translation; tightening anterior band on external rotation; and tightening the posterior band on internal rotation (Magee, 2014).

The inferior GH ligament (and posteroinferior capsule) stabilizes against posterior instability, subluxation, and inferior translation with the arm in 90 degrees of abduction (Wilk et al., 1997a). If the arm is in less than 90 degrees of humeral abduction, the posterior joint capsule and anterior portion of the inferior GH ligament are the primary restraints to anterior translation of the humeral head (Magee, 2014). In addition, tension in the anterior ligament creates a posterior-directed force on the head of the humerus, and it elongates with and limits GH extension (Matsen et al., 1991). In positions of abduction and external rotation, the anterior band moves forward and stabilizes the joint anteriorly, and the fibers of the posterior band are pulled under the head to stabilize it inferiorly. The posterior band elongates with and limits GH flexion. With internal rotation, these bands shift in the opposite direction as the anterior fibers move inferiorly and the posterior band shifts posteriorly (Figure 5-16).

The inferior GH ligament is lax in adduction. Because the inferior GH ligament is taut when the arm is abducted to 90 degrees or more, it provides anterior and posterior stabilization to the joint. It reinforces the capsular area between the subscapularis muscle and the origin of the long head of the triceps.

The coracohumeral ligament (see Figure 5-10) and the acromion of the scapula form an arch that prevents excessive upward dislocation of the humeral head. The triangular coracohumeral ligament originates from the lateral aspect of the

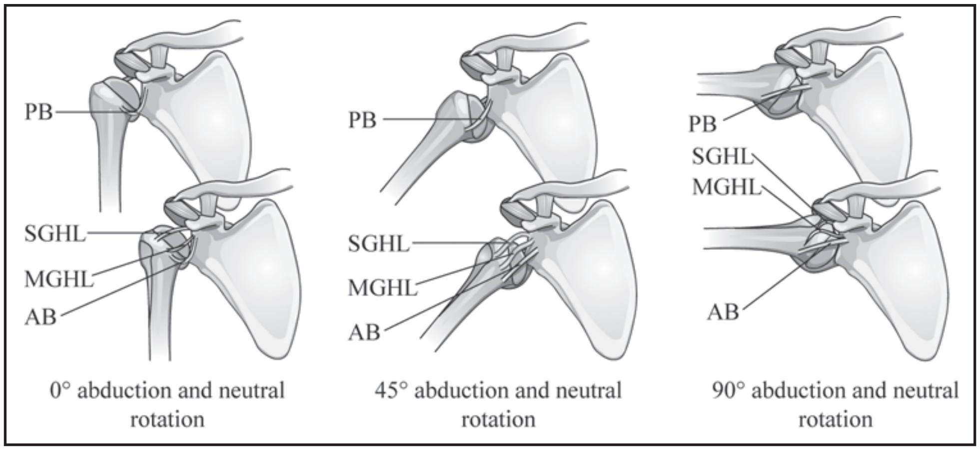


Figure 5-16. Ligamentous constraints to inferior-superior translation of the humerus.

coracoid process of the scapula and attaches to the anterior, medial, and inferior surfaces of the acromion, spanning the bicipital groove. The coracohumeral ligament blends with the rotator cuff muscles, which provides stability superiorly and joins with the joint capsule.

It represents the folded thickening of the GH capsule in the area of the rotator interval between the subscapularis and supraspinatus muscles. The coracoacromial arch is formed by the coracoid process, acromion, clavicle, AC, and coracoacromial ligament. The arch functions to protect superior structures of the GH joint, stabilizes the humeral head, and prevents upward translation. If not for the coracoacromial arch, carrying a heavy bag on the shoulder might damage the superior structures of shoulder (Muscolino, 2006).

When the humerus is externally rotated, the coracohumeral ligament is elongated, thereby limiting external rotation below 60 degrees (Magee, 2014). When the arm is externally rotated, flexed, or extended, the coracohumeral ligament gets taut, and this helps to resist inferior subluxation and dislocation of the humeral head anteriorly. Because this ligament helps to limit extremes in flexion, extension, and external rotation by virtue of its strength and strategic position, it is considered one of the most important ligamental structures in maintaining GH integrity and stabilization (Edelson, Taitz, & Grishkan, 1991; Gench, Hinson, & Harvey, 1995). In addition, the long and short head of the biceps serve as anterior stabilizers of the GH joint in the movements of abduction and external rotation.

Overall, the anterior and posterior capsule and capsular ligaments limit translation and rotation of the humerus. When these capsule and ligamentous constraint mechanisms are excessive, this can do joint damage. If there is a tight posterior capsule, this imposes an anterior-superior translation with flexion, causing impingement against the acromion. If the anterior capsule is too tight, posterior subluxation of the humeral head may result, with the potential of developing degenerative joint disease (Matsen et al., 1991). A summary of the passive structures of the GH joint is provided in Table 5-4.

Dynamic Structures

Dynamic stability is the combined efforts of muscles, intact proprioception, and the musculoligamentous relationship of the GH structures that stabilize the humeral head in glenoid through compression, enabling activity and movement to occur (Kibler & McMullen; 2003; Kibler et al., 2002; Neumann, 2010; Uhl et al., 2009; Wilk et al., 1997a, 1997b).

Primary dynamic muscles providing support to the GH joint are the rotator cuff muscles (supraspinatus, infraspinatus, teres minor, and subscapularis, or intrinsic muscles), deltoid muscle, long head of the biceps and triceps (considered extrinsic muscles), trapezius, rhomboids, levator scapula, and serratus anterior (considered periscapular muscles), which all act to stabilize and allow rotation of the scapula.

The importance of rotator cuff muscles lies in their strength, dynamic efficiency, and endurance in providing stability and unloading stress on capsular ligaments (Wilk et al., 1997b). Because the rotator cuff muscles blend into the shoulder joint capsule, these muscles create active and passive barriers to humeral head translation as well as act to absorb and dissipate repetitive microtraumatic stresses (Wilk et al., 1997b).

The rotator cuff muscles (specifically, the supraspinatus, infraspinatus, and teres minor) provide a balanced force to the humeral head, keeping it secure in the glenoid cavity while also protecting the labrum, joint capsule, and ligaments from damage during activities (Donatelli & Wooden, 2010). Not only do the individual rotator cuff muscles contribute to dynamic GH stability, but they also provide passive stability by muscular bulk.

The rotator cuff stabilizes the GH joint through force couples in both the coronal and transverse planes. Figure 5-17 illustrates the location of the rotator cuff muscles on the scapula. The subscapularis is seen as essential for joint stability and acts both as a passive stabilizer (depressor of the humeral head that aids in prevention of subacromial and posterosuperior glenoid impingement) and an internal rotator, preventing further anterior and superior translation of the humeral head as the arm is moved.

The infraspinatus muscle, a weak muscle, is a primary external rotator of the humerus and acts as a depressor during elevation. It provides a stabilizing effect by preventing posterior subluxation of the humeral head in internal rotation and creates an anterior force by tightening posterior structures. The infraspinatus also has an additional role of preventing anterior translation during external rotation and abduction.

Table 5-4

Passive Structures of the Glenohumeral Joint

Structure	Type of Stability Provided
Bone support (scapula)	• Compression of humeral head into glenoid due to centering of glenoid • Weight of arm produces downward and forward tipping of scapula creating a cohesive force • Size, tilt, and amount of deformation of glenoid fossa
Joint capsule	• Compression of joint surfaces and centering of glenoid • Spiral-shaped collagen fibers aid in stability • Taut superior capsule in adduction • Taut inferior capsule in abduction • Taut anterior capsule in external rotation • Taut posterior capsule in internal rotation • Posteroinferior capsule is a restraint to posterior dislocation • Vacuum function of sealed capsule creates suction effect
Gravity	• Pulls humeral head downward parallel to humeral shaft into adduction
GH ligament	
Superior	• Limits inferior translation of humeral head in adduction • Restraint to anterior translation of humeral head • Prevents downward displacement of humeral head • Limits external rotation between 0 and 60 degrees
Middle	• Restraint to inferior translation with arm adducted and in external rotation • Restraint to anterior movement at 45 to 60 degrees of abduction
Inferior	• Stabilizes against posterior instability, subluxation • Stabilizes against inferior translation with arm in 90 degrees of abduction ◦ Anterior band: Restricts abduction and external rotation ◦ Posterior band: Restricts abduction and internal rotation
Coracohumeral ligament	• Strengthens the superior portion of the joint capsule • Limits external rotation below 60 degrees • Resists inferior subluxation and dislocation
Coracoacromial ligament	• Protects superior GH structures • Stabilizes the humeral head • Prevents upward translation of the humeral head

The supraspinatus, due to its superior location, is most frequently involved in rotator cuff muscle tears. It helps to stabilize the humeral head and initiates abduction and some external rotation. The supraspinatus is active during any elevation. The supraspinatus, infraspinatus, and teres minor are the major dynamic structures limiting internal rotation during the first half of abduction. Once abduction or flexion occurs, the passive support of the superior joint capsule and supraspinatus muscle is eliminated, and stabilization is due to muscles. Given the location of the muscles and fiber architecture, one way the rotator cuff muscles help to stabilize the GH joint is by passive bulk.

The rotator cuff muscles also help to stabilize the GH joint by developing muscle tension to compress joint surfaces together. When rotator cuff muscles contract simultaneously, the humeral head is pressed into the glenoid socket. The combination of the deltoid muscle and the supraspinatus form a coronal force couple so that when the arm is abducted, the resultant joint reaction force is directed toward the glenoid fossa, which compresses the humeral head and improves stability when the arm is abducted and overhead (Parsons, Apreleva, Fu, & Woo, 2002).

The rotator cuff muscles help to stabilize the GH joint by selective contraction of muscles that resist displacing forces. By selective contraction of these muscles to resist displacing forces (as when the lateral deltoid muscle initiates shoulder abduction), the supraspinatus muscle and long biceps tendon actively resist displacement of the humeral head relative to the fossa. Another example is when the pectoralis major and anterior deltoid elevate and flex the shoulder; they tend to push the humeral head posteriorly out the back of the fossa.

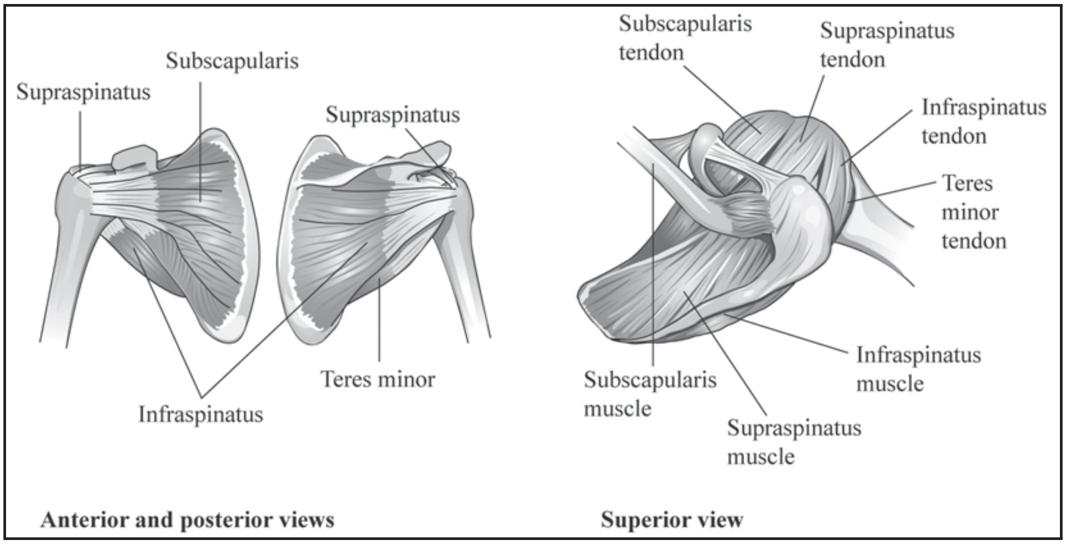


Figure 5-17. Rotator cuff muscles.

The subscapularis, infraspinatus, and teres minor muscles resist this displacement.

It is possible to identify the rotator cuff muscles by placing the hand over the shoulder, as in the superior view of Figure 5-17. Place your thumb anteriorly, and the biceps tendon will be between the thumb and just anterior to the index finger. The thumb will be over the subscapularis muscle, the index finger will be over the supraspinatus muscle, the middle finger will be located over the infraspinatus muscle, and the ring finger will be over teres minor (Biel, 2016; Magee, 2014).

The tendon of the biceps brachii muscle arches over the head of the humerus and under the joint capsule. When there is a strong contraction of the biceps muscle, as in flexion with a load in the hand, there is depression of the head of the humerus, which prevents elevation of the humeral head (Jordan et al., 2012).

Secondary dynamic muscles providing GH stability are the teres major, latissimus dorsi, and pectoralis major muscles (Wilk et al., 1997a). While not seen as primary or secondary stabilizers, the scapulothoracic muscles (serratus anterior muscle, rhomboid muscle, trapezius, levator scapula, pectoralis minor, subclavius muscles) do provide a significant role in shoulder stability. These muscles provide a stable base of support for GH muscles on which to fixate and function from, and they help to maintain sufficient length-tension relationships (Alexander, Miley, Stynes, & Harrison, 2007; Wilk et al., 1997a). Weakness in these muscles can contribute to loss of stability of the scapula and potentially to GH instability (Wilk et al., 1997a).

Two or more muscles that act together to produce rotation around an axis that otherwise work opposite to one another is known as a force couple (Houglum & Bertoti, 2012, p. 673). GH movement is associated with movement at several articulations, which presents constantly changing relationships of muscle origins and insertions and changes in joint axis. Agonist and antagonist muscle forces prevent joint dislocation, where one muscle is lengthened with a force of equal magnitude but opposite in direction to the muscle that is shortening (Nordin & Frankel, 2012). GH force couples combine to move the clavicle, scapula, and humerus to permit both stability and mobility of the arm. The muscles responsible for glenoid positioning are the trapezius, levator scapulae, serratus anterior, and rhomboids. The force couples responsible for scapular upward rotation are the upper and lower trapezius and the serratus anterior. Stability in rotation is accounted for by the rhomboids, trapezius, and pectoralis minor (Wilk et al., 1997a).

Force couples are important in dynamic stabilization by establishing a dynamic equilibrium (Wilk et al., 1997a). Subscapularis action is counterbalanced by the infraspinatus and teres minor in external rotation and, similarly, the deltoid actions are counterbalanced by the inferior rotator cuff muscles (infraspinatus, teres minor) in internal rotation of the humerus (Figure 5-18). The deltoid is counterbalanced by supraspinatus in abduction, and scapular stabilization is accomplished by the combined efforts of the upper and lower trapezius and rhomboids countering the action of the serratus anterior. Seen in this way, the force couples in the GH joint act as synergists and prime movers, producing the motion while the rotator cuff muscles act as a stable fulcrum for the motion (Wilk et al., 1997a). Wilk and colleagues (1997a) suggest that a better term for this relationship would be *balance of forces* rather than *force couple* (p. 373). Force couples that occur in the shoulder are listed in Table 5-5.

The trapezius and serratus anterior muscles form a force couple to produce elevation of the arm due to combining forces to create lateral, superior, and rotational movements of the scapula, producing abduction and upward rotation. The deltoid and supraspinatus muscles contract together to produce abduction or flexion at the GH joint. This illustrates that the rotator cuff muscles are unique in that, not only do these muscles produce (or contribute) to specific joint motions, but they are also considered dynamic stabilizers of the GH joint because they combine to stabilize and resist displacement of the humeral head (Greene & Roberts, 1999, p. 240). The combinations of movements are achieved by collaboration of many muscles, which favorably position the separate joint articulations for greater movement. Some muscles act simultaneously, and others follow in sequence.

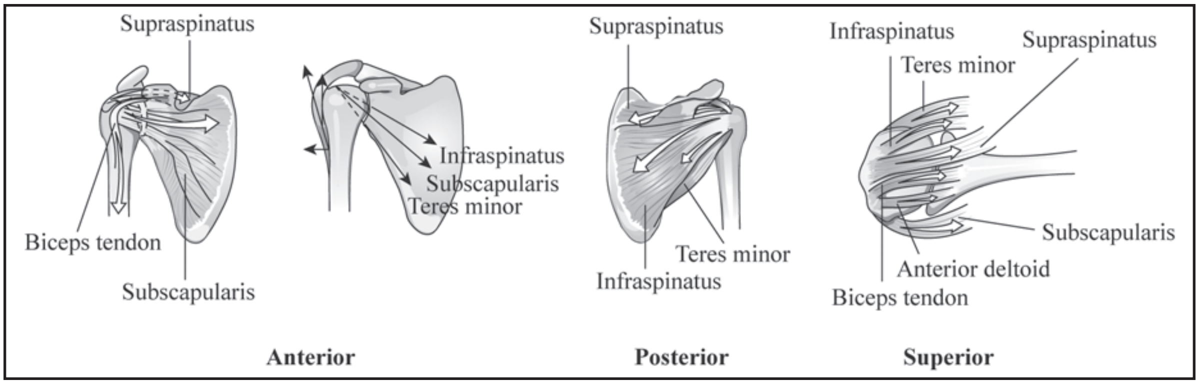


Figure 5-18. Co-contraction of dynamic stabilizers producing humeral head compression.

Table 5-5

Force Couples of the Shoulder

Movement	Agonist/Stabilizer	Antagonist/Stabilizer
Protraction (scapula)	• Serratus anterior* • Pectoralis major**/minor**	• Trapezius • Rhomboids
Retraction (scapula)	• Trapezius • Rhomboids	• Serratus anterior* • Pectoralis major**/minor**
Elevation (scapula)	• Upper trapezius** • Levator scapula**	• Serratus anterior* • Lower trapezius*
Depression (scapula)	• Serratus anterior* • Lower trapezius*	• Upper trapezius* • Levator scapula*
Lateral rotation (upward rotation of inferior angle of scapula)	• Trapezius (upper**, lower*) • Serratus anterior*	• Levator scapula** • Rhomboids
Medial rotation (downward rotation of inferior angle of scapula)	• Levator scapulae** • Rhomboids • Pectoralis minor**	• Trapezius (upper**, lower*) • Serratus anterior*
Scapular stabilization	• Trapezius (upper**, lower*) • Rhomboid	• Serratus anterior*
Abduction of humerus	• Deltoid	• Supraspinatus
Internal rotation humerus	• Subscapularis** • Pectoralis major** • Latissimus dorsi • Anterior deltoid	• Infraspinatus* • Teres minor • Posterior deltoid
External rotation humerus	• Infraspinatus • Teres minor • Posterior deltoid	• Subscapularis** • Pectoralis major** • Latissimus dorsi • Anterior deltoid

*Muscle prone to weakness.

**Muscle prone to tightness.

Reprinted with permission from Magee, D. J. (2002). *Orthopedic physical assessment.* Philadelphia, PA: WB Saunders.

Table 5-6

DYNAMIC STABILIZERS OF THE SCAPULA AND GLENOHUMERAL JOINT

JOINT/MOVEMENT	DYNAMIC STABILIZERS
Scapula	• Upper trapezius and serratus anterior
	• Middle trapezius and rhomboids
GH joint	• Rotator cuff
	◦ Supraspinatus compresses head of humerus into glenoid fossa
	◦ Subscapularis, infraspinatus, teres minor: Inferior directed translation force on humeral head
	◦ Infraspinatus and teres minor: Rotates humeral head externally
	• Deltoid
	• Long head of biceps brachii
Humeral elevation	• Rotator cuff and deltoid
Upward rotation of the scapula	• Long head of biceps stabilizes against humeral elevation
	• Long head of triceps stabilizes against inferior translation

Adapted from Kisner, C., & Colby, L. A. (2007). *Therapeutic exercise: Foundations and techniques* (5th ed.). Philadelphia, PA: F. A. Davis.

In early flexion or abduction, the teres minor and deltoid work together to depress the humeral head and stabilize it. Because the muscle force of the teres minor is equal and opposite to the deltoid, this is a force couple. The subscapularis and infraspinatus muscles join later in flexion or abduction to assist with humeral head stabilization; the latissimus dorsi contracts eccentrically to assist with stabilization, and this muscle increases in activity as the angle of motion increases; the deltoid and rotator cuff work together in flexion and abduction in that the rotator cuff acts to depress the humeral head and the deltoid elevates the arm (see Figure 5-18). The serratus anterior and trapezius now form a force couple to create lateral, superior, and rotational movements of scapula after the deltoid and teres minor have initiated elevation. Figure 5-18 illustrates how the humeral head is compressed into the glenoid fossa due to co-contraction of the dynamic stabilizers of the shoulder.

A functional example of the force couples that operate in the shoulder would be when one places the hand behind the head when combing the hair. This involves elbow flexion, SC elevation with upward rotation, scapular elevation with upward rotation and abduction, and GH abduction and external rotation. The biceps muscle is flexing the elbow, while the trapezius and serratus anterior are acting as a force couple at the scapula. The deltoid and supraspinatus form a force couple at the GH joint, as do the infraspinatus and teres minor muscles. When the arm is overhead, there would also be a contraction of the triceps muscle. These muscles all cooperate to enable successful performance of daily activities, while providing stability of the GH joint surfaces. Failure of the rotator cuff muscles to maintain humeral congruency may lead to GH joint instability, rotator cuff pathology, and labral injury (Donatelli & Wooden, 2010).

The blending of the rotator cuff muscles into the joint capsule is another method of achieving active GH stabilization. This creates both active and passive resistance to the humeral head translation and acts to absorb and dissipate microtraumatic forces (Wilk et al., 1997a). Anteriorly, the GH ligaments blend with the attachment of the subscapularis muscle; posteriorly, the tendons of infraspinatus and teres minor are combined.

Neuromuscular Control

The mechanical restraint interaction of the passive and dynamic structures of the shoulder is mediated by the sensorimotor system. Not only do the structures provide mechanical restraint of the humeral head, but they also provide neural feedback to the central nervous system, influencing the efferent output to dynamic shoulder stability structures (Myers, Wassinger, & Lephart, 2006). Based on a study by Lephart and Jari (2002), Myers and colleagues state that "neuromuscular control is the subconscious activation of the dynamic restraints about the shoulder in preparation and in response to joint motion and loading for the purpose of maintaining joint stability" (2006, p. 198). It is speculated that capsular or ligamentous injuries result from loss of proprioception, but this is an equivocal conclusion in the literature (Nyland, 2006). A summary of the dynamic stabilizers of the scapula and GH joint is provided in Table 5-6.

Sternoclavicular Joint

The SC joint is the articulation of the clavicle and manubrium of the sternum and first rib cartilage, as shown in Figure 5-19. This is the only true bony articulation of the shoulder girdle with the trunk and is considered the "base of operation" (Jordan et al., 2012). There is considerable clavicular motion at this joint, which guides the path of the scapula (Houglum & Bertoti, 2012). The SC joint provides load-bearing in compression and resists displacement in tension or distraction at the manubrium (Sewell, Al-Hadithy, Le Leu, & Lambert, 2013).

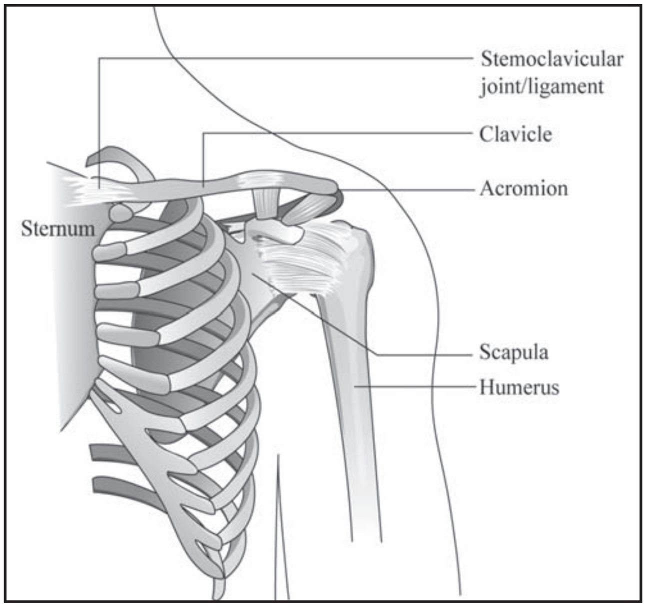


Figure 5-19. SC joint.

Table 5-7

Osteokinematics of the Sternoclavicular Joint

Functional Joint	Diarthrotic, triaxial
Structural Joint	Synovial
Close-Packed Position	Maximum shoulder elevation (full rotation of clavicle)
Resting Position	Arm at side in normal physiologic position
Capsular Pattern	Pain at extreme ROM, especially horizontal adduction and full elevation

There are intra-articular discs between the manubrium, first costal cartilage, and clavicle. These articular discs are composed of fibrocartilage, which acts as a shock absorber of forces transmitted along the clavicle from the upper limb.

The discs divide the SC joint into two saddle-shaped surfaces for gliding. The first unit is at the sternal end of the clavicle. This is considered an incongruous joint because not all of the articulating surfaces are in contact. In fact, the superior portion of the medial clavicle serves only as an attachment for the disc and interclavicular ligament and does not contact the sternum at all (Jordan et al., 2012).

The second unit is formed by the manubrium of the sternum and the first costal cartilage. These two saddle-shaped surfaces permit the movement of the clavicle on the disc and of the disc on the sternum. Because this articulation is considered incongruous, stabilization depends on ligaments. The structures providing stability are the articular capsule, SC ligament, interclavicular ligament, costoclavicular ligament, and articular disc (Figure 5-20). A third compartment has been proposed in the costoclavicular area in which midrange movements occur for anterior and posterior rotation (Barbaix, Lapierre, Van Roy, & Clarijs, 2000; Levangie & Norkin, 2011).

Osteokinematics

While the SC joint is an incongruent saddle-shaped (sellar) joint, it acts like a double gliding joint or, as some authors suggest, as a modified ball-and-socket joint (Greene & Roberts, 1999) or as a functional triaxial joint (Donatelli & Wooden, 2010; Kisner & Colby, 2012). As such, this joint can move in all axes with three degrees of freedom. The movements of elevation, depression, protraction, and retraction are described by the movement of the distal segment of the lever (i.e., the movements are visualized as movements of the lateral end of the clavicle; Jordan et al., 2012). In addition, rotation of the clavicle around its own longitudinal axis occurs, but as an accessory motion when the humerus is elevated above 90 degrees and the scapula is upwardly rotated (Kisner & Colby, 2012). Table 5-7 provides a summary of the osteokinematics of the SC joint.

The SC joint is capable of considerable mobility. Motions of the clavicle occur as a result of the scapular movements of elevation, depression (see Figure 5-20), protraction, and retraction (Figure 5-21). The rotation of the clavicle happens as an accessory motion when the humerus is elevated above 90 degrees and there is upward rotation of the scapula. Clavicular elevation occurs between 15 and 45 degrees, depression between 5 and 15 degrees, protraction at 30 degrees, and retraction between 15 and 29 degrees during arm elevation and up to 40 degrees of axial rotation (Houglum & Bertoti, 2012; Inman, Saunders, & Abbot, 1944; Veeger & vanderHelm, 2007).

Elevation and depression occur in the frontal plane around a sagittal (anterior-posterior) axis, which is between the convex clavicle and concave manubrial surface and first costal cartilage. The clavicle moves on the disc as a hinge, and there is superior-inferior gliding between the clavicle and meniscus or disc (Levangie & Norkin, 2011). The axis is oblique through the sternal end of the clavicle and takes a backward and downward course. Due to this orientation, elevation is actually an upward-backward movement, and depression is a movement in a forward-downward direction. The motion of the clavicle is stopped by the first rib. Excessive clavicular elevation is often found in people with shoulder pain (Ludewig & Reynolds, 2009).

Protraction and retraction occur between the articular cartilage, disc, and sternum in a horizontal plane around a nearly vertical (or superior-inferior) axis, which produces an anterior-posterior gliding as the disc moves with the clavicle on the manubrium. The vertical axis lies at the costoclavicular ligament. The ROM for protraction is 0 to 30 degrees, with further movement limited by the posterior SC ligament and costoclavicular ligament. Retraction has a range of 15 to 29 degrees, with the anterior SC ligament restraining further movement (Houglum & Bertoti, 2012; Inman et al., 1944; Ludewig & Borstad, 2011; Veeger & vanderHelm, 2007)

Approximately 30 to 40 degrees of transverse rotation of the scapula on the clavicle occurs in a sagittal plane around the long frontal axis of the clavicle following 90 degrees of

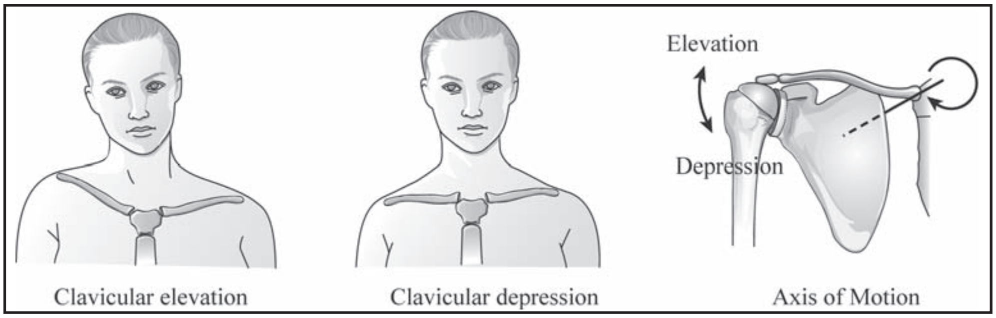


Figure 5-20. Clavicular elevation and depression at the SC joint.

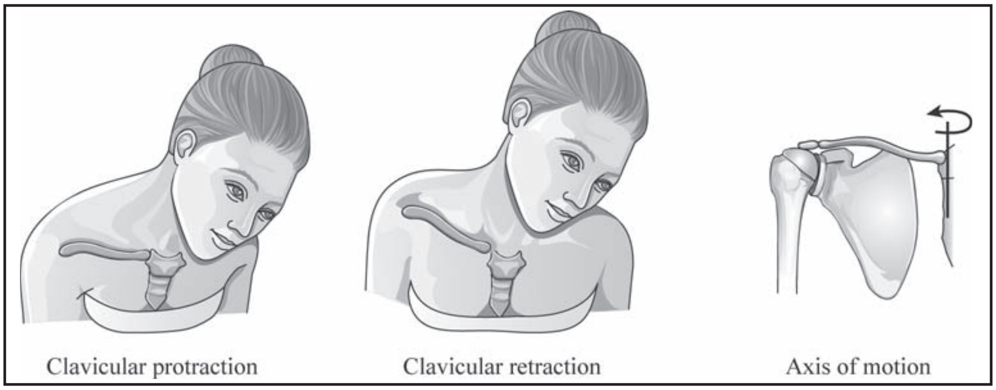


Figure 5-21. Clavicular protraction and retraction at the SC joint.

shoulder flexion or abduction. This motion occurs in a frontal axis as the disc and clavicle roll on the sternum. This rotational element is essential for full flexion or abduction and, should the rotation not occur, only 110 degrees of flexion or abduction would be possible (Houglum & Bertoti, 2012). Upward rotation occurs due to the tightening of the AC ligament (trapezoid and conoid). As the conoid ligament tightens, this becomes the axis for upward rotation of the SC joint. Given the S shape of the clavicle, the acromial end is higher and, therefore, able to further elevate and upwardly rotate the scapula. Posterior rotation is produced by the pull of the coracoclavicular and AC ligament by muscles that move the scapula on the thorax. There are no muscle groups that cross the SC joint that can produce active posterior axial rotation, so the clavicle moves as an intercalated segment (Ludewig et al., 2009).

The close-packed position for the SC joint is with the shoulder in maximum elevation (either abduction or forward flexion), which puts the clavicle in full rotation. The resting position is with the humerus at the side in adduction. Capsular restrictions would be suspected when there is pain at the extreme ends of ROM, especially in horizontal adduction and full humeral elevation.

Arthrokinematics

Given that the medial end of the clavicle is convex top to bottom (superiorly to inferiorly) and concave front to back (anterior to posterior; Figure 5-22) and that the manubrium and first costal cartilages are concave top to bottom and convex front to back, the physiologic motions of the clavicle depend on the direction of slide of the clavicle on the manubrium.

Because there is a convex superior-inferior clavicular surface and concave surface formed by manubrium and first costal cartilage in a frontal plane around a sagittal, anterior-posterior axis and with inferior-superior motion of the clavicle, arthrokinematically, the convex surface of the clavicle must slide on the concave manubrium and first costal cartilage in the direction opposite to movement of the lateral head of the clavicle. In elevation and depression, the medial clavicle glides in a superior-to-inferior direction on the upper attachment of the disc. For example, elevation of the clavicle results in a downward sliding of the medial clavicular surface on manubrium and first costal cartilage (Jordan et al., 2012; Kisner & Colby, 2012).

Conversely, the medial end of the anteroposterior clavicle is concave, and the manubrial side is convex; arthrokinematically, the clavicular surface will now slide on the manubrium and first costal cartilage in the same direction as the lateral end of the clavicle. The movement of these surfaces allows protraction/retraction or horizontal forward/backward motion in a horizontal plane around a vertical axis. In protraction and retraction, the clavicle and disc glide anteroposteriorly on the manubrium as a unit, pivoting around the inferior attachment of the disc. It can be considered that the disc functions as part of the manubrium during elevation and depression and acts as a part of the clavicle during protraction and retraction. For example, protraction of the clavicle is accompanied by anterior sliding of the medial clavicle on the manubrium and first costal cartilage (Jordan et al., 2012; Kisner & Colby, 2012).

Rotation of the scapula around its own axis results in a spin motion. This rotation occurs in one direction only from posterior placement to neutral position, which brings the anterior surface of the clavicle facing toward the front or anteriorly

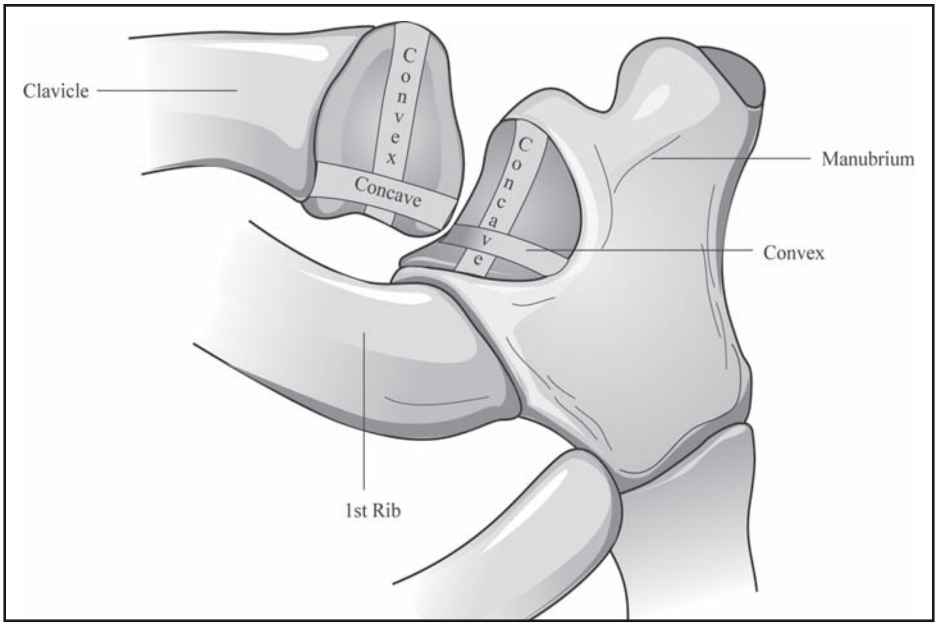


Figure 5-22. Anterior-lateral view of articular surfaces of the right SC joint.

(Houglum & Bertoti, 2012; Jordan et al., 2012). A summary of the arthrokinematics of the SC joint is presented in Table 5-8.

Supporting Structures

Both the SC and AC joints rely primarily on passive restraints (discs, ligaments) as stabilizing structures since there is little intrinsic or bony stability. Because of the changing function of the disc, acting as part of the manubrium during elevation and depression and as part of the clavicle during protraction and retraction, mobility of the joint is maintained and stability is enhanced (Levangie & Norkin, 2011). The SC joint is a bit more protected than the AC due to its more medial location. The bony surfaces are incongruent, adding little intrinsic joint stability. There is also little dynamic stability because there are no muscles crossing the joint (Kisner & Colby, 2012). Tissues that stabilize the SC joint are the anterior and posterior SC ligaments; interclavicular ligament; costoclavicular ligament; articular disc; and sternocleidomastoid, sternothyroid, and sternohyoid muscles (Table 5-9; Neumann, 2010).

The fibrocartilaginous articular disc (or meniscus) increases contact between incongruous joint surfaces. The disc also limits shoulder depression as well as serves as a hinge for motion and as a shock absorber for forces transmitted along the clavicle from the lateral end (Jordan et al., 2012; Levangie and Norkin, 2011; Muscolino, 2006). Due to the attachments of the disc above, below, and to the SC and interclavicular ligaments, the disc also adds strength to the joint and helps to prevent medial displacement of the clavicle and inferior displacement (Jordan et al., 2012). The articular capsule varies in thickness and strength and forms the anterior and posterior SC ligaments. The ligaments and capsule are reinforced by attachment of the sternocleidomastoid muscle.

The anterior and posterior SC ligaments attach the clavicle to the sternum and reinforce the joint capsule (Figure 5-23). Both ligaments resist anterior and posterior translation and superior displacement of the joint (Jordan et al., 2012). The anterior ligament covers the anterior surface of the articulation, while the posterior ligament covers the posterior portion of the joint. This posterior ligament tends to limit rotation of the SC joint during depression of the clavicle and is the strongest supporting structure, preventing upward and lateral displacement of the clavicle.

The interclavicular ligament is a curved ligament that goes from the superior portion of the sternal end of one clavicle to that of the other. Due to the attachment to the superior margin of the sternum, the interclavicular ligament serves to limit shoulder depression or downward glide along with the articular disc, which helps to protect the brachial plexis and subclavian artery (Ludewig & Borstad, 2011). The posterior portion of the interclavicular ligament assists with anterior restraint of the joint because the ligament tightens when the arm is lowered and becomes lax when the arm is elevated (Nordin & Frankel, 2012).

The costoclavicular ligament provides an axis for the movements of elevation and depression and for protraction and retraction. This ligament is attached inferiorly to the first rib and costal cartilage and superiorly to the inferior surface of the medial end of the clavicle. This ligament serves to limit clavicular elevation and superior glide of the clavicle (Ludewig & Borstad, 2011) and is considered the "principal stabilizing structure" (Jordan et al., 2012) of the joint. The costoclavicular ligament assists in restricting upward displacement and downward rotation of the medial clavicle by its attachment to the superomedial part of first rib carriage and to costal tuberosity of the inferior surface of the clavicle. While the costoclavicular and interclavicular ligaments restrain upward and downward movements of the clavicle, they have little effect on anterior or posterior translation (Spencer, Kuhn, Carpenter, & Huges, 2002).

Table 5-8

Arthrokinematics of the Sternoclavicular Joint

Movement of Clavicle on Sternum	Roll	Slide	Resultant Movement
Protraction	Anterior	Anterior	Same
Retraction	Posterior	Posterior	Same
Elevation	Superior	Inferior	Opposite
Depression	Inferior	Superior	Opposite

Adapted from Kisner, C., & Colby, L. A. (2007). *Therapeutic exercise: Foundations and techniques* (5th ed.). Philadelphia, PA: F. A. Davis.

Table 5-9

Supporting Structures of the Sternoclavicular Joint

Articular Disc	• Increases contact surfaces • Shock absorber • Prevents medial displacement of the clavicle
Sternoclavicular Ligaments (Anterior and Posterior)	• Limits rotation of SC joint during depression of clavicle • Resists anterior and posterior translation and superior displacement of the joint • Posterior SC ligament prevents upward and lateral displacement of clavicle
Costoclavicular Ligament	• Limits clavicular elevation and superior glide of the clavicle • Principal stabilizing structure • Restricts downward rotation of medial clavicle
Interclavicular Ligament	• Limits shoulder depression or downward glide with the articular disc • Helps to protect the brachial plexus and subclavian artery

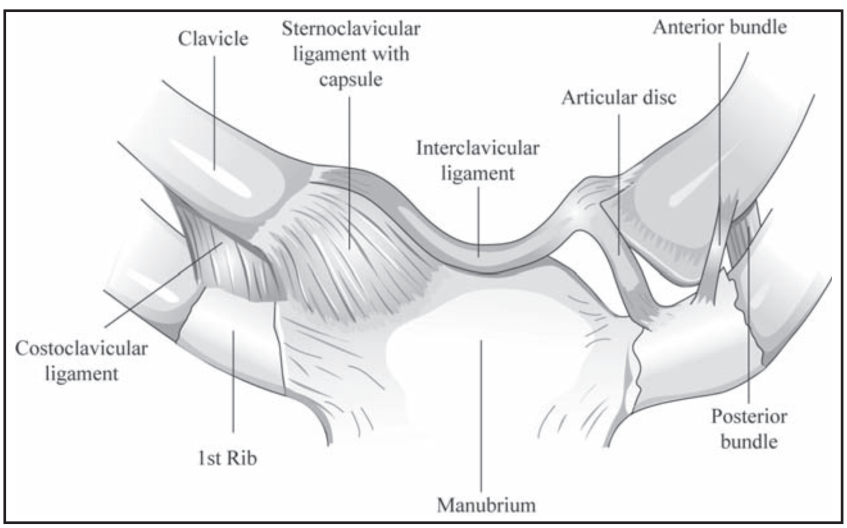


Figure 5-23. Ligaments of the SC joint.

Acromioclavicular Joint

The AC joint is a small joint formed by the articulation of the acromial (lateral) end of the clavicle with the acromion of the scapula. Articular discs may or may not be present at this articulation. Although the AC joint motions are smaller than those at the SC joint, the function of the AC joint is to maintain contact and make small adjustments between the scapula and thorax. There is very little motion between the clavicle and acromion, so fusion of the AC joint would produce little loss of shoulder function (Jordan et al., 2012). At the AC joint, ligaments suspend the scapula from the clavicle. Like the GH joint, the articular capsule is weak and encloses the joint. Due to the size and shapes of articulating bones, this joint is considered incongruent. The AC joint capsule is more lax than the SC joint capsule, and the joint is subject to high loads transmitted from the chest to the upper extremity, so there is greater incidence of dislocation of the AC joint (Donatelli & Wooden, 2010; Nordin & Frankel, 2012).

Movements at the AC joint are movements of the scapula relative to the clavicle in early arm elevation and to allow rotation on the thorax in later stages of elevation (Ludewig & Borstad, 2011). The scapula has five degrees of movement, which include two degrees of translatory motion and three degrees of rotary movement. Figure 5-24 illustrates these five movements.

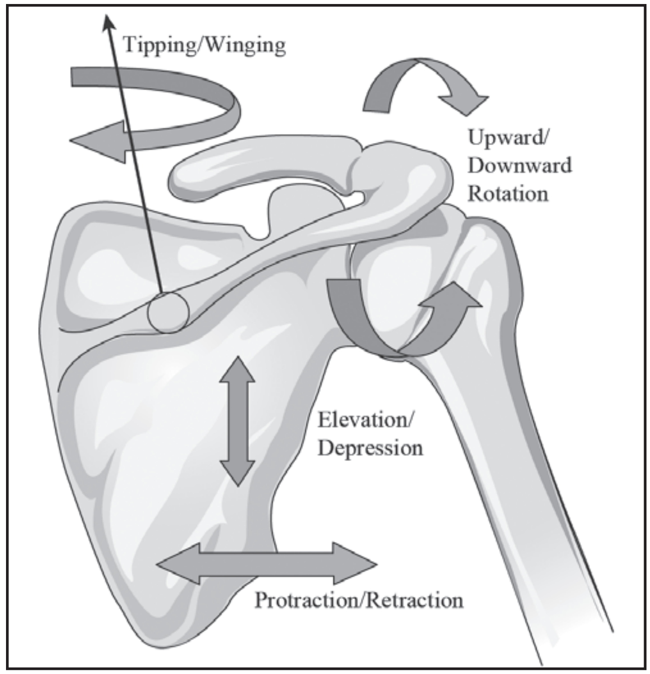


Figure 5-24. Movements of the scapula.

The primary movement of the AC joint is scapular rotation, which occurs in the frontal plane and anteroposterior (sagittal) axis (Figure 5-25). Rotating the scapula allows the glenoid to tilt up (upward rotation of scapula) or down (downward rotation). This motion is synonymous with and identical to the rotational movements that occur at the scapulothoracic joint (Ludewig & Borstad, 2011). The scapula can move an average of 30 degrees in upward rotation and 10 to 30 degrees of lateral and medial and upward/downward tilt at the AC joint. Without motion at the AC joint, the scapula and clavicle would always move as one unit (Muscolino, 2006).

In upward rotation, the scapula moves so that the glenoid cavity faces upward while the inferior angle moves laterally. Depending on the point of reference, the movement can be considered either lateral rotation of the scapula or upward rotation. This motion at the AC occurs during humeral forward flexion and abduction. Similarly, downward rotation moves the scapula so that the glenoid faces inferiorly (downward rotation) and the inferior angle moves medially (medial rotation).

Downward rotation increases the movement of the humerus when it moves on the scapula during shoulder extension and adduction. The trapezoid ligament (part of the coracoclavicular ligament) acts as a hinge for this scapular motion, and the movement occurs due to the tightening of this ligament.

Scapular rotation is described based on the movement of the inferior angle (medial rotation and lateral rotation) or based on movement of the glenoid fossa (upward and downward rotation). The point of reference is essential to accurately describe the movement. Medial rotation is when the inferior angle moves toward the midline, and lateral rotation is when the inferior angle moves away from the midline. Upward and downward rotation allows the glenoid fossa to tilt upward or downward. Upward rotation involves rotating the glenoid cavity while moving the inferior angle laterally and, similarly, downward rotation involves rotating the glenoid cavity downward while the inferior angle moves medially.

Anterior tilting (winging of vertebral border) of the scapula is the movement of the medial border of the scapula away from the chest wall. It occurs in a horizontal plane around a vertical axis. The acromion tilts forward and the inferior angle of the scapula moves away from the thorax. This movement occurs when there is anterior movement of the lateral end of the clavicle (protraction) and occurs naturally; the humerus is placed behind the back with humeral internal rotation and extension (e.g., reach into back pocket). The motion of abduction (protraction) and adduction (retraction) is accomplished by the conoid ligament, which acts as a longitudinal (vertical) axis for scapular rotation (Jordan et al., 2012). Often, the term *winging* refers to a pathological posterior displacement of the vertebral border of the scapula, often attributed to weakness in the serratus anterior muscle and damage to the long thoracic nerve, but this motion occurs in nonpathological joints (Donatelli & Wooden, 2010; Ellenbecker & Ballie, 2010; Magee, 2014). Clients with excessive winging often demonstrate excessive scapular internal rotation relative to the clavicle because the slight external rotation on the thorax during elevation is not offset by the normal internal rotation at the AC joint (Ludewig & Reynolds, 2009).

When there is posterior displacement of the inferior angle of the scapula, this is posterior tilting (tipping of the inferior angle). This motion occurs around a coronal axis, which passes through the AC joint and results in movement of the superior border of the scapula moving anteriorly. The top of the scapula moves posteriorly while the inferior angle moves toward the ribs. Posterior tilting of the scapula occurs when the humerus is elevated during shoulder flexion or abduction (Houglum & Bertoti, 2012). Both anterior and posterior tilting of the scapula function to position the glenoid fossa toward a more anterior or inferior position as well as changing the position of the humeral head.

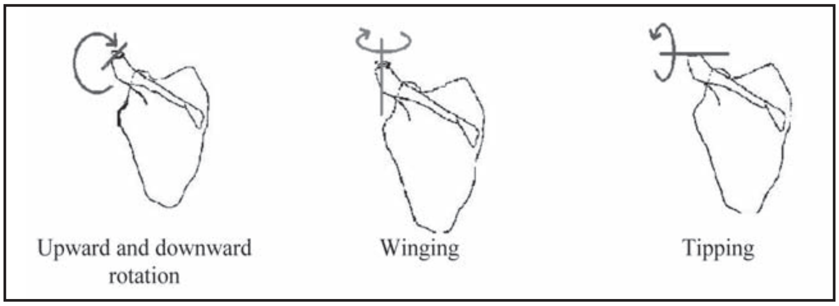


Figure 5-25. Axis of motion at the AC.

Table 5-10

OSTEOKINEMATICS OF THE ACROMIOCLAVICULAR JOINT

FUNCTIONAL JOINT	Diarthrotic, triaxial
STRUCTURAL JOINT	Synovial, plane
CLOSE-PACKED POSITION	Humerus abducted to 90 degrees
RESTING POSITION	Humerus resting by side in normal physiologic position
CAPSULAR PATTERN	Pain at extreme ROM, especially horizontal adduction and full elevation

Medial and lateral tilting (internal and external rotation) also occurs at the AC joint around the vertical axis. In medial tilting, the glenoid fossa faces more anteriorly, and in lateral tilting, the glenoid faces more laterally (Houglum & Bertoti, 2012; Levangie & Norkin, 2011). The scapula tilts medially in early elevation and laterally past 90 degrees (McClure et al., &, 2001; Teece et al., 2008). Medial and lateral tilting ensure that the scapula remains in contact with the thorax and that the glenoid fossa remains congruent with the humeral head (Levangie & Norkin, 2011).

Osteokinematics

The AC joint is a gliding joint with three degrees of freedom in three axes of motion. Movements of this articulation are seen as two different types: (1) a gliding motion of the clavicle and the acromion and (2) rotation of the scapula on the clavicle (Goss, 1976). Because the articulating surfaces of this articulation are small and there are wide individual variations, there are inconsistencies in identifying the movements and axes of motion for this joint (Ludewig & Borstad, 2011). Rotation of the scapula is the primary motion of the AC, with contributions of anterior and posterior tilting, which is 30 to 90 degrees of GH abduction (Hartley, 1995). Sahara, Sugamoto, Murai, and Yoshikawa (2007) determined that, in shoulder abduction, the clavicle retracts 30.6 degrees, elevates 7.3 degrees, and rotates posteriorly 33.2 degrees. The scapula protects 15.6 degrees, upwardly rotates 21.5 degrees, and tilts posteriorly 22.2 degrees in abduction relative to the clavicle (Sahara et al., 2007). A summary of the osteokinematics of the AC joint is shown in Table 5-10.

Arthrokinematics

Movements at the AC joint involve the convex portion on the lateral end of the clavicle and a concave facet on the acromion (Table 5-11). The movements of tilting and rotation of the scapula and the clavicle are in the same direction. For example, if the scapula rotates downward, then the clavicle also rotates in a downward direction. Houglum and Bertoti (2012) note that there is much variability in the convexity and concavity of the joint surfaces and often the surfaces are flat, prohibiting rolling and sliding.

Supporting Structures

The AC joint is primarily stabilized by the AC, coracoacromial, and coracoclavicular ligaments (Table 5-12). The weak joint capsule is reinforced by the superior and inferior AC ligaments that restrict anteroposterior horizontal movements of the joint. The AC ligament is supported by the strong coracoclavicular ligament. While there are no muscles that directly cross this joint, the upper trapezius and deltoid muscles add to the stability of the superior portion of the joint (Neumann, 2010).

The joint is reinforced superiorly by the AC ligament, which acts to restrain axial rotation and posterior translation of the clavicle (Jordan et al., 2012). The AC ligament, directed horizontally, is instrumental in providing horizontal stability. It is palpable as a shallow depression between the end of the clavicle and the acromion. The superior AC ligament is a very important ligament in stabilizing the AC joint for normal activities (Fukuda, Craig, An, Cofield, & Chao, 1986).

The coracoclavicular ligament binds the clavicle to the coronoid process and serves as the suspensory ligament of the upper extremity (Fukuda et al., 1986). It is a vertically directed ligament (Figure 5-26) that is strong but not stiff (Veeger & vanderHelm, 2007). It serves as a link between the scapula and clavicle and connects the coracoid process to the inferior surface of the clavicle. It is the primary stabilizer of the AC joint. The coracoclavicular ligament has two parts: the conoid and trapezoid ligaments.

The conoid ligament is the most important structure, preventing significant injuries and anterior and superior rotation and displacement of the clavicle from the scapula. A triangular-shaped ligament, it runs between the posterior surface of the coracoid and attaches on the conoid tubercle on the posterior clavicle and base of the coracoid. It aids in producing the motions of protraction and retraction by producing posterior rotation of the clavicle.

Table 5-11

ARTHROKINEMATICS OF THE ACROMIOCLAVICULAR JOINT

Movement of Concave Acromion on Convex Clavicle	Movement of Acromion	Movement of Clavicle	Resultant Movement
Upward rotation	Upward	Upward	Same
Downward rotation	Downward	Downward	Same
Winging	Posterior movement of vertebral border	Posterior	Same
Tipping	Anterior movement of superior border	Anterior	Same

Table 5-12

STABILIZING STRUCTURES OF THE ACROMIOCLAVICULAR JOINT

Structure	Amount of Support
Joint capsule	• Weak
Coracoclavicular ligament	• Primary stabilizer of the AC joint as it connects the coracoid process and the clavicle • Controls vertical stability (restrains superior and anterior displacement)
Conoid	• Prevents anterior and superior rotation and displacement
Trapezoid	• Restricts medial displacement of scapula on clavicle • Resists joint compression
AC ligament	• Restricts anteroposterior horizontal movements of the joint • Often first injured when joint stressed

The trapezoid ligament, which is located anterolateral to the conoid ligament, is broad, thin, and quadrilateral in shape. It is located on the inferior surface of the clavicle, and tends to restrict medial displacement of the scapula on the clavicle, and resists joint compression (Fukuda et al., 1986). Of the two parts of the coracoclavicular ligament, this is the larger and stronger of the two. Nordin and Frankel (2012) describe the action of this ligament as “a hinge for scapular motion about a transverse (horizontal) axis in the frontal plane” (p. 231).

The AC joint is very susceptible to injury (i.e., fall on outstretched hand) and degeneration (Muscolino, 2006). When the AC joint is dislocated, it is often due to a torn coracoclavicular ligament. The ligaments together contribute to the horizontal stability of the joint and are critical to preventing superior dislocation of the clavicle on the acromion (Ludewig & Borstad, 2011). Both the conoid and trapezoid ligaments limit scapular rotation, and these ligaments assist in transmission of compression forces from the scapula to the clavicle.

The AC joint is subject to high loads from the chest musculature to the upper extremity (Jordan et al., 2012). AC joint separations are not uncommon, accounting for about 12% of all injuries to the shoulder and often occurring secondary to a fall when the adducted shoulder hits a firm object (Dvir, 2000). In addition to trauma, in older age, degenerative changes occur and the joint space narrows (Houglum & Bertoti, 2012; Levangie & Norkin, 2011).

Scapulothoracic Articulation

The scapulothoracic joint is a physiologic/pseudo/false or functional joint, where the scapula glides on the posterior portion of the thorax to enable greater motion of the scapula. The scapula rests approximately 5 cm from the midline on the posterior thorax with 35 to 45 degrees of internal rotation, 10 to 15 degrees of anterior tilt, and 5 to 10 degrees of upward rotation (Houglum & Bertoti, 2012; Levangie & Norkin, 2011).

Scapulothoracic motion effects GH joint stability and the size of the subacromial space. The joint provides a movable base for the humerus and permits wide ranges of movement with the scapula and thorax, as well as providing stability in the GH joint for overhead activities. Rather than being a bone-to-bone articulation, this is a bone-muscle-bone articulation between the scapula and thoracic wall. The serratus anterior and subscapularis muscles glide on each other (Figure 5-27; Jordan et al., 2012). Because of this articulation, tension in the deltoid muscle can be maintained regardless of the arm position.

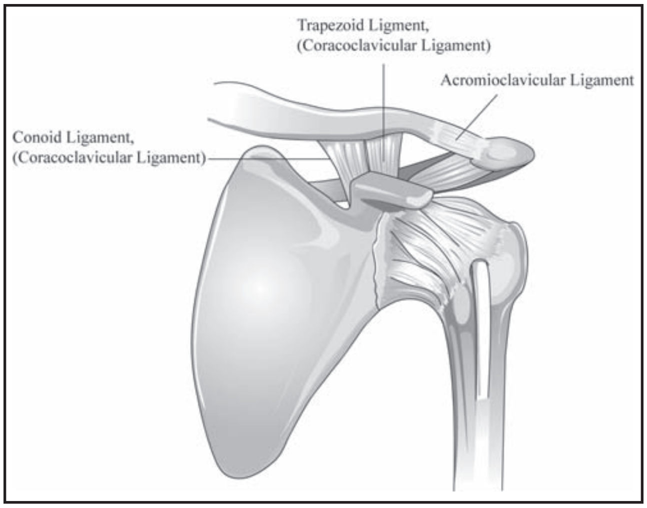


Figure 5-26. Ligaments of the AC joint.

The scapula moves relative to the clavicle at the AC joint, but it must also move relative to the ribs at the scapulothoracic joint. Scapulothoracic motion includes forward elevation in which the scapula rotates, increasing the stability of the GH joint and decreasing the tendency for impingement of the rotator cuff muscles beneath the acromion (Jordan et al., 2012). This functional articulation also acts as shock absorber for forces applied to outstretched hands and permits elevation of the body when crutch walking and during depression transfers.

The scapulothoracic joint is not a true joint and, as such, has no capsular patterns or close-packed position. The resting position is the same as that of the AC joint or with the humerus resting by the side in normal physiologic position (Magee, 2014).

The scapulothoracic joint allows two translatory motions: protraction/retraction and elevation/depression. Other scapular movements of rotation and tilting are secondary and occur in combination with the GH, SC, and AC joints (Muscolino, 2006).

Elevation occurs when the superior border of the scapula and acromion move in an upward direction as when you shrug your shoulders. Depression occurs when the superior border of scapula and acromion move in a downward direction to lower the scapula. Protraction (also considered abduction) is the movement of the scapula away from the midline, whereas retraction (or adduction) is movement of the scapula toward the midline. These motions are the result of SC elevation, protraction, and retraction (Ludewig & Reynolds, 2009).

Scapulothoracic movement motion is a combination of SC and AC joint motions. During elevation of the arm (flexion or abduction), the scapula will upwardly rotate, internally rotate, and posteriorly tilt on the thorax (Ludewig & Reynolds, 2009), with upward rotation the primary motion of the scapulothoracic articulation. The clavicle is in slight elevation and retraction during elevation. As elevation proceeds, the scapula will externally rotate. This video illustrates the movements at the scapulothoracic joint: https://www.youtube.com/watch?v=8VmW9nZDoWI

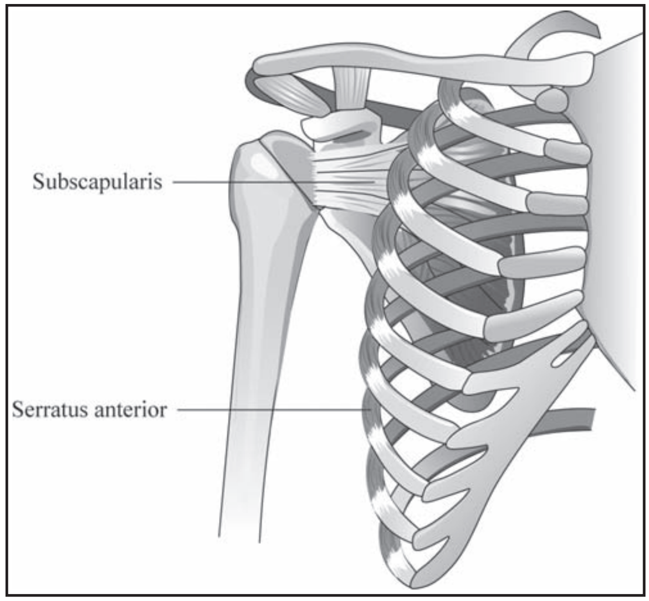


Figure 5-27. Scapulothoracic articulation.

Sternocostal and Vertebrocostal Articulations

The ability to achieve full shoulder flexion and abduction is accomplished by the ribs gliding on both the sternum and vertebrae. This occurs at the sternocostal (costosternal) articulation, where the ribs glide on the sternum, and the vertebrocostal (costovertebral) articulation, where the ribs glide on the vertebrae.

The sternocostal joint is a series of gliding synovial joints with the exception of the first rib, which is fused and is connected to the sternum via cartilage, making this a synarthrodial joint. The vertebrocostal, also a gliding synovial joint, is considered part of the thorax and chest and is the articulation of the head of the rib and two adjacent thoracic vertebra and discs (Levangie & Norkin, 2011). The joints of ribs 1, 10, 11, and 12 are more mobile than other vertebrocostal articulations, and the movements possible at these joints are rotation during depression and elevation and some rotation around its own axis as contributory movements for the total shoulder motion.

Movements at the Shoulder

The shoulder girdle is capable of much mobility due to the integrated, coordinated, and synchronous action of all of the joints acting together. A summary of the movements possible at each joint of the shoulder complex is shown in Table 5-13. Combined movements occurring at the scapula and clavicle during elevation of the arm are shown in this video: https://youtu.be/LF7oST34r4s.

Motion of the scapula relative to the thorax only occurs because of the simultaneous motion at the AC and SC joints (Ludewig et al., 2009). Full ROM of the humerus is also reliant on movement at the scapulothoracic joint, sternocostal, and vertebrocostal articulations.

The contributions of each joint at any time are dependent on the plane and axis of motion, amount of elevation of the humerus, total load applied to the extremity, and individual anatomic variations (Hamill, Knutzen, & Derrick, 2015; Kisner & Colby, 2012). The contributions of the AC and SC joints are that movement at these joints permits movement of the scapula, which places the glenoid fossa facing downward, upward, or forward while the costal surfaces remain close to the thorax for stabilization.

Movement at the scapula occurs because a muscle contracts. Whether the origin or insertion moves depends on which moves easier (Greene & Roberts, 1999). The acceleration of movement is related to its mass according to Newton's Second Law, and "since the scapula is less massive than the entire upper extremity when the GH muscles contract, they move the scapula unless other factors intervene" (Greene & Roberts, 1999, p. 83).

The contributions from these joints allow the synchronous gliding of the scapula, which permits the humerus to move freely in a large arc of motion at the GH joint. Four joint mechanics events must occur simultaneously to produce smooth motion during full arm elevation (Uhl et al., 2009):

1. Posterior rotation of the clavicle at both the AC and SC joints.
2. Depression of the proximal clavicle at the SC joint.
3. The acromion must glide superiorly to the clavicle.
4. The humeral head rolls superiorly and translates.

The coordinated action of the muscles at the various articulations occurs in a smooth way, with varying contributions of different muscles at different joints for different joint motions. The scapulothoracic joint, with the AC and SC joints, contributes to the motions of flexion and abduction of the humerus, which elevates the arm by upwardly rotating the glenoid fossa for a total of 60 degrees from resting position. This relationship of GH contribution to shoulder motion with scapulothoracic, AC, and SC motions is called *scapulohumeral rhythm*. Scapulohumeral rhythm is the movement of the scapula across the thoracic cage in relation to the humerus. The GH joint then moves an additional 120 degrees to give a total ROM for flexion and abduction of 180 degrees (Jordan et al., 2012).

For motion in the sagittal plane at the GH joint, flexion couples with protraction and upward rotation of the scapula at the scapulothoracic joint, while extension is accomplished by GH extension with retraction and downward rotation of the scapula at the scapulothoracic joint. Hyperextension of the arm is accompanied by upward tilt of the scapula at the scapulothoracic joint. Abduction of the GH joint is made possible by upward movement of the arm in a frontal plane and upward rotation of the scapula at the scapulothoracic joint. Internal and external rotation of the GH joint is possible in part due to protraction and retraction at the scapulothoracic joint (Howell et al., 1988).

Levangie and Norkin (2011) identified three purposes of scapulothoracic rhythm. First, distributing motion between two joints permits a large ROM with less compromise of stability than would occur if the same ROM occurred in one joint. Second, maintaining the glenoid fossa in optimal position to receive the head of humerus increases joint congruency while decreasing shear forces. Finally, permitting muscles that act on the humerus to maintain good length-tension relationships minimizes or prevents active insufficiency of GH muscles.

Table 5-13

Movements of the Shoulder Complex

Articulation	Movements Possible
GH	• Flexion/extension • Abduction/adduction • Internal/external rotation
SC	• Elevation/depression • Protraction/retraction • Rotation of clavicle
AC	• Rotation of the scapula • Protraction/abduction • Retraction/adduction • Upward/downward rotation
Scapulothoracic (bone-muscle-bone)	• Elevation/depression • Protraction/retraction • Upward/downward (medial/lateral) rotation • Winging • Tipping
Suprahumeral (functional joint)	• Prevents superior dislocation
Sternocostal (costosternal)	• Slight gliding
Vertebrocostal (costovertebral)	• Slight gliding

Overall, the ratio of the GH contribution to the scapulothoracic is 2:1 (i.e., if there are 15 degrees of motion, 10 degrees are due to the GH joint, and 5 degrees are due to the scapulothoracic articulations; Ludewig et al., 2009). This relationship is shown in Figure 5-28, where 30 degrees of joint elevation occurs at the SC joint and 30 degrees of upward rotation occurs at the AC joint, for a total of 60 degrees of combined scapulothoracic joint movement. There are also 120 degrees of humeral abduction for a total ROM for normal shoulder abduction of 180 degrees. The 60 degrees scapulothoracic and 120 degrees GH motions demonstrate the 2:1 ratio. Scapulohumeral rhythm can be compromised by anything that changes the position of the scapula such as muscle imbalance and pain.

This ratio has been debated, with some authors stating the ratio is 3:2, while others state the ratio is closer to 5:4 (Houglum & Bertoti, 2012; Jordan et al., 2012; Ludewig & Borstad, 2011; Poppen & Walker, 1976; Scibek & Carcia, 2012). Some of the differences are due to the measurement of abduction (measured in the plane of the scapula vs. the frontal plane, which yields different values for ROM) and some are due to the fact that each joint contributes differently to the motion depending on when in the arc of motion the measurement is

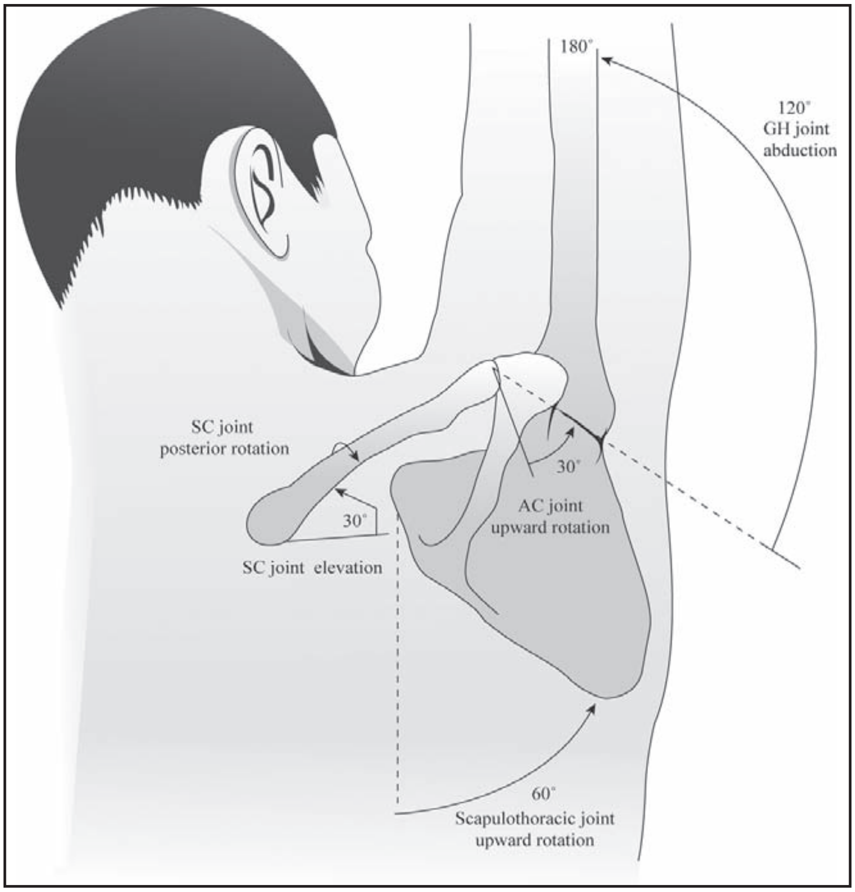


Figure 5-28. Scapulothoracic rhythm.

taken. Ludewig and colleagues (2009) found that, while the overall scapulohumeral rhythm for abduction was 2:1:1, for flexion, it was 2:4:1, and for scapular plane abduction, it was 2:2:1.

Not only do the GH and scapulothoracic joints contribute differently, but so do the SC and AC joints. For flexion and abduction of the humerus, of the 60 degrees contributed by the SC and AC joints, 65% of the motion was due to the SC joint and 35% was due to the AC joint, although the amount of contribution of these joints is also disputed (Hamill et al., 2015; Houglum & Bertoti, 2012). It is important to realize, too, that these synchronous and coordinated movements occur concomitantly and not sequentially, which produces smooth movements.

Combined movements of the SC and AC joints result in specific movements at each of the joints. At the AC joint, which relates to motion of the scapula relative to the clavicle, as the arm elevates overhead, the scapula internally and upwardly rotates with a posterior tilt relative to the clavicle. The scapula is more internally rotated relative to the clavicle in flexion than in either abduction or scapular plane abduction (Ludewig et al., 2009). For scapulothoracic joint movement, defined as motion of the scapula relative to the thorax, during elevation of the arm, there is decreased internal rotation of the scapula and increased posterior scapular tilt relative to the thorax (Ludewig et al., 2009). Motion at the SC joint is reciprocal with the AC for protraction and retraction and elevation/depression; however, this reciprocity is not true for rotational movement. For example, if the clavicle moves up at the medial end, it moves down at the lateral end.

The muscles of the scapula act in synchrony so that the scapulohumeral muscles can maintain effective length-tension relationships as they function to stabilize and move the humerus (Kisner & Colby, 2012). Tables 5-14 and 5-15 summarize motions produced at each joint, the plane and axis of motion, normal limiting factors to joint movement, normal end feel, and primary muscles producing movement at each joint for the scapula and GH joints.

The coordinated actions can be visualized by separating humeral flexion and abduction into different phases (Cailliet, 1980; Ebaugh & Spinelli, 2010; Ebaugh, McClure & Karduna, 2005; Hamill et al., 2015; Houglum & Bertoti, 2012; Inman et al., 1944; Ludewig & Borstad, 2011; Ludewig et al., 2009; Magee, 2014; Muscolino, 2006). Table 5-16 summarizes the four phases of abduction.

With the arm held at the side in full adduction, there is no GH elevation, no scapular rotation, and no clavicular elevation or rotation. The superior GH ligament and anterior and posterior capsule are limiting external rotation while abducting (Magee, 2014). Between 0 to 30 degrees of abduction (45 to 60 degrees flexion), the pull of the deltoid produces an upward force on the humeral head. The subscapularis, infraspinatus, and teres minor counteract this by providing a depressive force on the humeral head in the glenoid fossa. The subscapularis provides an anteriorly directed force, while the infraspinatus and teres minor provide posterior forces. Because these muscles

Table 5-14

Scapular Movements

Motion	Joint	Plane/Axis	Normal Limiting Factors (Tension in)	End Feel	Primary Muscles
Elevation	• AC • SC • Scapulothoracic	• Frontal/sagittal	• Costoclavicular ligament • Inferior SC joint capsule • Trapezius • Pectoralis major • Subclavius	• Firm	• Upper trapezius • Levator scapulae • Rhomboids
Depression	• AC • SC • Scapulothoracic	• Frontal/sagittal	• Interclavicular ligament • SC ligament • Articular disc • Trapezius • Levator scapulae • Bony contact between first rib and clavicle	• Firm/hard	• Pectoralis minor • Lower trapezius (pectoralis major) • Latissimus dorsi (these act on the humerus)
Protraction	• AC • SC • Scapulothoracic	• Horizontal/vertical	• Trapezoid ligament • Posterior SC ligament • Posterior costoclavicular ligament • Trapezius • Rhomboids	• Firm	• Serratus anterior • Pectoralis minor • Pectoralis major
Retraction	• AC • SC • Scapulothoracic	• Horizontal/vertical	• Conoid ligament • Anterior costoclavicular ligament • Anterior SC ligament • Pectoralis minor • Serratus anterior	• Firm	• Trapezius • Rhomboids
Upward rotation (lateral rotation)	• AC • SC • Scapulothoracic	• Frontal/sagittal	• Trapezoid ligament • Rhomboids • Levator scapulae	• Firm	• Middle trapezius • Serratus anterior
Downward rotation (medial rotation)	• AC • SC • Scapulothoracic	• Frontal/sagittal	• Conoid ligament • Serratus anterior	• Firm	• Levator scapulae • Rhomboids

Table 5-15

Glenohumeral Movements

Motion	Joint	Plane/Axis	Normal Limiting Factors (Tension In)	End Feel	Primary Muscles	Normative ROM/ Functional ROM (In Degrees)
Abduction	• GH • AC • SC • Scapulothoracic • Suprahumeral	• Frontal/sagittal	• Middle and inferior bands of GH ligament • Inferior joint capsule • Shoulder adductors • Greater tuberosity of humerus contacting upper portion of glenoid and glenoid labrum or lateral surface of the acromion • Scapular movement limited by ∘ Rhomboids ∘ Levator scapulae ∘ Trapezoid ligament	• Firm • Hard	• Middle fibers of deltoid • Supraspinatus • Infraspinatus • Subscapularis • Teres minor • Biceps (long head)	• 0 to 80/0 to 120
Adduction	• GH	• Frontal/sagittal	• Conoid ligament • Anterior costoclavicular ligament • Posterior SC ligament • Pectoralis major • Serratus anterior	• Firm	• Trapezius • Rhomboid	• 180 to 0/120 to 0
External (lateral rotation)	• GH	• Horizontal/ vertical	• GH ligament • Coracohumeral ligament • Anterior joint capsule • Subscapularis • Pectoralis major • Teres major • Latissimus dorsi	• Firm	• Infraspinatus • Teres minor • Deltoid (posterior)	• 0 to 90/0 to 60
Internal (medial) rotation	• GH	• Horizontal/ vertical	• Posterior joint capsule • Infraspinatus • Teres minor	• Firm	• Subscapularis • Latissimus dorsi • Teres major • Deltoid (anterior)	• 0 to 70/0 to 70

(continued)

Table 5-15 (continued)

Glenohumeral Movements

Motion	Joint	Plane/Axis	Normal Limiting Factors (Tension In)	End Feel	Primary Muscles	Normative ROM/ Functional ROM (In Degrees)

Flexion	• GH
	• AC
	• SC
	• Scapulothoracic
		• Sagittal/frontal	• Posterior band of coracohumeral ligament
			• Posterior joint capsule
			• Shoulder extensors
			• Scapular movement limited by
			  ◦ Rhomboids
			  ◦ Levator scapulae
			  ◦ Trapezoid ligament
				• Firm	• Deltoid (anterior)
					• Pectoralis major (clavicular part)
					• Biceps brachii
					• Coracobrachialis
						• 0 to 180/0 to 125

Extension	• GH	• Sagittal/frontal	• Anterior band of coracohumeral ligament • Anterior joint capsule • Pectoralis major (clavicular fibers)	• Firm	• Deltoid (posterior) • Latissimus dorsi • Teres major • Triceps (long head)	• 0 to 60/60 to 0
Horizontal abduction	• GH	• Horizontal/ vertical	• Anterior joint capsule • GH ligament • Pectoralis major	• Firm	• Deltoid (posterior) • Teres major • Teres minor • Infraspinatus	• 0 to 90/0 to 90
Horizontal adduction	• GH	• Horizontal/ vertical	• Posterior joint capsule • Soft tissue apposition	• Firm/ soft	• Pectoralis major • Deltoid (anterior)	• 0 to 45/0 to 45

Adapted from Gutman, S. A., & Schonfeld, A. B. (2003). *Screening adult neurological populations*. Bethesda, MD: American Occupational Therapy Association Press; Magee, D. J. (2002). *Orthopedic physical assessment*. Philadelphia, PA: Saunders; and Roy, J. S., MacDermid, J. C., Boyd, K. U., Faber, K. J., Drosdowech, D., & Athwal, G. S. (2009). Rotational strength, range of motion, and function in people with unaffected shoulders from various stages of life. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology*, *1*(4), 1-7.

Table 5-16

Phases of Abduction of the Shoulder

Phase	Glenohumeral Joint	Scapular Movement	Clavicular Movement	Scapulothoracic Joint	Sternoclavicular Joint
1	• No abduction		• No elevation	• 0 degrees scapular rotation	• 0 degrees of movement • No elevation of the clavicle
2	• 0 to 30 degrees abduction	• Protraction (abduction) • Elevated • Upward rotation • Posterior tilt • Internal rotation (Teece et al., 2008)	• Outer end elevated 12 to 15 degrees • Posterior rotation, protraction	• Tilting of scapula • 30 degrees upward rotation	• Movement produces elevation
3	• 30 to 90 degrees abduction (60 degrees GH; 30 degrees ScT)	• External rotation required >90	• 15 to 30 degrees elevation • 35 to 40 degrees posterior rotation of clavicle (Ludewig et al., 2009; McClure et al., 2001)	• 0 to 30 degrees scapular rotation	• 5 degrees elevation
4	• 90 to 180 degrees abduction (120 degrees GH; 60 degrees ScT)	• Posterior tilt of 20 to 30 degrees • 150 degrees elevation • Trunk movement for final 30 degrees elevation	• 30 to 50 degrees posterior clavicular rotation	• Coracoid depresses • Lateral tilt	• Posterior rotation • Protraction

ScT = scapulothoracic joint.

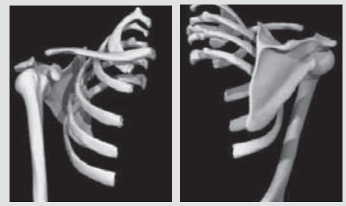
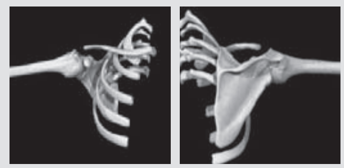
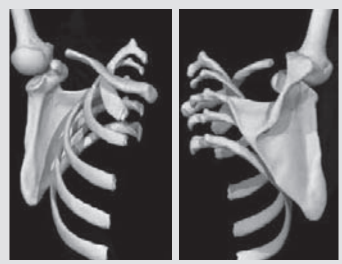
Adapted from Ebaugh, D. D., & Spinelli, B. A. (2010). Scapulothoracic motion and muscle activity during the raising and lowering phases of an overhead reaching task. *Journal of Electromyography and Kinesiology, 20*(2), 199-205. doi:http://dx.doi.org/10.1016/j.jelekin.2009.04.001; Hamill, J., Knutzen, K. M., & Derrick, T. R. (2015). *Biomechanical basis of human movement (4th ed.).* Philadelphia, PA: Wolters Kluwer; Inman, V. T., Saunders, J. B. D. M., & Abbot, L. C. (1944). Observations on the function of the shoulder joint. *Journal of Bone and Joint Surgery, 26*, 1-30; Levangie, P. K., & Norkin, C. C. (2011). *Joint structure and function: A comprehensive analysis* (5th ed.). Philadelphia, PA: F. A. Davis; Ludewig, P. M., Phadke, V., Braman, J. P., Hassett, D. R., Cieminski, C. J., & LaPrade, R. F. (2009). Motion of shoulder complex during multiplanar humeral elevation. *Journal of Bone and Joint Surgery, 91*, 378-389. doi:10.2106/JBJS.G.01483.

have approximately the same cross-sectional area, the forces are balanced and can resist both anterior and posterior translation of the humeral head.

During this phase, the scapula moves toward or away from the vertebral column in order to find a position of stability on the thorax (Hamill et al., 2015; Levangie & Norkin, 2011). During this early phase of elevation and upward rotation, the scapula and clavicle move together around an oblique axis near the spine of the scapula and through the SC joint. A force couple is formed by the upper and lower trapezius muscles and the serratus anterior muscle, which produces movement at the SC and AC joints (Ludewig & Borstad, 2011). The upper and lower trapezius and the upper and lower serratus anterior apply a rotary force on the scapula at the SC joint, but further

Table 5-16

Phases of Abduction of the Shoulder

Acromioclavicular Joint	**Normal Limiting Factors**	**Anterior/Posterior Views of Structures During Abduction**
• 0 degrees • Spinoclavicular angle	• Superior GH ligament • Anterior/posterior capsule	
• Angle increases • 0 to 10 degrees	• Coracohumeral ligament • Superior GH ligament • Anterior/posterior capsule	
• No change in spinoclavicular angle or movement	• 45 to 60 degrees • Middle GH ligament • Coracohumeral ligament • Inferior GH ligament • Anterior/posterior capsule • 60 to 90 degrees • Inferior GH ligament • Anterior/posterior capsule	
• Spinoclavicular angle increased to 20 degrees • Maximal posterior tilt of 20 degrees, anterior tilt of 40 degrees • 25 degrees upward rotation	• Inferior GH ligament • Anterior/posterior capsule	

Adapted from (continued) Magee, D. J. (2014). *Orthopedic physical assessment* (6th ed.). St. Louis, MO: Elsevier; McClure, P. W., Michener, L. A., Sennett, B. J., & Karduna, A. R. (2001). Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *Journal of Shoulder and Elbow Surgery, 10*(3), 269-277; Sahara, W., Sugamoto, K., Murai, M., & Yoshikawa, H. (2007). Three-dimensional clavicular and acromioclavicular rotations during arm abduction using vertically open MRI. *Journal of Orthopaedic Research, 25*(9), 1243-1249; and Teece, R. M., Lunden, J. B., Lloyd, A. S., Kaiser, A. P., Cieminski, C. J., & Ludewig, P. M. (2008). Three-dimensional acromioclavicular joint motions during elevation of the arm. *Journal of Orthopaedic & Sports Physical Therapy, 38*(4), 181-190. doi:org/10.2519/jospt.2008.2386.

movement is prevented by the coracohumeral ligament, superior GH ligament, and posterior and anterior portions of the joint capsule (Hamill et al., 2015; Houglum & Bertoti, 2012).

The movements that occur at the AC are 0 to 10 degrees of an increase in the spinoclavicular angle (from the spine of the scapula to the clavicle), but there is minimal movement due to the influence of the coracoclavicular ligament. Movement at the scapulothoracic joint includes about 10 degrees of tilting of the scapula, which maintains the scapula against the ribs, and about 30 degrees of upward rotation. The outer end of the clavicle is elevated 5 to 10 degrees, indicative of superior movement of the scapula and likely posterior tilt due to the taut coracoclavicular ligament, but there is little clavicular rotation.

Structures limiting abduction movement from 0 to 45 degrees include the coracohumeral ligament, superior GH ligament, and anterior joint capsule for external rotation; middle GH ligament, posterior capsule, subscapularis, infraspinatus, and teres minor for neutral position; and posterior capsule for internal rotation.

In phase 3, the humerus moves an additional 60 degrees, so the total amount of abduction is 90 degrees. Of this 90 degrees, 60 degrees of motion are due to movement at the GH joint and 30 degrees are due to scapulothoracic contributions. At 90 degrees of humeral elevation, external rotation produces scapular movement. There is posterior tilt and upward rotation. The scapula will move laterally, anteriorly, or superiorly during movements of upward rotation, protraction (abduction), and elevation. The upward rotary force created by the serratus anterior and trapezius muscles continues, and this produces movement at the SC joint, which forces the clavicle to elevate 5 degrees and posteriorly rotate 35 degrees. Because the clavicle is attached to the scapula, elevation of the clavicle produces elevation of the scapula as it is carried through 30 degrees of upward rotation. Further elevation of the clavicle is prevented when the coracoclavicular ligament becomes taut (Levangie & Norkin, 2011). No further elevation at the SC joint and upward rotation at the AC is now possible. There is no increase in the spinoclavicular angle.

Maximal ROM for abduction requires external rotation of the humerus for the greater tubercle of the humerus to clear the coracoacromial arch once the arm is elevated above the horizontal. If there is weakness or inadequate external rotation, there will be impingement of soft tissues in the suprahumeral space, causing pain, inflammation, and loss of function (Kisner & Colby, 2012). Once the humerus is externally rotated, an additional 30 degrees of abduction is possible.

Similarly, internal rotation of the humerus is required to achieve full elevation through flexion, and this rotation occurs at 50 degrees of passive shoulder rotation. Because most of the shoulder flexor muscles are also medial rotators, as the arm elevates above horizontal in the sagittal plane, the anterior capsule and ligaments get taut, causing the humerus to medially rotate (Kisner & Colby, 2012).

Structures limiting movement between 45 and 60 degrees of abduction are the middle GH ligament, coracohumeral ligament, inferior GH (anterior band), and anterior joint capsule (Magee, 2014). Additional structures limiting movement at this range are the middle GH ligament, inferior GH ligament (anterior portion), subscapularis, infraspinatus, and teres minor for neutral rotation during abduction; the inferior GH ligament (posterior band) and posterior joint capsule limit internal rotation during abduction at this range. At 60 to 90 degrees of abduction, the following structures limit abduction: the inferior GH ligament and anterior capsule limit external rotation; the inferior GH ligament (posterior portion) and middle GH ligament limit neutral rotation; and the inferior GH ligament (posterior band) and posterior joint capsule limit internal rotation (Magee, 2014).

Phase 4 completes the abduction range to 180 degrees, with the GH joint providing 120 degrees of the total and the scapulothoracic joints contributing 60 degrees. The coracoid process of the scapula is pulled down, tugging on the coracoclavicular ligament. Of the 60 degrees of scapular contribution, 20 degrees of motion occurs at the AC joint and 40 degrees at the SC joint (Ludewig et al., 2009; McClure et al., 2001).

Thirty to 40 degrees of clavicular rotation occurs around the longitudinal axis, which elevates the lateral end of the clavicle without additional elevation of the SC joint. Because the lateral end of the clavicle is elevated, the scapula will be carried through an additional 20 degrees of upward rotation around an anteroposterior axis through the AC joint, where the scapula will reach the maximum of 20 degrees of posterior tilt and 40 degrees of anterior tilt. Given that 180 degrees is considered the maximum ROM for humeral abduction and flexion (some sources say 170 degrees, with the additional 10 degrees due to trunk movement), horizontally, 60 degrees of GH and 30 degrees of scapulothoracic motion occurs, with scapular movement due to clavicular elevation at the SC joint. Horizontally to vertically, an additional 60 degrees of GH motion is produced (plus medial rotation in the sagittal plane for flexion and lateral rotation for abduction in the frontal plane), and 30 degrees of scapular movement is produced due to clavicular rotation and AC joint motion (Levangie & Norkin, 2011).

The final elevation from 90 to 180 degrees is due to the infraspinatus and teres minor, with the subscapularis preventing impingement during external rotation (Hess, 2000). With continued elevation, by 90 degrees of elevation, the compression forces are maximal so the joint is stable (Hess, 2000). The axis of motion is now at the AC joint because tension in the costoclavicular ligament prevents further elevation of the clavicle at the SC joint, and the serratus anterior and lower trapezius continue to produce upward rotation moments. The inferior GH ligament (anterior band) and anterior joint capsule limit external rotation during abduction at this range. The inferior GH ligament limits movement in both neutral and internal rotation during abduction at this range, and the posterior capsule also prevents further internal rotation (Magee, 2014) in this 90- to 180-degree range of abduction.

Internal Kinetics: Muscles

During hand use, there are large forces that occur in the shoulder because the resistance arm of the lever that is formed can be as long as 2 feet when using a tool, but the force arms of the muscles are measured in inches (Smith et al., 1996). The shoulder muscle is typified as being relatively small with large moment arms (Veeger & vanderHelm, 2007). The physiologic cross-section of the serratus anterior is much smaller than the deltoid, but the moment arm around the SC joint is much larger than moment arms crossing the knee or ankle (Veeger & vanderHelm, 2007). The scapula helps to provide the large moment arms for the scapulothoracic muscles; erratus anterior for elevation; trapezius for elevating the clavicle to allow rotation of the scapula; adduction via the pectoralis and latissimus dorsi muscles to direct forces to the thorax; gravitational forces that will lift the scapula from the thorax; and serratus anterior and rhomboids that press the scapula on the thorax to provide a stable base (Veeger & vanderHelm, 2007).

Calculating the reaction forces of the shoulder is challenging because of the large number of muscles, and the force contribution of each muscle varies with differing loads, planes of shoulder elevation, and degrees of elevation (Jordan et al., 2012). Smith and colleagues (1996) indicate that the greatest strength of the shoulder muscles occurs when the muscles contract in an elongated position and torque decreases as the muscles shorten. They add that favorable length-tension relationships over such a large ROM are accomplished by movement of the base of support of the humerus by the scapula and by changes in muscle lever arms. For example, lever arm lengths for the deltoid increased with the motion of abduction: the middle deltoid almost doubled its leverage, and the anterior deltoid increased leverage by eight times (Smith et al., 1996). Forces in the shoulder joint at 90 degrees of abduction have been shown to be close to 90% of body weight, whereas the forces are diminished to half of that if the forearm flexes to 90 degrees at the elbow (Hamill et al., 2015).

The greatest strength output in the shoulder muscles occurs in adduction due to the latissimus dorsi, teres major, and pectoralis muscles acting as major contributors. The strength of adduction is twice that of abductor strength even though abduction is used more frequently in activities of daily living (ADL) or sports (Hamill et al., 2015).

Extension is the next strongest action because muscles of extension involve the same muscle as adduction. Extension is seen as slightly stronger than flexion. The weakest muscles of the shoulder are the rotators. The muscles of external rotation are weaker than the muscles of internal rotation. The motions of internal and external rotation are most influenced by arm position, with the greatest internal rotation occurring in neutral and the greatest external rotation in 90 degrees of flexion (Hamill et al., 2015; Kibler & McMullen, 2003). Rotator cuff muscles as a group can generate forces of 9.6 times the weight of the limb. Because each arm weighs 7% of body weight, the rotator cuff muscles can generate forces in the shoulder joint of approximately 70% of body weight.

The location of the muscle in relation to the joint axis will also determine the direction of the force. For example, the anterior deltoid, pectoralis major, coracobrachialis, and biceps all cross the GH joint anteriorly and function to flex the joint. Similarly, the posterior deltoid, latissimus dorsi, teres major, and long head of the triceps cross the GH joint posteriorly and aid in extension. Muscles that abduct (deltoid, supraspinatus) cross superiorly to the joint axis, and muscles that adduct (pectoralis major, latissimus dorsi, and teres major) cross below the center of the joint (Muscolino, 2006).

While it is generally true that one can infer the action of a muscle given knowledge of origin and insertion, this is not always the case in shoulder muscles.

> For example, when the arm is at the side, contraction of the fibers of the middle portion of the deltoid lifts the humerus along its axis but does not produce the motion of elevation because the line of action of the middle deltoid fibers is essentially parallel to the long axis of the humerus and if "coupled" with other muscles, elevation can occur. (Nordin & Frankel, 1989, p. 239)

This is due to the unusual characteristics of shoulder muscles.

Nordin and Frankel (1989) indicate that muscle actions at the shoulder have three unusual aspects:

1. Because the GH joint lacks rigid stability, muscles exerting an effect on the humerus must act in concert with other muscles to avoid producing a dislocating force on the joint.
2. The existence of multiple linkages in the shoulder (clavicle, humerus, and scapula) gives rise to an interesting situation in which a single muscle may span several joints, exerting an effect on each.
3. The extensive range of shoulder motion causes muscle function to vary depending on the position of the arm in space.

The large numbers of muscles at the shoulder joint produce large moment arms that develop force dependent on the load applied to the muscle, the plane of motion, and the amount of elevation. The position of the arm in space determines the force produced and which muscles generate the force. An additional unique feature of the shoulder muscles is the large number of force couples that act to provide both stabilizing forces as well as movement.

The integrated muscular activity of the shoulder ensures that the force generated at one muscle requires antagonistic (and usually eccentric contraction) activation so that dislocation does not occur or the neutralizing force of a force couple is produced (Jordan et al., 2012). The actions of many muscles working alone or in combination produce movement and stability of the shoulder. By knowing the angle of muscle pull, length and cross-section, type of muscle fiber, and location of the muscle in relation to the joint axis, one can tell much about the action and strength of that muscle.

The following discussion about muscles acting on the shoulder girdle is organized according to the movement that occurs at the joint. Directions for muscle palpation are included the first time the muscle is mentioned.

Elevators of the Scapula

Elevators of the scapula attach from the scapula to a superior structure, and these are considered scapulothoracic muscles and include the trapezius, levator scapula, and rhomboid muscles (Figure 5-29).

Upper Trapezius

Because the upper trapezius attaches on the base of the skull and clavicle, these fibers will pull upward on the clavicle when it contracts. The resolution of the line of pull force on the clavicle is transferred to the scapula via the AC to elevate the scapula (Gench et al., 1995). The upper trapezius is seen as solely responsible for elevating the lateral angle of the scapula (Jenkins, 1998). Isolated weakness is unusual for the upper trapezius muscle but could result in a position of increased scapular depression (Magee, 2014). Muscle tightness can occur in an elevated shoulder or asymmetrical head position, with restricted head and neck ROM, and is likely to be accompanied by upward rotation of the scapula (Figure 5-30; Oatis, 2004).

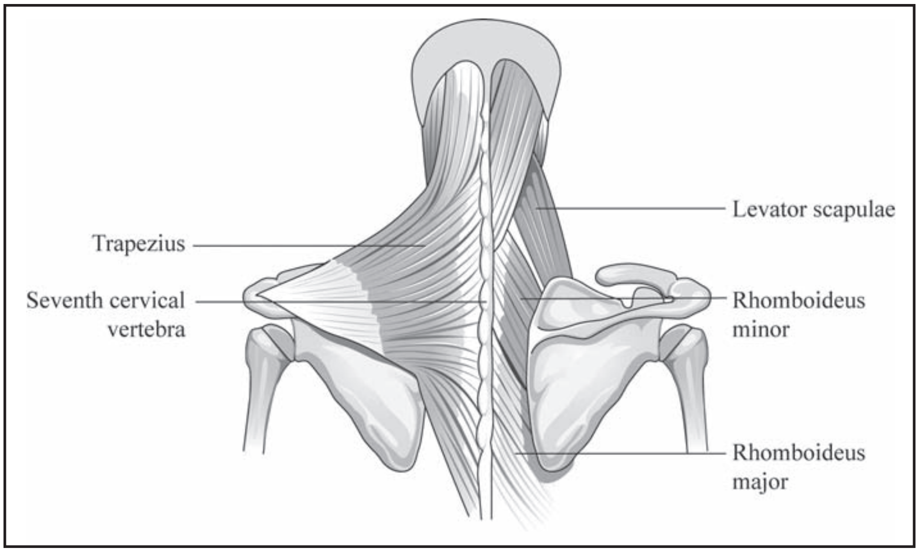


Figure 5-29. Muscles that elevate the scapula.

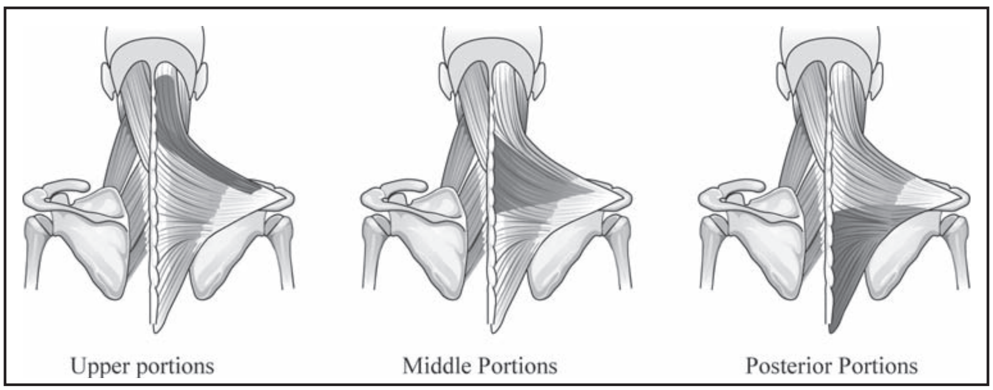


Figure 5-30. Trapezius muscle.

The trapezius is a superficial muscle of the neck and upper back, often called the *shawl muscle*. The upper fibers lie along the posterior neck, and by grasping the superficial tissue on the top of the shoulder, you can feel the thin upper trapezius muscle fibers. Follow the fibers to the lateral clavicle as you ask your subject to extend the neck.

Upper/Lower Trapezius and Serratus Anterior

The upper portions of these muscles form a force couple that moves the scapula during elevation. These muscles, with the levator scapula, support the shoulder girdle against the pull of gravity and act as stabilizing synergists for deltoid action working on the GH joint. This force couple is antagonistic to scapular movement and synergistic to GH moment, where the trapezius and serratus anterior produce scapular upward rotation while preventing undesired motion of the deltoid as it elevates the GH joint (Houglum & Bertoti, 2012; Jordan et al., 2012). An imbalance of muscle forces between the upper and lower trapezius may result in poor posture, with the upper trapezius being more dominant.

Levator Scapula

When the diagonal line of pull of the muscle is resolved into mobilizing and stabilizing forces, there is a long vertical component and a relatively short horizontal component. The long vertical component enables the levator scapula to be an elevator of the scapula (Figure 5-31; Gench et al., 1995).

The levator scapula is covered by the upper trapezius and sternocleidomastoid muscles; in elevation of the shoulder girdle, the upper trapezius and levator contract together. It is difficult to isolate and palpate this muscle. By placing the forearm behind you in the small of your back and then shrugging the shoulder, you will feel this muscle when you palpate in the neck region anterior to the trapezius but posterior to the sternocleidomastoid (Esch, 1989; Lumley, 1990; Magee, 2014).

An alternative method for palpation is to have the subject prone, supine, or in side-lying. Locate the upper fibers of the trapezius, move anteriorly off of the trapezius, and strum your fingers anteriorly and posteriorly across the levator fibers. Follow these fibers toward the lateral neck and inferiorly under the trapezius (Biel, 2016).

With weakness of the levator scapulae, rhomboid major, and rhomboid minor, pulling actions would be affected, and a posture of rounded shoulders may result (Oatis, 2004). Muscle

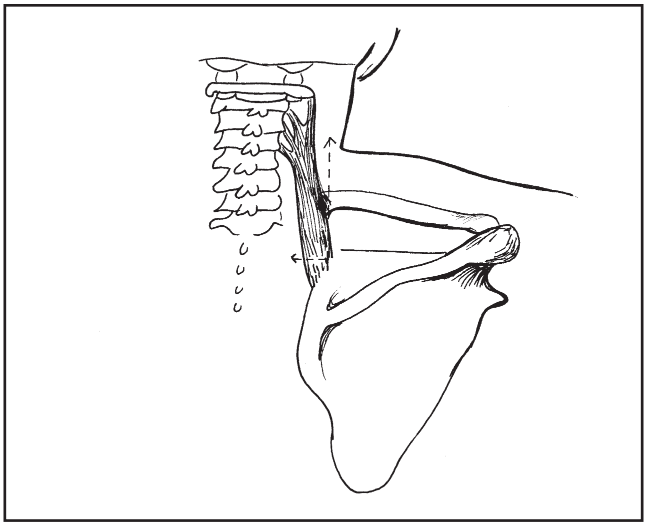


Figure 5-31. Levator scapula muscle.

tightness does produce a rounded shoulder posture with elevation, adduction, and downward rotation, causing the scapula to tilt anteriorly.

Rhomboids (Minor and Major)

These two muscles actually function as one muscle. There is a diagonal pull of the muscle that yields both elevation and adduction actions, but the muscle acts only on the medial border of the scapula (Jenkins, 1998). The rhomboids' downward rotation of the scapula offsets the undesired force of the teres major and contributes to depression of the shoulder. The rhomboids (major and minor) connect the scapula with the vertebral column, and they lie under the trapezius. The upper portion of the muscle is the rhomboid minor, while the lower portion is the rhomboid major.

These muscles can best be palpated when the trapezius is relaxed. Have a subject place his or her hand at the small of the back. The therapist then places fingers under the medial border of the scapula. If the subject raises his or her hand just off the small of the back, the rhomboid major contracts as downward rotator and pushes the fingers out from the medial border.

Depressors of the Scapula

Muscles that depress the scapula attach from the scapula to a structure located more inferiorly. The muscles responsible for depression of the scapula include the trapezius, pectoralis minor, subclavius, pectoralis major (sternal portion), and latissimus dorsi. These muscles are shown in Figure 5-32.

Trapezius, Lower Fibers

The lower fibers of the trapezius produce a diagonal force vector. The origin of this portion of the muscle is lower than insertion, so there are two component forces: one directed downward for depression and the other toward the spine for adduction (see Figure 5-32; Gench et al., 1995).

To palpate the lower fibers of the trapezius muscle, first locate the spinous process of T12. Palpate the superficial lower fibers while the subject holds his or her arm out in front in the plane of the scapula (Biel, 2016).

Pectoralis Minor

These fibers are directed downward from the attachment on the coracoid, and their function as a depressor can be easily seen. The pectoralis minor is entirely covered by the pectoralis major. A person with a weak pectoralis minor muscle will have difficulty controlling the shoulder girdle, particularly during weightbearing activities (Oatis, 2004) and may have difficulty with downward rotation of the scapulothoracic joint. Muscular tightness will result in a posture characterized by downward rotation and forward tilt of the scapula, which may impinge on the brachial plexus or axillary blood vessels, leading to a form of thoracic outlet syndrome (Oatis, 2004).

If you have your subject place the forearm at the small of the back, this relaxes the pectoralis major. Place a finger just below the coracoid process. When the subject lifts the arm off of the back, the tendon of pectoralis minor becomes taut.

Subclavius

Although small, this muscle does produce a downward force when the line of pull is resolved, making the subclavius a weak depressor (Gench et al., 1995). This muscle has not been studied in much depth, but weakness in the subclavius muscle might limit elevation at the SC joint, thereby causing shoulder girdle dysfunction. Its fibers run parallel to the clavicle and can be difficult to palpate.

Pectoralis Major

The inferior fibers of the pectoralis major protract the scapula as it assists in depressing it (Jenkins, 1998). While the pectoralis major assists the deltoid with flexion of the humerus, the sternal and abdominal portions serve as depressors of the shoulder complex (Ludewig & Borstad, 2011). Both portions depress the shoulder complex in weightbearing on the hands, while anterior and posterior movement of the humerus and abduction and adduction of the scapula are neutralized (Gench et al., 1995; Hinkle, 1997; Houglum & Bertoti, 2012; Jenkins, 1998).

This muscle is easily observed and palpated because it is superficial in location and is bulky. The upper portion can be

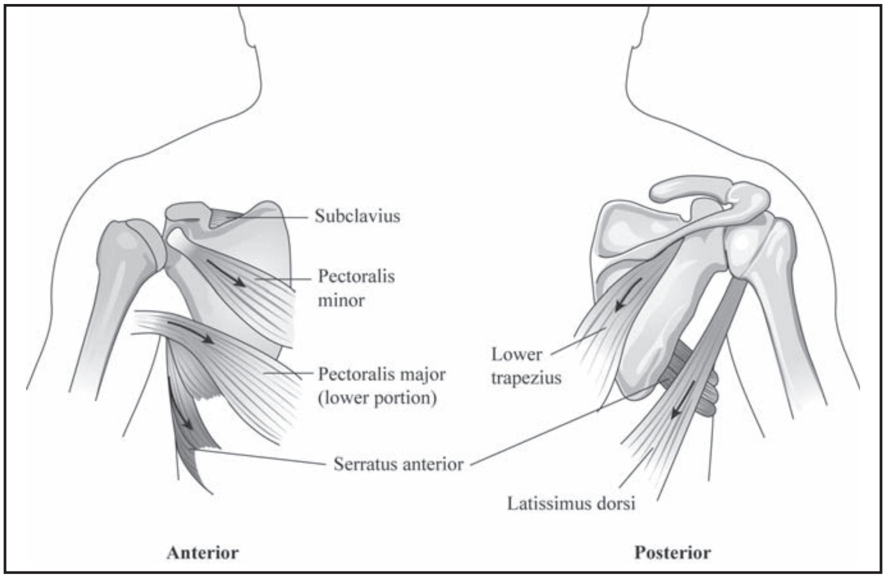


Figure 5-32. Muscles that depress the scapula.

seen when the arm is brought obliquely upward toward the head against resistance. The lower portion contracts separately when the arm is adducted in a lower position. You can feel the antagonistic movements of the upper and lower fibers by having your subject lie supine and asking him or her to abduct the humerus to 90 degrees and attempt to horizontally adduct the arm against resistance. The upper fibers will contract while the lower fibers are relaxed. Next, try to see if the subject can attempt to move from flexion to extension against resistance, and the lower fibers will contract while the upper fibers will be lax (Biel, 2016).

Latissimus Dorsi

The latissimus dorsi is the broadest muscle of the back. It is a thin, sheet-like muscle, and it forms the posterior fold of the axilla. The latissimus dorsi and teres major contract when adduction or extension is resisted, as when the subject presses down on the examiner's shoulder. The latissimus dorsi retracts the scapula as it depresses it (Jenkins, 1998) and serves to adduct and medially rotate as well as extend the humerus and adduct and depress the scapula (Houglum & Bertoti, 2012). Some studies say the latissimus dorsi is active in abduction and flexion of the arm and may contribute to joint stability because compression of the GH joint occurs when the arm is overhead (Houglum & Bertoti, 2012). The latissimus dorsi attaches to the crest of the ileum so when the arms are stabilized, the distal attachment can aid in lifting the pelvis, as occurs when a client places his or her hands on the armrests of a wheelchair. This is helpful in that the client can do a sitting pushup for pressure relief. This is also useful for clients with injuries to the spinal cord C8 and below because the latissimus dorsi is innervated by the thoracodorsal nerve (C6, C7, and C8; Gench et al., 1995; Hinkle, 1997; Houglum & Bertoti, 2012; Jenkins, 1998).

With the subject prone, locate the thick muscle lateral to the lateral border of the scapula. Ask the subject to internally rotate the shoulder against resistance and follow the fibers superiorly to the axilla and inferiorly on the ribs (Biel, 2016).

Protractors (Abduction) of the Scapula

Muscles that abduct or protract the scapula run from the scapula to anterior surfaces and include the pectoralis minor and serratus anterior (Figure 5-33).

Pectoralis Minor

The fibers of the pectoralis major pull downward, inward, and forward. Parts of this muscle pull the coracoid medially, which enables the scapula to slide laterally along the ribs while the acromion glides forward against the distal end of the clavicle (Gench et al., 1995). Both the clavicular and sternocostal portions draw the arm medially, which abducts the scapula.

Serratus Anterior

Referred to as the *saw muscle* because of the multiple digitations, the serratus anterior allows one to raise the arm overhead. Because the fibers are nearly horizontal, this is an effective scapular abductor (Gench et al., 1995). When the serratus anterior is injured and this motion is attempted, pathological winging of the scapula occurs because the scapula fails to slide forward on the rib and does not stay anchored on the thorax.

The lower digitations of the muscle can be seen and palpated near their proximal attachment on the ribs when the arm is overhead. The middle and upper portions can be palpated in the axilla close to the ribs and posterior to the pectoralis major if the arm is elevated to horizontal in the plane of the scapula (between flexion and abduction) while reaching forward.

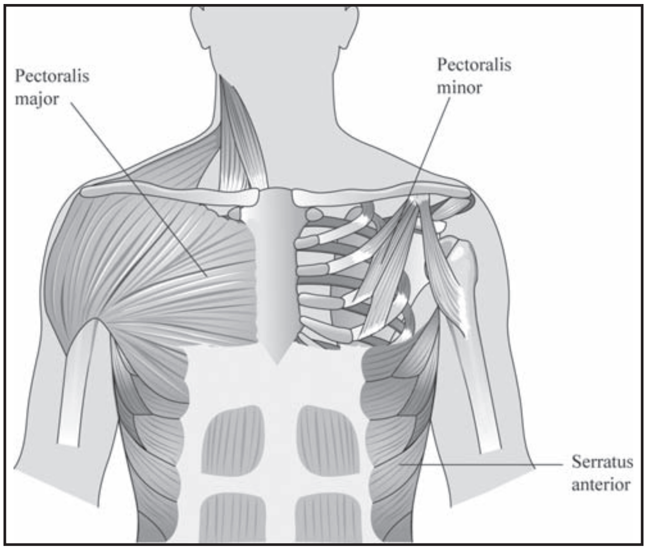


Figure 5-33. Muscles that abduct the scapula.

Retractors (Adduction) of the Scapula

Muscles that act to pull the scapulae toward the vertebral column (adduct or retract) arise from the scapula and insert in the posterior midline (Figure 5-34). These include the trapezius and rhomboids.

Rhomboids

The diagonal line of pull of this muscle produces two components, which explains the role in both elevation and adduction actions.

Trapezius

The middle fibers of the trapezius adduct and stabilize the scapula. Fibers 2, 3, and 4 may be seen to function in retraction in the following ways (Esch, 1989; Lumley, 1990; Magee, 2014):

- Fiber 2 (upper): Fibers are in a diagonal direction, which yields two component forces, one of which is directed toward the spine for adduction.
- Fiber 3 (middle): Fibers are nearly horizontal, so this muscle functions only in adduction.
- Fiber 4 (lower): Diagonal forces with two forces directed down (depression) and toward the spine (adduction).

Isolated weakness of the middle trapezius is unusual and would result in a significant decrease in scapular adduction strength. In addition, weakness in the middle trapezius may result in difficulty contracting the scapulohumeral muscles, such as the infraspinatus and posterior deltoid muscles (Oatis, 2004).

To palpate this muscle, have the subject abduct the shoulder and retract the scapula. If the subject is prone or if the trunk is inclined forward, the muscle works against gravity, so the intensity of the contraction increases and the muscle will be more easily identified. If you move your hand medially from the spine of the scapula, you can feel the superficial and thin middle trapezius muscle fibers (Biel, 2016).

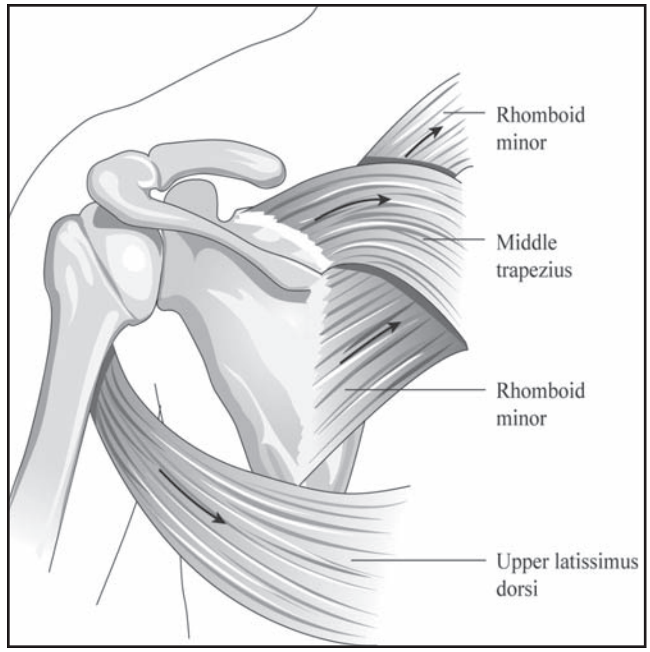


Figure 5-34. Muscles that adduct the scapula.

Levator Scapula

This muscle, with a diagonal pull, has a short horizontal component that weakly adducts and a long vertical component that elevates (Gench et al., 1995).

Upward Rotators of the Scapula

Muscles that work to produce upward rotation of the scapula include the upper and lower portions of the trapezius muscle and serratus anterior.

Trapezius (Upper and Lower)

The upper portion of the trapezius crosses the AC joint above the sagittal axis of that joint and pulls the acromion toward the neck by pivoting the acromion around its articulation with the clavicle. The lower portion attaches medially to the AC joint and is below the joint, so the muscle upwardly rotates the scapula by pulling downward on the base of the spine of the scapula (Gench et al., 1995).

Serratus Anterior

These horizontal fibers have a lateral pull on the inferior angle, pulling this portion of the medial border laterally and forward to depress the scapula and upwardly rotate the scapula (Jenkins, 1998). The lower fibers are effective as upward rotators because they exert a lateral pull on the inferior angle (Gench et al., 1995).

Downward Rotators of the Scapula

Downward rotators of the scapula include the rhomboids, levator scapulae, and pectoralis minor.

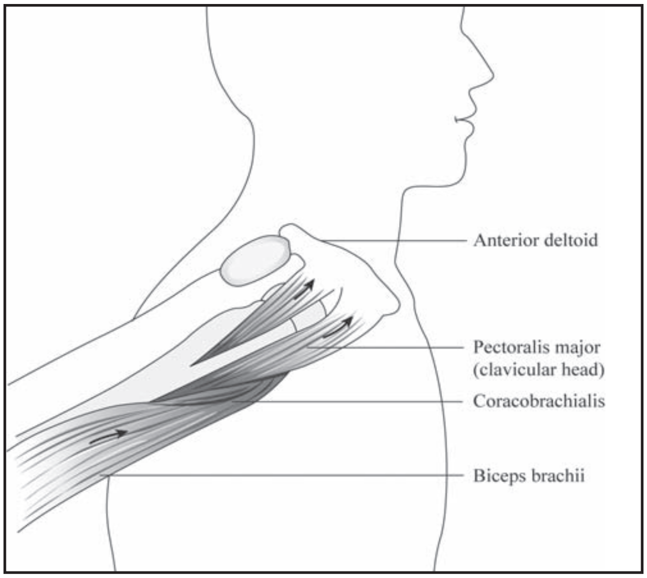


Figure 5-35. Muscles that flex the humerus.

Rhomboids (Major and Minor)

Both the rhomboid major and rhomboid minor contribute to downward rotation of the scapula because their lower fibers, which pull medially and upward on the inferior angle of the scapula, raise the medial border, resulting in downward rotation of the scapula.

Levator Scapula

This muscle pulls upward on the vertebral border of the scapula to lower the inferior angle and raise the medial border.

Pectoralis Minor

With a downward pull on the end of the coracoid and lateral angle, the scapula returns to the anatomical position (Gench et al., 1995). The pectoralis major and latissimus dorsi were also identified as downward rotators (Jenkins, 1998) because these muscles pull down on the lateral angle of the scapula.

Flexors of the Humerus

Muscles that flex the humerus lie anterior to the GH joint axis, and those fibers further from the axis will be the most effective. The flexors of the humerus include the anterior deltoid, pectoralis major, coracobrachialis, and biceps (Figure 5-35).

Anterior Deltoid

The deltoid muscle resembles the Greek letter D (Δ) in shape and comprises 40% of the mass of the scapulohumeral muscles. The deltoid is responsible for the roundness of the shoulder. Its multipennate structure and considerable cross-section compensate for small mechanical advantage and less-than-optimal length tensions. This muscle is seen by some as the most important flexor of the humerus (Jenkins, 1998). Weakness of the anterior deltoid muscle would result in weaker GH flexion, medial rotation, GH abduction, and horizontal adduction. If the anterior deltoid becomes tight, there will be diminished shoulder extension and lateral rotation (Oatis, 2004).

When the humerus is moved into a horizontally abducted position, the anterior portion of the muscle contracts vigorously when horizontal adduction is resisted.

Pectoralis Major—Clavicular Head

Because this muscle crosses the shoulder in front of the frontal axis and attaches to the clavicle, it acts as a powerful flexor. Peak muscle strength is at 75 degrees and again at 115 degrees of flexion. The clavicular head of the pectoralis major works synchronously with the anterior deltoid in forward flexion.

Coracobrachialis

Because of the size and location of the two attachments, this muscle has limited effectiveness, but it does cross anterior to the frontal axis, so it functions in humeral flexion. Studies have not confirmed the effects of weakness or tightness of the coracobrachialis muscle, but it has been suggested that weakness would lead to diminished strength in flexion and adduction of the shoulder, and tightness would lead to decreased ROM in abduction and extension of the shoulder (Oatis, 2004).

The coracobrachialis is covered by the deltoid and pectoralis major. It is possible to palpate this muscle in the distal portion of the axillary region if the arm is externally rotated and abducted to 45 degrees. Find the pectoralis major muscle, which forms the axilla's anterior wall. Palpate the coracobrachialis by having your subject horizontally adduct the arm against resistance, and find the muscle posterior to the pectoralis fibers (Biel, 2016).

Another method is to find the short head of the biceps. The coracobrachialis lies medially and parallel to the tendon of the short head of the biceps, which is seen by supination of the forearm, and follows the short head proximally (Esch, 1989; Lumley, 1990; Magee, 2014).

Biceps Brachii

The line of pull of the biceps fibers is similar to the coracobrachialis and, like the coracobrachialis, has limited effectiveness as a shoulder flexor. This capacity is enhanced by maintaining the elbow in extension, thereby putting some stretch on the muscle (Gench et al., 1995). It is important to consider, however, that complete flexion of the shoulder is impossible when the elbow is extended unless accompanied by internal rotation to diminish the pull of the biceps against the front of the humerus (Jenkins, 1998). The biceps can also aid in preventing subluxation of the GH joint because, when the muscle contracts, tension occurs to produce downward and inward force on the head of the humerus, compressing it against the glenoid cavity (Houglum & Bertoti, 2012)

The biceps brachii can be felt as a hard, round structure on the anterior surface of the arm when the elbow is flexed against resistance.

Extensors of the Humerus

The posterior deltoid, latissimus dorsi, teres major, and long head of the triceps cross the GH joint posteriorly and are extensors of the humerus. These muscles are shown in Figure 5-36. Some sources also include the pectoralis major (sternocostal fibers), coracobrachialis, and subscapularis as assisting with extension of the humerus.

Posterior Deltoid

The posterior fibers lie posterior to the frontal axis, and they function to extend the humerus. Fibers further from the joint axis will be more effective in this action, and the posterior deltoid is capable of extending the humerus back further than other extensors (Gench et al., 1995; Jenkins, 1998). Weakness of this muscle would result in decreased extensor strength, while restricted shoulder flexion and medial rotation ROM might be expected when this muscle is tight (Oatis, 2004).

This portion of the deltoid is most easily seen when the arm is hyperextended against resistance or resistance is given to horizontal abduction (Esch, 1989; Lumley, 1990; Magee, 2014).

Latissimus Dorsi

This muscle is an excellent extensor because it is located inferior and anterior to the frontal axis, and its origin is lower than the insertion.

Teres Major

This muscle is located along the axillary border of the scapula and contributes to humeral extension only when resistance is applied to the arm. The teres major also adducts and medially rotates the humerus and is active only in static positions of the humerus. The proximal attachment of the teres major must be stabilized because unopposed motion would upwardly rotate the scapula (Gench et al., 1995; Hinkle, 1997; Houglum & Bertoti, 2012; Jenkins, 1998).

Palpate this muscle along the inferior aspect of the axillary border of the scapula when prone, with the arm hanging over the side or in a forward inclined trunk position. If there is internal rotation of the GH joint, then the teres major rises. If you palpate higher on the axillary border and externally rotate, the teres minor can be felt as the teres major relaxes. The teres major acts in pulling motions when the shoulder is extended or adducted against resistance (Houglum & Bertoti, 2012).

Triceps—Long Head

The triceps is ineffective as a mover of the humerus because it passes directly over the axis. Because the line of pull passes slightly posterior to the frontal axis, the triceps contributes to humeral extension. It is possible to increase the effectiveness of the triceps in extension by flexing the elbow and thereby putting a stretch on the triceps muscle (Gench et al., 1995).

Palpate the posterior aspect of the arm and locate the olecranon process. Ask the subject to extend the elbow against

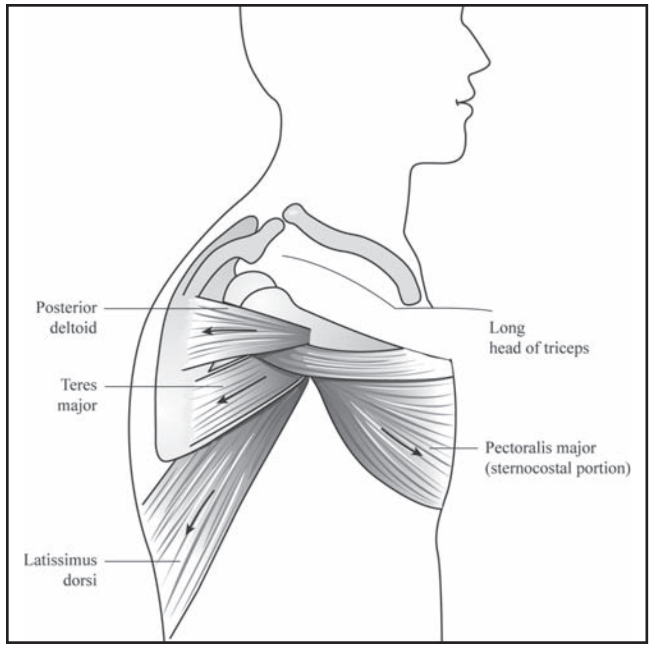


Figure 5-36. Muscles that extend the humerus.

resistance, and you can palpate the medial and lateral heads of the triceps. The long head of the triceps is the only band of muscle on the posterior arm that runs superiorly along the proximal and medial part of the arm (Biel, 2016).

Pectoralis Major—Sternocostal Fibers

Because the fibers are located anterior to the frontal axis with the origin lower than insertion, these fibers pull downward on the humerus to extend it. With weakness, there would be decreased strength in medial rotation, adduction, and horizontal adduction of shoulder. This muscle can become tight, as is seen following thoracic or breast surgery, which limits the ROM of lateral rotation, horizontal abduction, and, possibly, shoulder flexion (Oatis, 2004).

Coracobrachialis

Because of the size and location of the two attachments, the line of pull of this muscle is quite close to respective axes and acts with limited effectiveness to assist other muscles. Not all sources indicate that the coracobrachialis is an extensor of the humerus.

Abductors of the Humerus

Muscles that abduct the humerus (deltoid, supraspinatus, biceps, and infraspinatus) cross superiorly to the joint axis and are shown in Figure 5-37.

Deltoid—Middle and Lateral Fibers

As a whole, the deltoid acts as the chief abductor of the GH joint. The middle portion is the most important as an abductor because most of the anterior and posterior fibers are close to the axis, which diminishes their effectiveness. In shoulder abduction and flexion, the deltoid contributes half of the muscle force for elevation, and the contribution increases

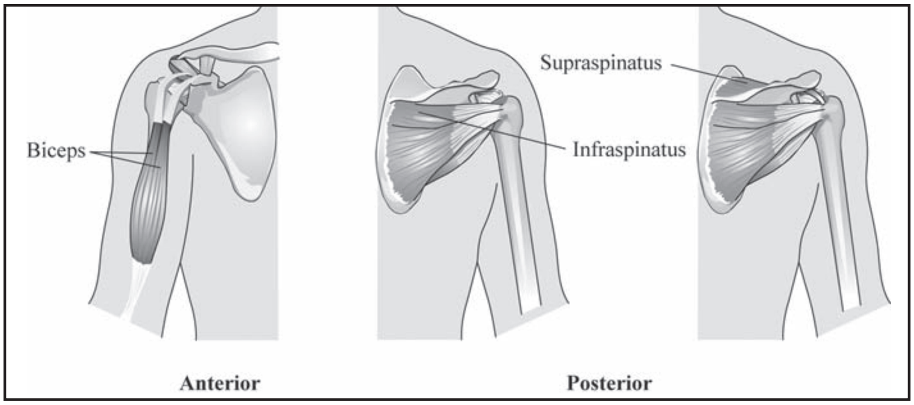


Figure 5-37. Muscles that abduct the humerus.

as abduction increases, with the muscle most active between 90 and 180 degrees. However, the deltoid is most resilient to fatigue at 45 to 90 degrees, so this is the more popular position for arm-raising exercises and is relevant in developing physical abilities in areas of occupation such as combing one's hair or upper extremity dressing.

Weakness in the middle deltoid weakens abduction and contributes to decreased shoulder flexion. Tightness in this muscle does not restrict adduction but may cause pain or disruption to the deltoid tendon or bursae (Oatis, 2004).

The middle deltoid can be seen when the humerus is maintained in an abducted or adducted position.

Supraspinatus

Located above the spine of the scapula and hidden by the trapezius and deltoid, the supraspinatus is an abductor of the GH joint. While the supraspinatus fibers are well superior to the sagittal axis, there is a pull on the head of the humerus into the glenoid fossa, which acts in a complementary way with the deltoid muscle as it initiates abduction (Gench et al., 1995). The supraspinatus was considered the initiator of abduction, but this has not been shown to be true (Inman et al., 1944). The supraspinatus works with the deltoid progressively through the entire range.

When the deltoid is paralyzed, the supraspinatus alone can bring the humerus through much of the range, but it is weak. The supraspinatus also compresses the GH joint and acts as the vertical steerer for the humeral head (Houglum & Bertoti, 2012). Weakness of the supraspinatus is common, resulting from entrapment of the supraspinatus nerve or from mechanical disruption of the tendon or insertion into the GH joint capsule. This can cause pain due to tendonitis, degeneration of tendons, and a significant decrease in the strength of shoulder abduction. Tightness of the supraspinatus can occur after surgical repair of the rotator cuff muscles, so it is important to avoid medial rotations and horizontal adduction (Oatis, 2004). Tears of rotator cuff muscles typically begin in the supraspinatus tendon (Clark & Harryman, 1992), which may be related to avascularity of the tendon, age-related changes in collagen, and mechanical trauma. The supraspinatus tendon often degenerates with age, especially in people whose livelihood has depended largely on the forceful use of their upper limb (Clark & Harryman, 1992; Oatis, 2004).

The deepest portion of the supraspinatus muscle is too deep to palpate, but the more superficial fibers can be felt through the trapezius muscle. Find the spine of the scapula and place your fingers above the spine. Have the subject perform a quick abduction movement in a short range, and you will feel momentary contraction of the supraspinatus. You can also test for this by having the subject lie prone with the arm over the edge of a table, which causes upward rotation of scapula, where one can feel supraspinatus without trapezius.

Biceps Brachii—Long Head

The biceps assists with abduction if the humerus is externally rotated. It is important to note that lateral rotation of the humerus is always accompanied by complete abduction of the arm to allow the greater tubercle to slide under, and not hit against, the acromion.

Infraspinatus

The infraspinatus is a flat muscle located in the infraspinous fossa. The muscle belly is superficial with a medial portion deep to the trapezius and a lateral portion under the deltoid (Biel, 2016). The infraspinatus is seen as a significant contributor to abduction in the scapular plane (Reinold, Escamilla, & Wilk, 2009).

To palpate the infraspinatus, locate the spine, medial border, and lateral border of the scapula and form a triangle around these structures. Ask your partner to protract the scapula, and you will feel the infraspinatus contract (Biel, 2016).

Adductors of the Humerus

Muscles that adduct the humerus (pectoralis major, latissimus dorsi, and teres major) cross below the center of the joint (Figure 5-38). Other muscles that assist with adduction include the triceps, teres minor, and infraspinatus.

Pectoralis Major—Sternal Portions

Because the sternal portions cross inferior to the sagittal axis, the pectoralis major functions as an adductor muscle.

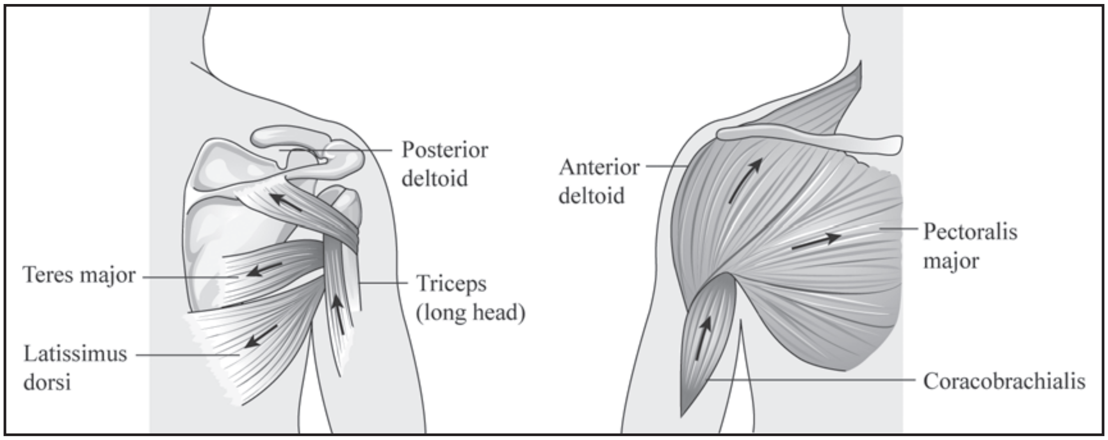


Figure 5-38. Muscles that adduct the humerus.

Latissimus Dorsi

Due to its location well inferior to the sagittal axis, the latissimus dorsi is a powerful adductor. Weakness in the latissimus dorsi would result in decreased strength not only in the adductors, but also in shoulder extension, medial rotation, and scapular depression. A tight latissimus dorsi muscle would limit shoulder ROM in flexion, lateral rotation, and abduction (Oatis, 2004).

Teres Major

> The relationship of the teres major to the three axes of the shoulder is the same as that of the latissimus dorsi and is frequently called the latissimus dorsi's 'little helper.' This conception has been largely in error, however, because the teres major contracts only when resistance has been applied to the arm and only when positions are reached and held in the ranges of movement in adduction, internal rotation and extension. (Gench et al., 1995, p. 75)

Coracobrachialis

This has limited effectiveness and assists with adduction.

Triceps—Long Head

As previously discussed, the triceps is ineffective at the GH joint and generally is seen to assist with adduction.

Deltoid—Posterior

The deltoid assists with adduction.

Lateral (External) Rotators of the Humerus

The lateral rotators of the humerus include the deltoid, supraspinatus, infraspinatus, and teres minor. The infraspinatus and teres minor are closely related in location and action to externally rotate and adduct the GH joint as they both pass posterior to the long axis of the shoulder joint, regardless of the position of the humerus, to become external rotators and horizontal abductors. That they are not also extensors, adductors, or abductors is explained by the fact that they pass directly over both the sagittal and frontal axes of the shoulder (Gench et al., 1995; Houglum & Bertoti, 2012).

It is unusual to have isolated weakness in the infraspinatus muscle, but, should this occur, there would be a significant reduction in the strength of lateral rotation. Weakness in the teres minor would only result in a slight decrease of lateral rotation. A tight infraspinatus muscle results in decreased ROM of shoulder medial rotation and horizontal adduction, while tightness in the teres minor muscle is unlikely and would probably accompany the infraspinatus tightness, limiting medial rotation (Oatis, 2004).

Some parts of the infraspinatus and teres minor are covered by the trapezius and posterior deltoid, but most parts are superficial and can be palpated. Have the subject lie prone or stand with the trunk inclined forward and the arm hanging vertically. Find the margin of the posterior deltoid and place your fingers below the deltoid on the scapula near the lateral margin. Have the subject externally rotate, and these two muscles will rise under the fingers, with the teres minor next to the infraspinatus but farther from the spine.

Deltoid—Posterior Fibers

Along with extension and horizontal abduction, the posterior fibers of the deltoid muscle externally rotate the humerus.

It is possible to feel the antagonistic characteristics of the anterior and posterior fibers of the deltoid muscle. Have the subject keep his or her arm in humeral adduction and have the person medially and laterally rotate against resistance. The anterior fibers will contract upon medial rotation, and the posterior fibers will be taut during lateral rotation (Biel, 2016).

Supraspinatus

Due to the distal attachment of the posterior portion on the greater tubercle, the line of pull of this muscle is slightly posterior to the long axis of the shoulder joint, which makes this muscle an external rotator.

Medial (Internal) Rotators of the Humerus

Subscapularis

Since the subscapularis is medial to the long axis and wraps around the anterior aspect of the upper humerus, the subscapularis has a medial rotation action. There would be a significant decrease in shoulder medial rotation due to weakness in the subscapularis, and this would contribute to anterior instability of the GH joint. A weak subscapularis and teres major with tight infraspinatus and teres minor would result in anterior humeral translation (Magee, 2014). When the subscapularis is tight, there is decreased external rotation of the shoulder (Oatis, 2004). The subscapularis has been identified as being the muscle providing the greatest resistance to posterior subluxation of the humerus (Blasier, Soslowsky, Malicky, & Palmer, 1997).

Pectoralis Major

Because the fibers are anterior relative to the long axis of the GH joint, the pectoralis major is effective as an internal rotator. A short pectoralis major and/or latissimus dorsi muscle would result in decreased lateral rotation (Magee, 2014).

Latissimus Dorsi

The line of pull of this muscle is medial to the long axis when in the anatomical position, so the latissimus dorsi medially rotates as it adducts, flexes, or extends.

Deltoid—Clavicular Fibers

The clavicular fibers rotate the humerus as it flexes.

Teres Major

The teres major muscle medially rotates with resistance against the arm but is weak for pure medial rotation. Oatis (2004) hypothesized by that weakness in the teres major muscle would result in limited shoulder medial rotators, extensors, and hyperextension. Tightness would be expected to result in restricted ROM in shoulder lateral rotation, flexion, and abduction, which might contribute to a posture of rounded shoulders.

The biceps (short head) and coracobrachialis muscles have also been identified as weak medial rotators. A summary of the muscles producing movement of the scapula and humerus are shown in Table 5-17.

Assessment of the Shoulder

Evaluation of the shoulder is complicated by several factors. First, many articulations at the shoulder are required to produce the wide variety of movements. Evaluation of the AC, scapulothoracic, SC, and GH joints, as well as movement along the ribs and thorax, are an essential part of this evaluation. Posture and core stability of the client needs to be part of the assessment, as does an evaluation of muscle patterning, structural laxity, and proprioception.

Second, many muscles add mobility not only to the joint, but also to the stability. The function of these muscles varies depending on the amount of elevation of the humerus, load in the distal extremity, axis of movement, and position of the scapula. Any interruption in the coordinated synchrony of these muscles and their actions will interfere with normal shoulder function.

Evaluation of the shoulder should start with an understanding of the client and client priorities. This can be done through an interview with the client and family and an understanding of the client's occupational profile. Observation and palpation of the shoulder region would then be followed by an assessment of joint movement, muscle strength, joint stability, and pain. Figure 5-39 illustrates the assessment process.

Occupational Profile

As with any occupational therapy assessment, the evaluation should start with chart review, pertinent history, and discussions with the client and family. Although a person's diagnosis may be specific to the shoulder, it is important that the therapist not be so focused on the shoulder joint that other areas of involvement may be missed. As an occupational therapist, the value of the evaluation is not only on the specific limitations of shoulder girdle musculature and dynamics, but also on how these limitations prevent the client from engaging in valued occupations.

Specific information that should be collected from the client answers the following open-ended questions (American Occupational Therapy Association, 2014):

- Who is the client?
- Why is the client seeking services?
- What is the client's concern about engagement in occupations?
- What areas of occupation are successful, and which are not?
- What contexts support engagement in occupation?
- What is the client's occupational history?
- What are the client's priorities?

The answers to these questions, in addition to an assessment of movement and shoulder structures, will enable a client-centered intervention plan with meaningful outcomes for the client. The outcome of occupational therapy is to return the client to participation in meaningful activities, so assessment of the shoulder is needed as well as a careful analysis of the tasks required by the client in daily activities. Treatment would then be focused toward maximizing shoulder ROM, strength, and endurance and minimizing pain by using activities related to the client's chosen occupations.

Observation and Palpation

Much information can be gathered by looking at the symmetry and alignment of shoulder joint structures. Note the characteristics of the joints and visualize the anatomy involved in joint movements. Pay attention to the rhythm, smoothness, and patterns of motion, watching for any nonverbal indications of pain (wince, grimace, etc.). Note any skin discoloration, swelling, abrasions, or masses, and note the relationship of the neck, shoulder, and thorax. Notice if there is any slipping, popping,

Table 5-17

Muscles of the Shoulder

Joint Motion	Muscles	
Scapula		
Elevation	• Upper trapezius • Levator scapulae	• Rhomboids (major and minor)
Depression	• Lower trapezius • Latissimus dorsi	• Pectoralis (major and minor)
Protraction	• Serratus anterior	• Pectoralis (major and minor)
Retraction	• Upper and lower trapezius	• Rhomboids (major and minor)
Upward rotation	• Serratus anterior	• Upper and lower trapezius
Downward rotation	• Levator scapulae • Rhomboids (major and minor)	• Pectoralis minor • Latissimus dorsi
Shoulder		
Flexion	• Anterior deltoid • Coracobrachialis	• Pectoralis major • Biceps
Extension	• Posterior deltoid • Teres major • Latissimus dorsi • Pectoralis major	• Coracobrachialis • Infraspinatus • Triceps
Abduction	• Deltoid • Supraspinatus	• Biceps • Infraspinatus
Adduction	• Pectoralis major • Teres major	• Latissimus dorsi
External rotation	• Infraspinatus • Teres minor	• Deltoid • Supraspinatus
Internal rotation	• Subscapularis • Pectoralis major • Latissimus dorsi	• Teres major • Deltoid • Biceps

or sliding of the joint surfaces, which may indicate instability. Observe the shoulder girdle from all sides and viewpoints.

Palpation should be done to discriminate differences in muscle tension to assess if there is effusion, edema, or muscle spasm as well as muscle tone (spasticity, rigidity, flaccidity). Palpation can help distinguish differences in tissue texture, thickness, direction, and shapes of structures and tissue types. By using the back of the hand or fingers, variations in temperature can be ascertained. Tissue integrity should also be assessed by looking at the condition of the tissues, amount of moisture, ecchymosis (bruising), and any abnormal sensations (Magee, 2014).

Observable deformities, such as squaring of the shoulder (suggestive of an anterior dislocation) or extreme scapular winging (associated with shoulder instability and serratus anterior or trapezius dysfunction or scapulothoracic dysfunction) or rounded shoulder (possibly due to short pectoralis minor muscle or lengthened post rotator cuff muscles), can be seen. Look for both shoulders to be at the same height and for symmetrical muscle development. Elevated shoulders may be due to a shortened levator scapula, upper trapezius, and rhomboids, resulting in scapular elevation, scapulothoracic dysfunction when flexing, or with upward rotation. A lengthened upper trapezius, resulting in scapulothoracic dysfunction with upward rotation, will be seen in a depressed scapula. If the scapula is downwardly rotated, this can result in scapular dysfunction with upward rotation due to shortened levator scapulae, shortened rhomboids, or lengthened trapezius or serratus anterior (Kendall, McCreary, Provance, Rodgers, & Romani, 2005). Posterior shoulder dislocations are rare but can result from a posteriorly directed force with the arm adducted and internally rotated, often resulting in a posterior joint capsule tear, posterior disruption of inferior GH ligament, and, potentially, in the labrum.

By having a client engage in activities relative to areas of meaningful occupation, observation of active, coordinated patterns of movement; compensatory and substitution movements; and indications of the amount of pain the motion elicits

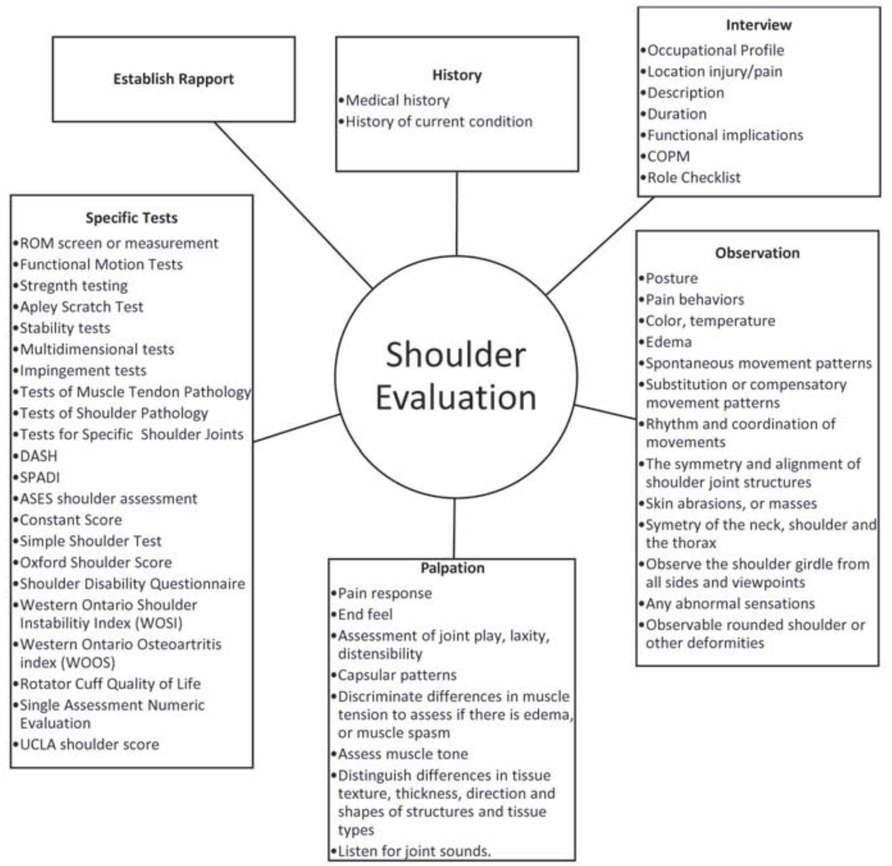


Figure 5-39. Evaluation of the shoulder. (Adapted from Cooper, C. [Ed.]. [2007]. *Fundamentals of hand therapy: Clinical reasoning and treatment guidelines for common diagnoses of the upper extremity.* [p. 74]. St. Louis, MO: Mosby Elsevier.)

can be obtained. A sense of the client's cooperation is gained and a sense of the amount of functional loss can be suggested by watching the client move actively.

Posture

General posture and symmetry can influence shoulder motion and is an important part of the shoulder assessment. Poor joint position sense and balancing mechanisms are predisposing factors to muscle patterning disorders (Lewis, Kitamura, & Bayley, 2004). The position of the neck and head determine how well the arm, wrist, and hand will work. The neck and shoulder are dynamic aspects of daily movement but are often required to act as a static base, while the hands perform skilled tasks. Spinal alignment influences scapular position, and both spinal alignment and scapular position influences shoulder function (Kebaetse, McClure, & Pratt, 1999). This is due to the numerous muscular connections between the spine, scapula, clavicle, and humerus and is due to the need for coordinated scapulohumeral rhythm for full shoulder movement.

Often, tasks require a forward position of the head (e.g., working on a computer), which causes a shift of weight that makes the neck and upper back work harder with decreased control and circulation to the arms. Positions of sustained elevation of the arms may cause supraspinatus tendonitis due to compression of the humeral head against the coracoacromial arch or bicipital tendonitis due to repeated friction between the synovial sheath of the long head and lesser tuberosity.

In the position of rounded shoulders and a forward head position (slouch), the scapula is more elevated during 0 to 90 degrees of abduction, and between 90 and 180 degrees, there was less scapular posterior tilt. This resulted in less active shoulder abduction and a decrease in horizontal muscle force. By assuming this position, the normal scapulohumeral relationship was altered (Kebaetse et al., 1999).

The combination of forward head posture, increased cervical lordosis and thoracic kyphosis, elevated and protracted shoulders, and rotation or abduction and winging of the scapulae has been called *upper-crossed syndrome* or *proximal* or *shoulder girdle crossed syndrome*. This posture is the result of a tight upper trapezius and levator scapula on the dorsal side with tightness of the pectoralis major and minor. In addition, there is weak cervical flexors and weak rhomboids and lower trapezius. These muscle imbalances result in decreased GH stability since the glenoid fossa become more vertically positioned due to serratus anterior weakness (Janda, 1988).

In a study comparing healthy volunteers with clients with shoulder dysfunction, there was a statistically significant difference between clients with shoulder impingement syndrome and healthy controls in core stability and function ($P < .05$), as well as core stability and functional deficiency in clients with subacromial impingement syndrome. The authors concluded that core stability deficits are related to shoulder dysfunction (Hazar, Ulug, & Yuksel, 2014).

Scapula

Assessment of the scapula would include "any observable alterations in the position of the scapula and the patterns of scapular motion in relation to the thoracic cage" (Kibler & McMullen, 2003, p. 143). By observation, one may note leg-length discrepancies or hip rotational abnormalities and the degree of lumbar lordosis, which would result in a lack of symmetry between the two scapulae. Cervical lordosis affects scapular retraction and protraction. Observe for excessive winging, tipping, elevation, or rotation. In chronic scapular dyskinesis, winging may be seen in the resting position (Kibler, 1998).

Scapula dyskinesis (differences in position and/or motion of the two scapulae) interferes with the closed kinetic chain coupling of scapula motion with humeral motion (Kibler et al., 2002). Most frequent dyskinesis is due to changes in muscle coordination between the upper and lower trapezius and between the rhomboids and serratus anterior (Kibler et al., 2002). Other causes of scapular dyskinesia could be bony (thoracic kyphosis, clavicular nonunion or malunion fracture), joint problems (AC joint instability or arthrosis, GH internal derangement), neurological (cervical radiculopathy, long thoracic nerve palsy or spinal accessory nerve palsy), as well as soft tissue pathology (Hamill et al., 2015).

Kibler and colleagues (2002) developed a classification system based on observations of the area of the scapula that is visually prominent during evaluation. Type I is characterized by the prominence of the inferior angle of the scapula with the arm at rest. There is a posterior tilting of the inferior angle around a horizontal axis through the scapula (Kibler et al., 2002). Type II is characterized by a prominent medial border at rest. Upon moving, the medial scapular border tilts off the thorax. In type III, the superior border of the scapula is elevated, and the scapula may be anteriorly displaced. In type IV, both scapulae are relatively symmetrical. The scapulae rotate symmetrically upward and the medial border of the scapula remains against the thoracic wall (Kibler et al., 2002). Use of this classification system can make observational descriptions of scapular function more consistent.

Scapulothoracic Motion

Observe scapulothoracic motion during humeral elevation. This would include the movements of upward rotation of the scapula, external rotation of the humerus, and posterior tilting. In the standing position, compare the outlines of each scapula for bilateral symmetry regarding scapular position and prominence (Ellenbecker & Ballie, 2010). Standing behind the client, have the client place his or her hands on the hips while you observe the movement of the scapula through concentric elevation and eccentric lowering (Ellenbecker & Ballie, 2010). Shoulder pain is often aggravated by humeral motion, particularly abduction.

An assessment of muscular forces involved in scapulothoracic motion would include discerning if the upper trapezius is most active with abduction less than 60 degrees; that lower trapezius is active when abduction is greater than 90 degrees; that middle trapezius is most active during abduction at 90 degrees; that serratus anterior is most active in forward flexion; and that rhomboids are most active during flexion and abduction end range (Uhl et al., 2009).

Humerus

When observing the humerus, a sharp change in the deltoid contour suggests dislocation (Shafer, 1997; Woodward & Best, 2000b). This may result in the ability to passively or actively externally rotate the affected arm.

A loose GH joint may result from repeated subluxations without dislocation. There may be an audible click as the head of the humerus glides back into the glenoid fossa. Pain or clunking sounds with overhead motion may also be indicative of labral disorders (Woodward & Best, 2000b). Young clients with glenoid-rim fractures or labrum tears often retain residual capsule weakness and excessively wide ranges of motion, further encouraging future dislocations.

Acromioclavicular Joint

Forces that are directed toward separating the clavicle from the scapula will cause severe sprain to the AC, coronoid, and trapezoid ligaments unless the clavicle fractures first. Because the AC ligament is a part of the AC joint's capsule, a sprain would also involve a capsular tear to some degree. Repeated trauma to this joint would result in contusion, sprain, separation, and posttraumatic arthritis (Shafer, 1997). Minor sprains are characterized by minimal local swelling and tenderness, moderate pain when moving, but no limitations in joint mobility. A major sprain consists of stretching and tearing of the coracoclavicular ligaments, and there will be acute tenderness and swelling near this ligament and below the clavicle. There will be abnormal mobility of the clavicle relative to the acromion, and a subcutaneous discoloration will appear after 1 week or more post-injury (Shafer, 1997).

Neither the AC nor SC joints can be moved by voluntary action, so dynamic assessment includes evaluation of the small but essential joint play at both the lateral and medial ends of the clavicle. The client needs to be fully relaxed, and joint play is elicited as a slight inferior and superior glide.

Clavicle

A freely moveable clavicle is necessary for full shoulder function. The clavicle needs to pivot and rotate, and limitations at either the AC or SC joints will limit GH motion.

A fracture or dislocation at either end of the clavicle would result in changes in the contour of the shoulder. Look for asymmetrical roundness or fullness of the anterior deltoid and an exaggerated, rounded shoulder (Shafer, 1997). When the tip of the clavicle fractures, bony fragments can be felt under the skin, and often the client is unable to raise the involved arm above 90 degrees. The most common site of clavicle fracture is near the midpoint or outer third of the clavicle, which may also result in inferior, anterior, and medial displacement of the lateral clavicle. If this injury is the result of a fall on an outstretched hand, all structures within the kinematic chain need to be evaluated because the force of impact is transferred from the palm to the carpal bones, to the radius and ulna, and to the elbow, the humerus, AC, and SC joint (Shafer, 1997).

Clavicle dislocations, which can occur because of injuries in football, soccer, horse racing, bicycling, gymnastics, wrestling, and unusual accidents at work or in the home, are not

Table 5-18

Active Range of Motion Screen for the Shoulder

Motion Tested	Instructions to the Client/Ask the Client to ...
Scapular elevation	Shrug their shoulders up toward the ear.
Scapular retraction	Squeeze their shoulder blades together.
Scapular protraction	Raise their arm in front of them to shoulder height, then reach forward.
Humeral flexion	Raise their arm straight out in front of them and raise the arm toward the ceiling.
Humeral abduction	Raise their arm out to the side and up to touch the ear.
Humeral external rotation	Place their hands behind the head or to the back of the neck with elbows pointed out.
Humeral internal rotation	Place their hands behind the back.
Horizontal adduction	Bring their arm across the chest to the opposite shoulder.

as common as fractures. If the injury is to the lateral clavicle, the bone will be elevated with an increase in the distance between the clavicle and coracoid process. This is the palpable and visible step deformity. The scapula will be separated from the clavicle, the acromion will lie below and anterior to the clavicle, and fracture of the coracoid process often is associated with clavicle dislocations (Shafer, 1997).

Subluxation of the clavicle will be felt as a characteristic down step. The clavicle tends to displace superiorly and anteriorly as a common result from falls, blows, and contact injuries. Often, the clavicle subluxation is accompanied by joint ligament separations.

Localized swelling at the tip of the shoulder near the lateral aspect of the clavicle is a common site of painful and tender contusions to the trapezius. You might observe shoulder girdle depression in an attempt to alleviate the pain associated with the contusion. These symptoms may be similar to AC joint separation, so careful evaluation is warranted.

Range of Motion

Because the complex series of articulations of the shoulder allows a wide ROM, the affected extremity should be compared with the unaffected side to determine the client's normal range. Active and passive ranges should be assessed. For example, a client with loss of active motion alone is more likely to have weakness of the affected muscles than joint disease. By observing how the person moves both actively and passively, an understanding of synchronous action of the integrated parts of the shoulder girdle can be determined. Compensatory movements can be observed as clients substitute these motions for impaired function. Information can be obtained regarding the stability and symmetry of joint structures.

Active Range of Motion

Evaluation of active range of motion (AROM) is an assessment of voluntary and physiologic movement. When assessing AROM, look at both the quality and quantity of movement. It would involve elevation of the arm (forward flexion and abduction), horizontal abduction and adduction, and internal and external rotation (Wilk et al., 1997a). Also, it is necessary to differentiate between the scapular and GH motions because movements of the scapula may compensate for restrictions in GH motion (Magee, 2014). Because tension produces joint restrictions, client relaxation is necessary for an accurate assessment. If active motion is normal, assessment of passive motion is usually not necessary. As with palpation, visualizing the underlying anatomy is important to assessing joint motion.

Averages for shoulder flexion and abduction AROM are between 150 and 180 degrees, extension averages between 40 and 60 degrees, internal rotation is between 60 and 90 degrees, and external rotation is between 80 and 100 degrees of movement (Baxter, 2003; Houglum & Bertoti, 2012).

If there is uncomplicated muscle weakness, PROM may be normal, but active may be limited. Spasm, contractures, fracture, and dislocation are the common causes of motion restriction and muscle weakness. Active and passive restriction is likely from a bone or soft tissue block, and any atrophy will likely be from disuse (Magee, 2014).

Elevation, depression, abduction, adduction, extension, flexion, internal rotation, and external rotation are the basic movements of the shoulder girdle. Other movements normally tested are scapular retraction (military position of attention) and shoulder protraction (reaching). The client may be in either the standing or sitting position during testing.

Table 5-18 describes a screening test for AROM of the shoulder. Elevation and depression are checked by having the client hunch the shoulders and return to the normal position. Full active bilateral abduction is tested by having the client abduct the arms horizontally to 90 degrees while keeping the elbows straight and the palms turned upward, then continuing abduction in an arc until the hands meet in the middle over the head. Shoulder abduction involves the GH joint and scapulothoracic articulation. GH motion can be isolated by holding the client's scapula with one hand while the client abducts the arm. The first 20 to 30 degrees of abduction should not require scapulothoracic motion.

If impairments or pain occur in the first phase of shoulder elevation, this may indicate severe restrictions in the GH joint. It may also indicate restriction of the SC joint in rare cases (Donatelli & Wooden, 2010). If the client reports acute pain

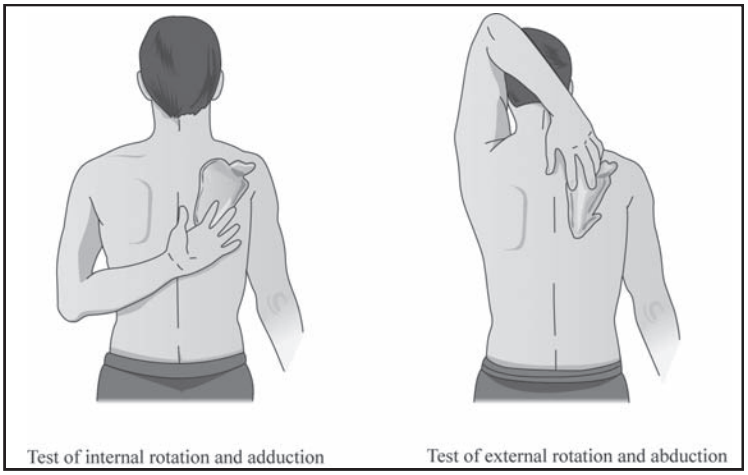


Figure 5-40. Apley scratch test.

above 110 degrees, this may be indicative of AC joint arthritis. If the client is able to hold a position of horizontal abduction above 90 degrees but not below, this may indicate a rotator cuff tear, and if there is pain throughout the full range of horizontal abduction, this may suggest bicipital tendonitis or bursitis (Shafer, 1997).

Pain in a particular part of the arc of movement can occur for many reasons (acromion neoplasm, capsule laxity, cervical disc lesion, cervical subluxation syndrome, infraspinatus tendonitis, intracapsular bicipital tendon, subdeltoid bursitis, subscapular tendonitis, or supraspinatus tendonitis; Shafer, 1997). A painful arc may also be observed if the client is able to abduct the arm 45 to 60 degrees with little difficulty, but between 60 and 120 degrees of abduction, subacromial bursa and rotator cuff tendon insertions (supraspinatus in particular) may become impinged. Once past 120 degrees, the tissues are not compressed beneath the acromion process. A second painful arc occurs in between 160 and 180 degrees, caused by pathology in the AC joint (lesion, impingement syndromes; Magee, 2014).

Flexion and extension are assessed by seeing if the client can bring the humerus up or down in the sagittal plane and frontal axis. Rotation movements are assessed by seeing how the client can move in the horizontal plane and vertical axis. Internal rotation is the motion one uses to fasten a bra or tuck a shirt into pants (Gutman & Schonfeld, 2003). External rotation is the motion needed when one is braiding his or her hair (Gutman & Schonfeld, 2003). If there is acute pain that is increased by humeral rotation, synovitis may be the cause (Shafer, 1997).

Protraction and retraction are movements of the scapula toward or away from the vertebral column. When one brings the arms to the center of the body in a horizontal plane and vertical axis, this produces protraction. When you bring your arms back behind you in a horizontal plane, this is retraction.

External rotation and abduction can be tested bilaterally at the same time by having the client place both hands behind the neck with interlocking fingers, and then the elbows, which are initially pointing forward, are moved laterally and posteriorly in an arc (Magee, 2014). The Apley scratch test (Figure 5-40) is a useful maneuver to assess abduction, external rotation, internal rotation, and adduction shoulder ROM. In this test, the client is asked to reach behind the back and touch the bottom of the opposite scapula (internal rotation and adduction) and then to reach behind the head and touch the top of the opposite scapula (abduction and external rotation). The inability to perform these maneuvers indicates loss of AROM and possible rotator cuff muscle limitations. These combined motions of abduction, flexion, and external rotation or adduction combined with extension and internal rotation are needed to comb hair, zip a back zipper, or reach for a wallet in the back pocket. With the arm internally rotated (palm down), abduction continues to 120 degrees. Beyond 120 degrees, full abduction is possible only when the humerus is externally rotated (palm up).

Restrictions in the second phase of elevation, the most common phase for shoulder dysfunction, may be due to limitations in the AC or SC joints limiting scapular rotation due to restricted clavicular elevation and rotation. Limited scapulothoracic rotation may be due to weakness in the levator scapulae, serratus anterior, and/or upper and lower trapezius muscles. Pathological winging of the scapula would occur in this phase. In the last phase of shoulder elevation, much flexibility is required of the muscles (teres major, subscapularis, pectoralis major, latissimus dorsi, teres minor, and infraspinatus) involved in the primarily GH movements of the final elevation.

Internal rotation and adduction can be tested as a combined motion by having the client reach across his or her chest (internal rotation) and, keeping the elbow as close to the chest as possible (adduction), touch the opposite shoulder. Another method is to have the client reach behind the back and attempt to touch the bottom angle of the opposite shoulder blade.

You can also observe the client during functional activities to visually ascertain the amount of AROM. For example, grooming tasks such as hair care and facial hygiene require shoulder abduction and flexion. Adjusting a blouse or tucking a shirt into pants in the back requires internal rotation, and adjusting a collar on a shirt in the back may involve shoulder adduction and external rotation (Constant & Murley, 1987; Magermans et al., 2005). The American Shoulder and Elbow Surgeon's Shoulder Evaluation form assesses motion, strength, stability, and function. The functional items are rated on a 0 to 4 scale. The Disabilities of the Arm, Shoulder, and Hand

Questionnaire (DASH; Hudak, Amadio, & Bombardier, 1996) asks clients to rate their ability to do 21 tasks and in what ways completion of those tasks were limited using a 1 to 5 scale.

AROM within normal limits is not often required for many ADL. Humeral elevation values range from 99 to 109 degrees for deodorant application and from 46 to 86 degrees for perineal care. Combing the hair requires 105 to 120 degrees humeral elevation, and eating requires approximately 63 to 87 degrees of horizontal adduction and 60 to 80 degrees of elevation. Full ROM is needed for the rotational movements of internal and external rotation in many daily activities, such as combing hair or tucking in a shirt (Aizawa et al., 2013; Doorenbosch et al., 2003; Gates et al., 2016; Harryman et al., 1990; Magermans et al., 2005; Matsen et al., 1994; van Andel et al., 2008; Veeger et al., 2006).

Reliability of shoulder ROM measurement is affected by many factors, including the complexity of the movement, variations in joints, active vs. passive motion, which joint is tested, variations among clients, and testing by the same or different examiners (Gajdosik & Bohannon, 1987; Hayes, Walton, Szomor, & Murrell, 2001). In addition, different tools have been used to measure shoulder ROM, including goniometry, visual estimation, high-speed cinematography, still photography, and functional motion tests (Hayes et al., 2001). Of the different tools used, there is fair to good reliability for visual estimation, goniometry, still photography, and the stand and reach test for shoulder motions of flexion, abduction, external rotation, and overhead reach (Hayes et al., 2001).

Both intrarater and interrater reliability needs to be considered. Intrarater reliability is higher than interrater (Gajdosik & Bohannon, 1987; Sabari, Maltzev, Lubarsky, Liszkay, & Homel, 1998). Intrarater reliability interclass correlation coefficients (ICC) for the measurement of shoulder motion ranged from 0.87 to 0.99, indicating good intrarater reliability. Interrater reliability was good for PROM for shoulder flexion abduction and external rotation (ICC values ranged from 0.84 to 0.90), but less for shoulder horizontal abduction and adduction, extension, and internal rotation (ICC values ranged from 0.25 to 0.55; MacDermid, Chesworth, Patterson, & Roth, 1999; Riddle, Rothstein, & Lamb, 1987). Overall, interrater reliability is better for the upper extremity than for the lower (Hellebrandt, Duvall, & Moore, 1949). Intrarater reliability for ROM and strength of the shoulder were good to excellent for athletes and volunteers using standardized testing positions and handheld dynamometer shoulders and groups (athletes: ICC = 0.94 to 0.97, standard error of measurement [SEM] 1.07 degrees to 4.76 N; controls: ICC = 0.96 to 1.00, SEM = 0.00 N to 4.48 N; Fieseler et al., 2015).

PROM is more difficult to measure reliably because of the stretch of soft tissues and the control of force required, which is difficult to measure and must be carefully controlled (Gajdosik & Bohannon, 1987). Also, complex passive movement is more difficult than simple passive movement, and this affects reliability. Consider the difference between the measurement of PROM of the elbow and that of the shoulder in terms of complexity of movement, and issues of reliable measurement become more apparent.

The validity of shoulder ROM measurements may be affected by edema, pain, strength deficits, muscle hypertrophy, and client characteristics (Gajdosik & Bohannon, 1987). The validity of the measurement is based on the clinician's knowledge of anatomical structures, experience in visually inspecting and palpating the skeletal landmarks, and accurately aligning and reading the goniometer (Gajdosik & Bohannon, 1987). Of critical consideration in both reliability and validity is having the same examiner measure the ROM of the same client, using the same positions and standardized techniques in an optimal testing environment.

Age and gender were found to affect ROM values for shoulder internal and external rotation. Women were more flexible and had more ROM in a seated position during external rotation. The reason posited for the difference is that muscle bulk may limit flexibility in stronger individuals (Roy et al., 2009). In a study by Walker, Sue, Miles-Elkousy, Ford, and Trevelyan (1984), women had greater ROM in all shoulder motions as compared to men. In a study by Roy and colleagues (2009), age was also found to be a factor in a study when measuring external rotation and internal rotation. Decreased internal rotation on the dominant side was found in people older than 60 years as compared to those 18 to 39 years of age, and there was a negative correlation between age and external rotation in a supine testing position (Roy et al., 2009).

Passive Range of Motion

An assessment of PROM can provide different information about the shoulder joint than AROM. When moved passively, there is a pulling of the joint capsule and antagonist muscles and ligaments. An evaluation of PROM looks at joint play and accessory movements possible at each joint. The joint is positioned in the resting position (or the loose-packed position) so that there is minimal congruency of articular surfaces and the joint capsule to enable slide, spin, and rolling motions. PROM should not be performed if your client is at risk for fractures (e.g., osteoporosis), dislocation, tears, or advanced bone pathology (Magee, 2014).

The application of overpressure is helpful in determining if the end feel of the joint is pathological or physiologically normal. With passive movement, bone blocks will feel like an inflexible obstacle that abruptly halts movement, while extra-articular soft-tissue blocks will be less abrupt and slightly flexible upon additional pressure (Magee, 2014).

With PROM, end feel sensations in the shoulder can be helpful in suggesting joint dysfunction. In a normally firm end feel joint, instability may be considered if the end feel exhibited is that of a spasm or empty end feel. If there is excessive external rotation with soft end feel, this may suggest hypermobility and hyperelasticity, which can lead to anterior GH displacement (Wilk et al., 1997b).

A screening test for PROM would be the same as described for AROM, with the exception that the client is not producing the movement and the therapist is moving the arm. All shoulder motions should be assessed. If there is mild to moderate pain when you are assessing the shoulder in all directions, adhesive capsulitis might be suspected. If crepitus is noted with acutely painful abduction above 110 degrees, AC joint arthritis may be the reason. If the joint elicits acute pain at all levels of abduction, there may be joint synovitis (Shafer, 1997). Limited passive motion without a capsular pattern may be due to a variety of deficits, including AC joint sprain, capsule adhesions, costocoracoid contracture, first rib fracture, pulmonary neoplasm, subacromial bursitis, or subdeltoid bursitis (Donatelli & Wooden, 2010; Ellenbecker & Ballie, 2010; Shafer, 1997).

Joint-play movements, an important part of normal shoulder motion, are also evaluated passively, and there is a comparison of the available motion and end feel of both sides of the body. Commonly, the following five joint-play movements are tested: lateral glide of the humerus relative to the glenoid cavity; medial glide of the humerus relative to the glenoid cavity; anterior glide of the humerus relative to the glenoid cavity; posterior glide of the humerus relative to the glenoid cavity; and downward separation from the glenoid cavity (Shafer, 1997).

In assessing posterior glide of the humerus, the client is supine. With one of the examiner's hands over the anterior humeral head and the other around the humerus above the elbow, a backward force is applied (Magee, 2014). A posterior glide assessment can occur during external rotation and abduction of the humerus (Shafer, 1997). Anterior glide would entail a forward force against the client's arm while controlling for rotation. Lateral, upward, and downward glides can also be used to assess additional GH joint-play movement. AC and SC joint play can be assessed by gently grasping the clavicle as close to the joint as possible and moving it in and out or up and down, which may be uncomfortable for the client, so prior warning to the client and careful observation of nonverbal client cues is warranted (Magee, 2014). In addition, passive movement of the scapula should also be assessed as it moves posteriorly, medially, laterally, caudally, cranially, and away from the thorax (Magee, 2014). Passive movement of the scapula can be tested by having the therapist stand behind the client, stabilize the scapula with one hand, and move the client's arm through shoulder movements.

If both active and PROM are restricted and passive mobility is limited in a capsular pattern of external rotation, abduction, and internal rotation, adhesive capsulitis may be suspected (Donatelli & Wooden, 2010). The client may also describe a vague, dull pain over the deltoid, which increases with motion and disturbs sleep. This is also known as *frozen shoulder, periarthritis, stiff and painful shoulder, periarticular adhesions, Duplay's disease, scapulohumeral periarthritis, tendonitis of the short rotators, adherent subacromial bursitis, painful stiff shoulder, bicipital tenosynovitis, shoulder portion of shoulder-hand syndrome, bursitis calcarea, supraspinatus tendonitis,* and *periarthrosis humeroscapularis*. By observation, the client may have a stooped posture with rounded shoulders and tends to hold the involved extremity in adduction and internal rotation. Donatelli and Wooden (2010) suggest that evaluation should include active and passive elevation of the shoulder, passive scapulohumeral abduction, passive lateral and medial rotation, resisted abduction and adduction, resisted internal and external rotation, and resisted elbow extension and elbow flexion.

Capsular pattern problems occur in characteristic proportions and have effects throughout the entire upper extremity. In the shoulder, the greatest limitations that occur due to capsular impairments are seen in limitations in external rotation, then in abduction, followed by impairments in internal rotation and flexion. If the capsular pattern does not occur in this order, a noncapsular problem may be suspected. Magee (2014) states that the end feel of capsular tightness is different from the tissue stretch end feel of muscle tightness in that capsular tightness has a more hard, elastic feel. Using end feel as an indication of tissue function is useful clinically, but, due to individual variation, the reliability may be questionable (Donatelli & Wooden, 2010). Limited passive motion that occurs in a capsular pattern may be due to arthritis, bone blocks, hemarthrosis, hemiplegia, neoplasm, neuropathic arthropathy, complex regional pain syndrome, or systemic lupus erythematosus (Donatelli & Wooden, 2010; Ellenbecker & Ballie, 2010; Shafer, 1997).

The location of capsular tightness and the effects on movement are shown in Table 5-19. For example, if there is tightness in the posterior capsule, this results in excessive anterior and superior movement in the GH joint. Treatment would focus on inferior and posterior mobilization techniques at the GH joint (Uhl et al., 2009).

Dynamic flexibility is the resistance of tissue to movement. How muscles respond to movement is related to age, gender, levels and types of activities, tissue temperature, heredity, injury, and pain. Flexibility screens can be done to test how individual muscles respond to movement. For example, with your client in supine, by passively abducting and externally rotating the arm to 140 degrees, you can test the flexibility of the pectoralis major muscle (sternal portions). In the same position, moving the client passively to 90 degrees of horizontal abduction and external rotation, you could test pectoralis major clavicular fibers. In each case, if the client cannot reach the frontal plane, this would indicate a flexibility deficit in the pectoralis major muscle. Other specific tests have been used for pectoralis minor, subscapularis, internal and external shoulder rotators, latissimus dorsi, upper trapezius, and levator scapulae muscles.

More commonly, shoulder flexibility tests may include holding a stick (or dowel or golf club) out in front of you with both hands on either end of the stick. Bring the stick up and overhead, and then repeat by moving the stick behind you and up. Another flexibility test is to raise your right arm overhead. Bend your right elbow and let your palm rest on the back of your neck. Then, slide it between your scapulae. Then, reach behind you so that the back of your hand rests on the middle of your back. Reach back with both hands to the middle of your back and touch the fingers of both hands. Excellent flexibility is when fingers overlap, good is when fingers touch, average is when fingers are less than 2 inches apart, and poor is when there is more than 2 inches between fingers.

Stability Assessment

The shoulder joint is not an inherently stable joint. There are two reasons for instability: structural causes (capsule and labral damage due to injury or repetitive microtrauma) or unbalanced muscle recruitment around the shoulder (as opposed to muscle weakness) so the humeral head is displaced on the glenoid (Jobe, Kvitne, & Giangarra, 1989; Kvitne & Jobe, 1993; Matsen et al., 1991). Trick movements, or instability that is voluntarily controlled and deliberate, are due to unbalanced muscle action, but there is also involuntary positional instability in which the joint subluxes or dislocates during normal movement, which can also be caused by unbalanced muscle action or incongruency of joint surfaces (Lewis et al., 2004).

Table 5-19

PATTERNS OF CAPSULAR TIGHTNESS AND THE EFFECT ON MOVEMENT

LOCATION OF TIGHTNESS	EFFECT ON MOVEMENT
Posterior	• Horizontal adduction decreased • Medial rotation decreased • End range of flexion decreased • Decreased posterior glide • Weak external rotation • Weak scapular stabilizers
Posteroinferior	• Elevation anteriorly • Medial rotation of elevated arm decreased • Horizontal adduction decreased
Posterosuperior	• Medial rotation limited
Anterosuperior	• Flexion end range limited • Extension end range limited • External rotation limited • Abduction end range decreased • Decreased posteroinferior glide • Increased night pain • Weak rotator cuff
Anteroinferior	• Abduction decreased • Extension decreased • External rotation decreased • Increased posterior glide

Adapted from Magee, D. J. (2002). *Orthopedic physical assessment* (6th ed.). Philadelphia, PA: Saunders.

In trying to classify and describe instability, a distinction is often made between laxity and instability, with the understanding that these terms are not synonymous. Laxity is considered a degree of translation in the GH joint that falls within a physiologic range and is asymptomatic. This is the ability of the humeral head to be passively translated on the glenoid fossa. Instability is characterized by abnormal motions, which result in pain, subluxation, or dislocation. Instability is a clinical condition in which there is unwanted translation of the humeral head on the glenoid, which compromises the comfort and function of the shoulder (Matsen et al., 1991). Further definitions of terms include subluxation, which is a symptomatic separation of the joint surfaces without dislocation (which is a complete separation of joint surfaces; Lewis et al., 2004).

Instability can be defined based on the degree of instability, onset (traumatic/atraumatic, overuse), severity, and direction. Multidirectional instability is characterized by a loose feeling in the joint with tingling, paresthesia, weakness of arm, and diffuse, poorly localized pain. In contrast, with unidirectional instability, the clients report more localized pain and discomfort that occurs only in specific arm positions (Wilk et al., 1997b).

There are several systems of classification of joint instability with misunderstandings of many of the terms, different combinations of pathologies, and changes in classification through time (Lewis et al., 2004). One system classifies instability based on the direction of the instability. This includes Bankart lesions, which are unidirectional and multidirectional. The Rockwood classification is based on whether the instability is due to trauma with and without previous dislocation or is atraumatic with voluntary or involuntary subluxation.

The Thomas and Matsen classification system classifies instability as either traumatic unidirectional instability (TUBS) or atraumatic multidirectional bilateral instability (AMBRI). TUBS refers to a traumatic event that gives rise to a unidirectional anterior instability with a Bankart lesion, which requires surgery. The GH joint has lost the stabilizing effect of the inferior GH ligament complex and deepening of glenoid due to anterior glenoid labrum damage with the arm in abduction, extension, and external rotation. In the TUBS classification, the tissue is traumatic, torn loose with a Bankart lesion the pathology, resulting in unidirectional instability requiring surgery. AMBRI syndrome describes someone who was "born loose": atraumatic onset of multidirectional instability that is accompanied by bilateral laxity, rehabilitation helps, and if an operation is necessary, then the goal is to tighten the inferior capsule and rotator cuff interval (Matsen et al., 1994). AMBRI lesions are atraumatic or minor trauma resulting in multidirectional and bilateral instability. In AMBRI lesions, rehabilitation is the treatment of choice or inferior capsular surgery if rehabilitation is unsuccessful. Instability may also result from nonstructural causes with no structural damage to the articular surfaces, but is the result of capsular dysfunction, abnormal muscle patterning, and, like AMBRI lesions, is often bilateral.

A final system is advocated by Schneeberger and Gerber in which the degree of joint laxity (e.g., no laxity, generalized laxity), degree of trauma (e.g., multiple events, single trauma event, minor trauma event), and direction of instability (e.g., multidirectional, unidirectional) are classification factors (Lewis et al., 2004).

Lewis and colleagues (2004) indicate that these classification systems are inadequate because they ignore that instability is a dynamic process with mixed pathologies that can change over time. They recommend the Stanmore classification, which uses classification characteristics from several of the described systems. For example, type I is considered a true TUBS, type II is a true AMBRI, and type III includes muscle patterning disorders that are habitual and nonstructural. This system considers the changing nature of pathology and includes traumatic/nontraumatic causes and muscle patterning (Lewis et al., 2004).

A systematic assessment of instability would first include an appraisal of the amount of passive translation between the humeral head and glenoid fossa. Second, an assessment of end feel would be necessary, as directional stresses are applied to the joint. Finally, reproduction of symptoms, subluxation, or apprehension would be done (Wilk et al., 1997b). Individual client factors also need to be considered in the assessment of instability, which would include information about the person's age, structural laxity, sport activity, and areas of occupations.

It is necessary to determine if the amount of passive translation between the humeral head and the glenoid is indicative of laxity or instability. A few tests of laxity specific to the shoulder are the anterior drawer test of the shoulder, posterior drawer test of the shoulder, load and shift test (a modification of the anterior and posterior drawer tests), and sulcus sign (test for inferior shoulder instability). Table 5-20 lists additional tests for shoulder instability.

The anterior drawer test assesses the laxity of the anterior capsule, while the posterior drawer (Gerber-Ganz Posterior Drawer) assesses the integrity of the posterior capsular structures and posterior portion of the glenoid labrum. Both tests are performed with the client in supine, in 80 to 120 degrees of abduction, and in 0 to 20 degrees of forward flexion. The examiner holds the client's scapula with the index and middle fingers on the spine of the scapula and the thumb applying counterpressure on the coracoid. Force is applied anteriorly for the anterior drawer test or by applying a slightly rotational force to the upper arm medially and flexing the shoulder to about 60 to 90 degrees and applying a posterior force for the posterior drawer test. Both tests should be pain free.

The load and shift test is a modification of the anterior and posterior drawer tests. Directional forces are applied anteriorly and posteriorly to relocate the humeral head in the glenoid. The test is then repeated in the supine position. Assessment of the translations in other positions, such as external and internal rotation, is also done. In the first 60 degrees of abduction, the structures tested include the superior GH ligament, coracohumeral ligament, and rotator interval. Between 60 and 90 degrees, the middle GH ligament is tested, and at 90 degrees and greater, the inferior GH ligament is tested.

Posterior and anterior instability can also be tested by apprehension tests. The posterior apprehension test positions the client's arm in 90 degrees of abduction and 90 degrees of elbow flexion, and the therapist pushes posteriorly on the humeral head. For the anterior apprehension test, the therapist applies slight anterior pressure to the humerus and externally rotates the arm. Pain and apprehension about impending subluxation or dislocation indicates instability (Gibson, 2010).

The sulcus test (Figure 5-41) is done with downward force applied to the humerus while observing the shoulder area for a depression lateral or inferior to the acromion, which would indicate inferior translation of the humerus and suggests inferior GH instability (Gibson, 2010; Wilk et al., 1997b). The shoulder is in neutral position with stress applied above the elbow to eliminate the effects of biceps and triceps. Palpation might reveal a widening of the subacromial space between the acromion and humeral head. While the sulcus test is seen as essential to the diagnosis of multidirectional instability, this could also be a sign of a rotator interval lesion and/or an injury of the superior ligament complex.

Other symptoms that may be indicative of instability may include pain, inflammation, tendonitis, or other pathological conditions. For example, if there is multidirectional instability, the client may present with localized biceps tendon inflammation and diffuse rotator cuff muscle tendonitis. Clients with traumatic injuries with unidirectional instability may report localized pain and discomfort when the joint is placed in specific positions. The pain reported in instable shoulders may not be indicative of where the instability is occurring, such as when there is traumatic anterior instability and the client

Table 5-20

Stability Tests for the Shoulder

Direction or Location	Test
Scapular	• Lateral scapular-slide tests • Scapular load test* • Wall/floor pushup test • Scapular retraction test • Scapular isometric pinch or squeeze test • Scapular assistance test
Inferior	• Sulcus test (at 0; at 90 degrees)* • Gagey's test • Feagin test • Inferior apprehension test
Posterior	• Posterior drawer test • Fukuda test • Posterior fulcrum test • Load and shift test • Posterior apprehension test • Norwood stress test for posterior instability • Push-pull test • Jerk test* • Circumduction test
Anterior	• Anterior drawer test of the shoulder • Anterior apprehension test* • Load and shift test • Crank (apprehension) and relocation test* • Fowler sign or test • Jobe relocation test (fulcrum test) • Anterior release test • Dynamic rotatory stability test • Dynamic anterior jerk test • Anterior instability test (Leffert test) • Rockwood test for anterior instability • Throwing test • Rowe test • Prone anterior instability test • Andrews' anterior instability test • Dugas test • Protzman test for anterior instability • Surprise/release rest
Multidimensional	• Rowe test for multidirectional instability
Core instability	• Kibler's corkscrew test

*Indicates moderate to strong evidence support.

Adapted from Magee, D. J. (2014). *Orthopedic physical assessment* (6th ed.). St. Louis, MO: Elsevier.

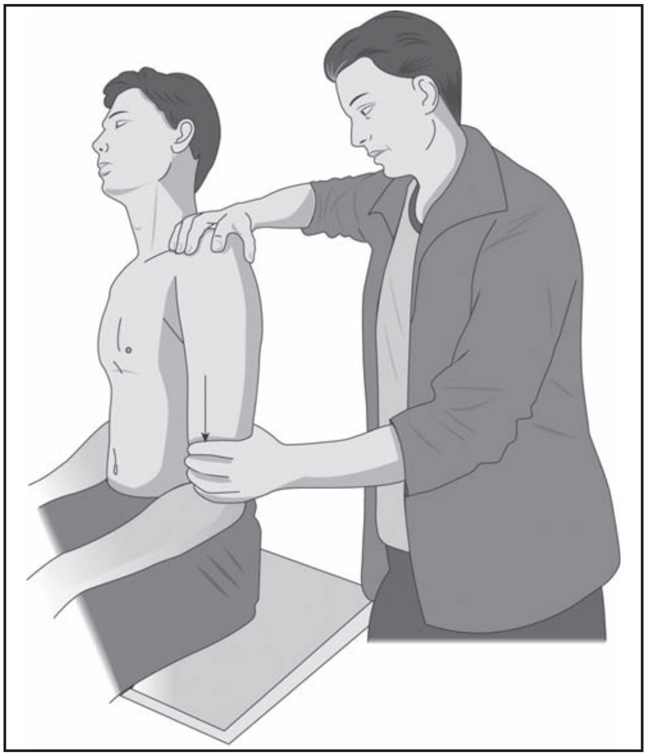


Figure 5-41. Sulcus test for instability.

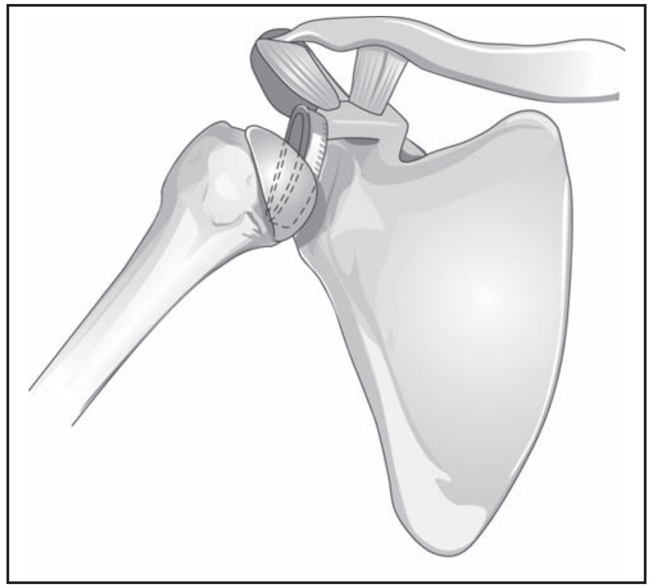


Figure 5-42. Anterior subluxation of the GH joint.

describes posterior shoulder pain secondary to impingement (Wilk et al., 1997a).

Instability may result in dislocation and subluxation of the shoulder. Careful observation, movement, and palpation of the GH head will provide valuable information about the integrity of the joint. Dislocations and subluxations occur when the articulating surfaces of the bones that comprise a joint lose contact with each other, usually due to an external force.

Anterior humeral head displacement might be seen in clients who are unable to raise their arms overhead and is the most common type of GH dislocation (Figure 5-42). There may be a fullness noted on the upper anterior arm that is tender when palpated, the deltoid may feel tight, and the coracoid process may be sensitive to palpation and be higher up on the head of the humerus than is normally seen. There may or may not be pain, and there will be loss of upper extremity function and possibly loss of sensation. Often, anterior displacement is due to falls on outstretched arms, a fall or blow to the lateral shoulder from behind, or forced abduction with the humerus in either internal rotation with abduction or flexion with external rotation. With this type of displacement (subcoracoid is the most common but may also include intracoracoid or subclavicular), there are frequently tears in the labrum and capsule, fracture of the greater tuberosity, and tears of the rotator cuff. Any anterior subluxation can do great harm to the brachial artery, vein, or nerves. Circulation should always be checked (Shafer, 1997).

Posterior humeral head displacement (which is rare) may occur when there is direct pressure applied laterally and posteriorly to the joint or when a force is exerted in the same direction along a flexed, adducted, and internally rotated humerus. In some cases, the posterior area of the GH joint may feel fuller, and an unusually prominent coracoid process may be felt, but physical signs are often not noticeable. The client's arm is abducted and rotated internally, and the elbow is directed slightly forward. The head of the humerus lies on the outer edge of the glenoid fossa. In severe cases, the lateral side of the capsule is usually torn, and there may be an associated rotator cuff tear or an avulsion fracture of the greater tuberosity resulting in persistent pain. The internal and external scapular muscles are often torn and may contain fragments of the avulsed tuberosities (Shafer, 1997).

Inferior humeral head displacement is characterized by severe pain and disability (Figure 5-43). The head of the humerus lies below the glenoid fossa, typically after a forced abduction movement followed by rotation (e.g., an injury to an abducted arm in a football tackle). The deltoid will often feel firm, flattened, and spastic, but other signs are often vague. Superior humeral head displacement is more likely the result of contractures within the upper humeral area that prevent the greater tuberosity from gliding smoothly under the coracoacromial ligament during abduction. The humerus cannot dislocate much superiorly due to bony arch, and a supraglenoid displacement is rare except in sports or severe accidents (Shafer, 1997).

Subluxation is commonly seen in the shoulders of people with hemiplegia because the muscles that control the shoulder are weak or paralyzed, which allows the humeral head to be displaced inferiorly by gravity. Weakness/paresis of the rotator cuff, the prolonged gravitational pull that stretches the capsule and ligaments, also contributes to shoulder dysfunction after a stroke. Positioning is often a choice for treatment (e.g., slings, lapboards); physical agent modalities (e.g., electrical stimulation) and muscle facilitation techniques are often used in the treatment of the hemiplegic shoulder (Donatelli & Wooden, 2010; Gillen & Burkhardt, 2004).

Several tests are used to assess displacement, subluxation, and dislocation. The Callaway test is a measurement of the circumference of the affected shoulder, measured over the acromion and through the axilla. If this measurement is greater than that on the opposite, unaffected side, this indicates dislocation. In the Dugas test, the client is asked to place his or

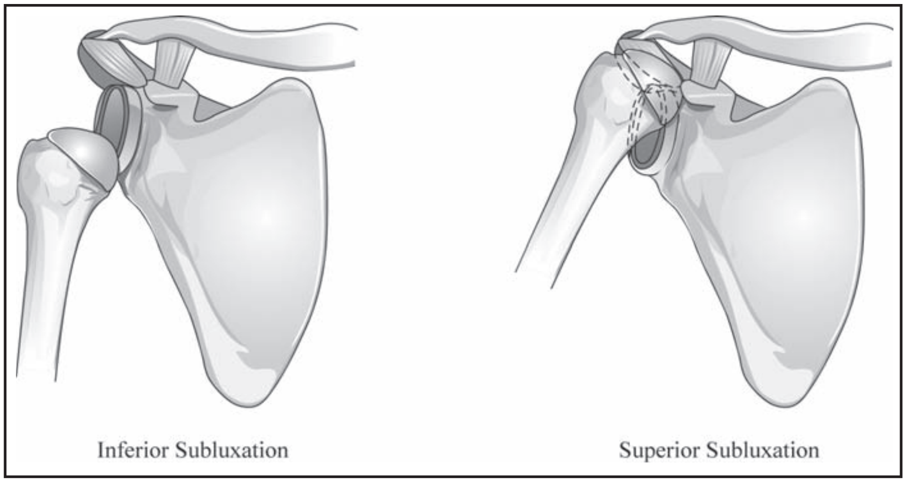


Figure 5-43. Inferior and superior subluxation of the GH joint.

her hand on the opposite shoulder and touch the elbow to the chest. If there is pain or an inability to perform the test, this is indicative of dislocation. If there is a lowering of the axillary fold, this is known as *Byrant's Sign*, also indicating dislocation on the lowered side.

Impingement Assessment

Pain, weakness, and loss of motion are the most common symptoms of impingement of the structures of the shoulder (Neer, 1972). An early classification system developed by Neer (1972) categorized impingement as stage I if there was edema and/or hemorrhage in people younger than 25 years old. This was seen as a reversible condition, and there was no permanent damage to structures or tissue tears. Stage II occurred with those 25 to 40 years of age, and there is evidence of irreversible tendon changes and fibrosis resulting in permanent scarring but no tissue tears. Stage III was seen in people over age 50 years and was a result of tendon rupture or tears, often due to longstanding fibrosis and tendinosis.

Since the development of this classification, impingement classification is focused on external or internal impingement. External impingement (also known as *outlet impingement or extrinsic*) is the most common type of impingement. This type of impingement involves compression of the rotator cuff muscles (primarily, the supraspinatus and then infraspinatus and biceps tendon) by the acromion. The rotator cuff muscles and subacromial bursa become impinged between the greater tuberosity and anterior one-third of the acromion. The compression occurs anteriorly with forward flexion. Other causes may be greater tuberosity fractures and humeral neck fractures (Woodward & Best, 2000). There may also be coracoid impingement, in which the pain is felt lower and more anteriorly than in the superior impingement. In this case, there would be decreased horizontal adduction and pain at the tip of the coracoid and not at the AC joint. External forces are those originating outside of the rotator cuff muscles and are largely mechanical.

Primary extrinsic causes are related to the acromion and coracoacromial arch. There may be bone spurs on the acromion, or the shape of the acromion may be more prone to impingement (a beaked shape due to genetic determination or degenerative changes has a higher incidence of impingement as compared to a curved or flat acromion). Similarly, there may be spurs or bursal scarring on the coracoacromial arch because of aging, disease (e..g, to rotator cuff atrophy, scapular weakness, increased thoracic kyphosis; Woodward & Best, 2000).

Secondary causes of external impingement are related to poor scapular stability, which changes the position of the scapula. The problem in secondary impingement is keeping the humeral head centered in the glenoid fossa. This is prevented by weakness in the rotator cuff muscles, resulting in functional instability and laxity in the GH capsule and ligaments. Secondary impingement occurs in the coracoacromial space secondary to anterior translation of the humeral head (Woodward & Best, 2000).

Internal impingement (nonoutlet or intrinsic impingement) occurs in the posterosuperior portion of the joint. It is more common in younger people and those involved in overhead sports. It is also known as an *athletic impingement* because of adaptive shortening and scarring of posterior rotator cuff and scapular muscles. Superior labral tear from anterior to posterior lesions, or injury to the superior labrum in the anterior-posterior portion of the joint, occur in overhead athletes. There is a loss of internal rotation and upward translation of the humeral head, and there may be excessive external rotation and/or recurrent anterior instability (Bach & Goldberg, 2006; Woodward & Best, 2000). This is due to impingement on the posterior labrum and glenoid and irritation of the rotator cuff and biceps tendons. The client will describe pain in the back of the joint due to irritation of the posterior fibers of the supraspinatus and irritation of the anterior fibers of the infraspinatus muscle. In advanced cases, the pain may shift to the front of the joint due to biceps tendon and labral involvement. Internal impingement results in a mechanical pain, activated upon specific movements; otherwise, it is asymptomatic (Woodward & Best, 2000).

Jobe's classification of impingement combines the factors of age, impingement, and instability. Grade I in the Jobe system is joint impingement without instability, usually in people older than 40 years with degenerative changes in the rotator cuff, coracoid, and anterior tissues. There may be intrinsic changes due to rotator degeneration, or there may be extrinsic factors (e.g., the shape of acromion or degeneration of the

Table 5-21

IMPINGEMENT TESTS FOR THE SHOULDER

- Neer impingement test
- Hawkins-Kennedy impingement test
- Reverse impingement sign (impingement relief test)
- Clancy impingement test
- Copeland impingement test
- Horizontal impingement test
- Posterior impingement test
- Coracoid impingement test
- Subcoracoid impingement test
- Glenohumeral internal rotation deficit test
- Posterior internal impingement test

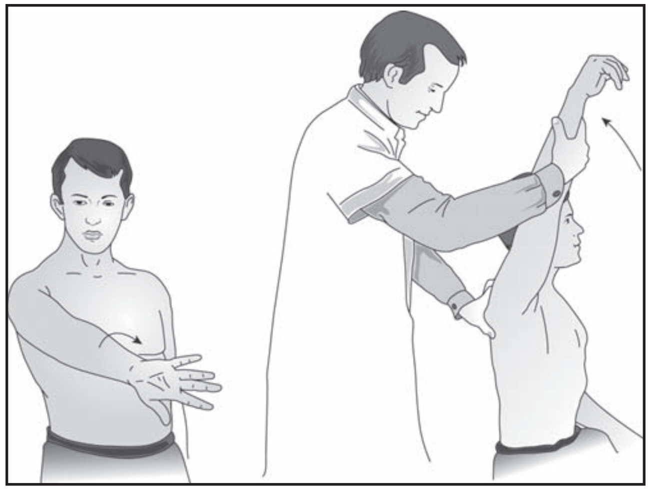


Figure 5-44. Neer impingement test.

coracoacromial ligament). Grade II is characterized by secondary impingement and instability caused by chronic capsule and labral trauma. Grade III is the result of secondary impingement and instability due to generalized hypermobility or laxity. Grade IV is primary instability with no impingement (Jobe et al., 1989; Kvitne & Jobe, 1993).

Deficient shoulder biomechanics, a cause of impingement, results when there is weakness in or tearing of the rotator cuff muscles (especially supraspinatus), GH instability, an anatomically prominent acromion process, inflammation of any of the subacromial structures (often the subacromial bursa), or stiffness of the posterior joint capsule (Ellenbecker & Ballie, 2010; Magee, 2014; Shafer, 1997; Wilk et al., 1997b). The compression of subacromial space may be due to inadequate rotation of the humerus during flexion and abduction. This results in movement of the greater tubercle closer to the acromion or excessive superior glide of the humeral head. The result may be abnormal scapulothoracic joint motion and rhythm and pain in the superior aspect of the GH joint during the mid-range of shoulder elevation. This in turn can lead to an inflammatory response and impingement syndromes (Oatis, 2004).

Because the cause of impingement is often faulty biomechanics, improving the joint biomechanics is an important part of treatment. Correcting joint capsule tightness and muscle imbalance (between the deltoid and rotator cuff muscles and strengthening scapular stabilizers) while using anti-inflammatory medications can help correct the structural limitations. Joint protection techniques and modification of activities are important ways to restrict motion through the painful ranges and ensure inferior joint capsule laxity. Postural evaluation is also an important part of ensuring full normal GH movement.

Many tests have been developed to assess shoulder impingement. Tests for shoulder impingement are listed in Table 5-21. The Neer impingement test is done by having the client fully pronate the arm (Figure 5-44). The examiner then stabilizes the scapula to prevent scapulothoracic motion and then forcefully elevates the arm in flexion, causing impingement of the rotator cuff tendons under the coracoacromial arch. When the arm is put in this position under the coracoacromial arch, the supraspinatus, infraspinatus, and long head of the biceps are at risk for impingement, degenerative tendonitis, and tendon ruptures (Gibson, 2010).

In the Hawkins-Kennedy impingement test, pain occurs as the greater tuberosity and the supraspinatus tendon impinge under the anterior surface of the coracoacromial ligament and coracoacromial arch. In this test, the arm is moved into 90 degrees of forward flexion and then forcibly internally rotated.

Strength/Muscle Assessment

Mobility in the shoulder is achieved by sufficient movement at joint surfaces and appropriate tension and movement in soft tissues. Testing the strength of shoulder muscles can be performed via manual muscle tests (muscle groups or isolated muscles) or using functional tests. In these tests, evidence of a contraction, the effect of gravity, and external resistance are used to assess the strength of the muscles. Observing the client during daily activities will also give information about how the client moves, if there is pain with movement, and if the movement is coordinated. It is also crucial that clients are asked about the areas in which they are limited and about their status in personally relevant outcomes. Impairment measures alone are not sufficient to base treatment (Roddey, Cook, O'Malley, & Gartsman, 2005).

Muscle strength screening requires that the client assume a particular position and is instructed to hold that position as the therapist applies resistance. Muscle screens are a quick way to get an overall appraisal of the strength of muscle groups involved in particular shoulder motions (Table 5-22). If limitations are noted or more specific information is needed about the degree to which a specific muscle is limited, a manual muscle test would then be done. Many ADL require only a fair muscle grade, such as placing a garment into a closet, washing the opposite side of the body, or reaching back to put an arm into a sleeve (Gutman & Schonfeld, 2003).

Resistive tests may also be done for evaluation of strength and provocation of pain. These are isometric tests, advocated by Cyriax (1982), to assess shoulder dysfunction. Six tests are recommended and include shoulder adduction, abduction, external rotation, internal rotation, elbow flexion, and elbow extension. If the client responds to the resisted movement with a strong, painless contraction, that is considered normal.

Table 5-22

STRENGTH SCREEN FOR THE SHOULDER

Muscle Action Tested	Instructions to the Client/Ask the Client to ...	Therapist's Action
Scapular elevation	Shrug their shoulder up toward the ear; tell them, "Don't let me push your shoulder down."	Apply resistance with palms toward the floor
Shoulder flexion	Raise their shoulder to 90 degrees in front of the body; tell them, "Don't let me push your arm down."	Apply resistance to mid-humerus toward extension
Shoulder extension	Raise their shoulder to 90 degrees in front of the body; tell them, "Don't let me push your arm up."	Apply resistance to mid-humerus toward flexion
Shoulder horizontal abduction	Raise their shoulder to 90 degrees with the elbow extended in front of them; tell them, "Don't let me push your arm."	Apply resistance to mid-humerus toward horizontal adduction
Shoulder horizontal adduction	Bring their hands together in front of the body; tell them, "Don't let me separate your arms."	Attempt to separate the arms into horizontal abduction
Shoulder abduction	Raise their shoulder out to the side to 90 degrees with the elbow; tell them, "Don't let me push your arm down."	Apply resistance to the mid-humerus into adduction
Shoulder adduction	Raise their shoulder out to the side to 90 degrees with the elbow; tell them, "Don't let me push your arm up."	Apply resistance to the mid-humerus into abduction
Shoulder external rotation	Bring their arm out to the side to 90 degrees abduction and bend the elbow to 90 degrees flexion and up in the air; tell them, "Don't let me push your arm down."	Apply resistance toward internal rotation
Shoulder internal rotation	Bring their arm out to the side to 90 degrees abduction and bend the elbow to 90 degrees flexion and down toward the floor; tell them, "Don't let me push your arm up."	Apply resistance toward external rotation

If the result is a strong but painful contraction, this may indicate a minor muscle or tendon lesion. For example, painful resisted abduction and external rotation may indicate rotator cuff disease. Weak and painful responses may indicate a gross traumatic lesion, such as a fracture or the rupture of muscle or tendon. A weak and painless result may indicate neurologic dysfunction or muscle and tendon rupture (Donatelli & Wooden, 2010). A description of various shoulder disorders by characteristic motion patterns with resistance is shown in Table 5-23.

Another aspect of muscle evaluation is the evaluation of the synchronized muscle contractions and relaxation during movement, which is known as *muscle patterning*. If the contraction/rest patterns of the shoulder muscle are altered, then shoulder instability can result. While muscle pattern instability may begin in younger clients who voluntarily dislocate or sublux their shoulder, joint mechanics may deteriorate so that the shoulder dislocates repeatedly and involuntarily. If this pattern continues, the client may not perceive the involuntary dislocation to be abnormal and may easily dislocate the shoulder by coughing or sneezing. The focus of intervention for positional or patterning instability is to regain normal neuromuscular control to allow full return to daily occupations (Funk, 2005).

Specific tests for muscle tendon pathology are listed in Table 5-24. Manual resisted muscle testing is used to help isolate the etiology of the impingement and in making differential diagnoses of muscle pathology. An example of this is Speed's test, which is used to assess the proximal tendon of the long head of the biceps. In this test, the examiner resists forward flexion of the shoulder distally at the wrist while the client is in supination and the elbow is extended. Pain would be elicited in the bicipital groove or cubital fossa for a positive sign (Gibson, 2010; Shafer, 1997).

The Yergason test (Figure 5-45) is a test of biceps tendon instability or tendonitis. The client's elbow is flexed to 90 degrees and stabilized against the thorax with the forearm pronated. The therapist resists forearm supination while the client externally rotates the arm. A positive sign is when pain is elicited in the bicipital groove, suggesting pathology in the long head of the biceps in its sheath (Gibson, 2010). Inflammation of the biceps tendon frequently occurs when there is rotator cuff tendonitis.

The lift-off test (Gerber's test) is a test of subscapularis rupture or dysfunction. The client places his or her hand behind the back with the dorsum of the hand resting in the mid-lumbar region. The client then raises the hand off the back, maintaining internal rotation of the humerus. Inability to lift the hand off the back would indicate subscapularis dysfunction. A modified version of the lift-off test is useful for clients who cannot place the hand behind the back. Instead, the client places the hand on the abdomen and resists attempts by the therapist to externally rotate the arm.

Table 5-23

Motion Patterns and Common Causes of Dysfunction

Characteristic Motion Pattern	Movement	Common Causes
Full passive motion with painful resisted	Abduction	• Deltoid strain • Supraspinatus strain
	Adduction	• Bicipital (long head) strain • Latissimus dorsi strain • Pectoralis major strain • Teres (major and minor) strain
	Internal rotation	• Latissimus dorsi strain • Pectoralis major strain • Subscapularis strain • Teres major strain
	External rotation	• Infraspinatus strain
	Forward movement	• Bicipital strain • Coracobrachialis strain
	Elbow flexion and supination	• Bicipital (long head) strain
	Elbow extension	• Triceps strain
Full passive motion with painless weak	Deltoid	• Axillary nerve lesion
	Deltoid, biceps, and spinatus group	• C5 lesion • Myeloma • Traction palsy
	Spinatus group alone	• Suprascapular neuropathy
	Supraspinatus alone	• Supraspinatus tendon rupture
	Infraspinatus alone	• Infraspinatus tendon rupture
	Serratus anterior	• Long thoracic neuropathy
	Weak trapezius	• Spinal accessory neuropathy
	Weak biceps and forearm muscles	• C5 lesion
	Weak triceps and forearm muscles	• C6 lesion

Adapted from Shafer, R. C. (1997). Shoulder girdle trauma: Monograph 16. Retrieved from http://www.chiro.org/ACAPress

There are several tests for supraspinatus. One is the empty can test (also known as *Jobe test* or *supraspinatus test*). The client attempts to elevate the arm against resistance with the elbows extended and the arms abducted and in external rotation. Other tests include Apley's scratch test, Dawburn's sign, Sherry party sign, Codman's sign (Drop arm sign), Rent test, Zero degree abduction test, and the Scapular retraction test.

Pain Assessment

There is a high incidence of shoulder pain due to a variety of reasons. Table 5-25 provides a few examples of extrinsic, intrinsic, and psychological causes of pain. Pain can be due to intrinsic or extrinsic causes, can be traumatic or atraumatic, can be chronic or acute, or even can be referred from other locations and structures. The assessment of shoulder pain necessitates an accurate history and interview with the client about when, where, and how the pain is elicited.

Intrinsic causes of shoulder pain may be due to joint and muscular impairments that are within the shoulder joint. Causes of intrinsic shoulder pain may include shoulder instability, nerve and muscle impingement, fractures, tendonitis, myositis ossificans, adhesive changes (adhesive capsulitis), or neurovascular injuries. Pain can be referred from a shoulder muscle to another part of the shoulder or arm. For example, referred pain from the rhomboids may go to the medial border of the scapula. The infraspinatus may refer pain to the anterolateral shoulder and medial border of the scapula or down the lateral aspect of the arm. If pain is felt near the deltoid insertion, up the shoulder, and down the lateral arm to the elbow, this may be referred pain from the teres minor (Magee, 2014). The pain the client experiences is also influenced by the

Table 5-24

Tests of Muscle Tendon Pathology

Muscle	**Test**	
Biceps	• Speed's test* • Speed's maneuver test • Biceps test • Abbott-Saunders test • Transverse humeral ligament test • Snap test	• Hueter sign • Duga sign • Beru sign • Traction test • Compression test • Yergason's test*
Infraspinatus	• Infraspinatus test* • Infraspinatus/teres minor (lateral rotation)	• External lateral rotation lag sign*
Subscapularis	• Lift-off test (Gerber's test)* • External (lateral) rotation lag sign*	• Lag or "spring back" tests (subscapularis [medial rotation])* • Bear-hug test
Supraspinatus	• Empty can test (Jobe's test)* • Apley's scratch test • Dawbarn's sign • Sherry party sign	• Codman's sign (drop arm sign) • Rent test • Zero-degree abduction test • Scapular retraction test
Ligament pathology	• Crank test* • Posterior inferior glenohumeral ligament test	• Coracoclavicular ligament test
Additional tests	• The dropping sign (Walch) • French horn shoulder test (internal and external rotation) • Internal rotation resistance strength test • Ludington's test • Gilchrest's sign • Lippman's test • Heuter's sign • Abrasion sign • Codman (drop-arm) test • Abdominal compression (belly-press) test	• Lateral scapular slide test/scapular load test • Wall pushup test • Scapular retraction test • Hornblower's (Signe de Clairon) sign • Teres minor test • Pectoralis major contracture test • Belly off sign • Belly press/Napoleon sign

*Indicates moderate to strong evidence support.

Adapted from Magee, D. J. (2014). *Orthopedic physical assessment* (6th ed.). St. Louis, MO: Elsevier.

emotional status of the individual, especially for those clients who are experiencing depression, anxiety disorders, adjustment disorders, or psychosis. The assessment and intervention are directed toward therapeutic change in the whole person, which includes awareness of the mind-body connections.

Specific extrinsic causes of shoulder pain might be a herniated cervical disc (common at C5 to C6), where pain may radiate from the neck into the whole upper extremity accompanied by paresthesias and sensory loss in corresponding dermatomal regions. Pain is often referred from viscerosomatic reflexes from the liver, gallbladder, and right diaphragm to the right shoulder and from the stomach, left diaphragm, and heart to the left shoulder. Pain that is not easily reproduced suggests a visceral origin (Shafer, 1997).

Pain is often referred to the shoulder from other areas, and the pain experienced in the shoulder region may well be due

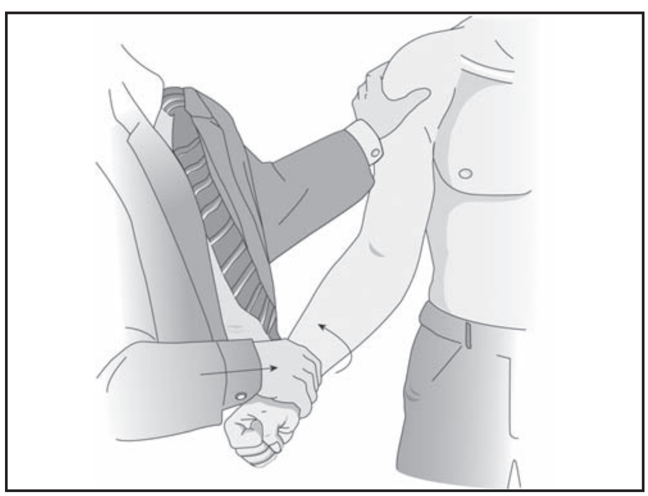


Figure 5-45. Yergason test for biceps tendonitis.

Table 5-25

Causes of Shoulder Pain

Extrinsic Causes

- Brachial plexus injury
- Cervical spondylosis
- Cervical disc herniation
- Syringomyelia
- Thoracic outlet syndrome
- Diaphragmatic irritation
- Lung tumor(s)
- Brachial neuropathy
- Myocardial ischemia
- Contusions/lacerations
- Neuropathy
- Referred pain
- Vascular disorders

Intrinsic Causes

- Instability
- Impingement
- Fractures
- Arthritis
- Myositis ossificans
- Tumors
- Neurovascular injury
- Bursitis
- Dislocation
- Adhesive capsulitis
- Lax shoulder stability
- Nerve contusion
- Complex regional pain syndrome
- Rotator cuff lesions
- Sprains/strains
- Subluxation/fixation
- Tendonitis/tendinosis

Psychological Causes

- Depression
- Anxiety disorders
- Adjustment disorders
- Somatoform disorders
- Factitious disorders
- Malingering
- Psychosis

to lesions and trauma from other structures and organs of the body. For these reasons, the following extrinsic problems first must be ruled out prior to attributing the cause of shoulder pain to shoulder girdle joints or muscles (Hartley, 1995):

- Heart problems: Myocardial infarction, angina, pericarditis, which may radiate pain to the left shoulder
- Lung or diaphragm problems: Spontaneous pneumothorax, pulmonary tuberculosis, lung cancer, abscesses, Pancoast tumor, which can relay pain along the same nerve roots of C4 and C5
- Chest problems: Aortic aneurysm, nodes in the axilla or mediastinum, breast disease, hiatal hernia, which can refer pain to the local area and shoulder
- Cervical problems: Intervertebral disc herniation or degeneration, facet joint effusion, nerve root irritation, which may also radiate pain to shoulder and scapula
- Pain radiating below the elbow with decreased cervical ROM may indicate cervical disc disease
- Spinal fracture: Cervical or thoracic fracture can radiate pain to the shoulder as well as produce local pain
- Elbow problems: Humeroulnar, humeroradial, or radioulnar joint dysfunction or pathology can also refer pain into the shoulder and humerus
- Temporomandibular joint problems due to degeneration or effusion can refer pain down the neck into the shoulder
- Rib problems: costovertebral joint or costosternal joint dysfunction
- Thoracic spine problems
- Abdominal problems: Ruptured spleen and pancreas pathology can refer pain to the left shoulder; liver pathology and gallbladder disease can refer pain to the right shoulder

Pain assessments start with asking the client about the pain he or she is experiencing. Often, clients are asked to show where the pain is or to indicate where the pain is on a body map or diagram. Pain is less likely to be referred if the therapist can reproduce the pain in the structure indicated by the client with gentle palpation.

Have the client describe how the pain feels. If there is a sharp, localized pain, this might suggest an acute inflammatory process, such as a muscle strain. Sharp, burning, and radiating pain may indicate a neurological disorder. A dull ache that is poorly localized may suggest referred pain from another part of the body. Differentiate stiffness from pain and elicit information from the client about the sensations he or she may be experiencing, such as grating, clicking, or snapping sensations. For example, if pain and a clunking sound are heard with overhead movement, this may indicate a labral disorder. Table 5-26 lists some possible structures that may be responsible for pain, as described by clients.

A thorough exploration of the history of the shoulder pain is essential to the assessment. Determining if this is the first time the client has had pain, if there was a precipitating event, or if there were any unusual activities involved are important to understanding the mechanism and underlying problems related to the client's pain. Shoulder pain may have an inflammatory, neurologic, psychologic, vascular, metabolic, neoplastic, degenerative, congenital, autoimmune, or toxic origin in addition to pain because of direct trauma (Shafer, 1997).

A sudden onset due to acute trauma may result in muscle strain, and the client can often recount the circumstances surrounding when and how the injury occurred. A gradual onset suggests an injury that is progressively worsening or other nonmusculoskeletal causes. Be sure to ask the client about possible repetitive causes of muscle strain, such as poor posture and static positioning during activities that can affect shoulder function and pain. Recurrent pain may be linked to stress, so discussion with the client about stressors may be helpful. Understanding what causes the part to feel better or worse may lead to an understanding of the type of activities or movements that aggravate the condition and the timing of the pain (morning or night, constant or intermittent). Client-based measures of pain and function have been shown to reliably assess outcomes after surgery to the shoulder (Dawson, Hill, Fitzpatrick, & Carr, 2001).

The Shoulder pain and disability index is used to assess pain and disability specifically in the shoulder. There are 13 items, with 5 items in the pain subscale and 8 in the disability subscale. This tool takes 5 to 10 minutes to administer and requires no formal training (Roach, Budiman-Mak, Songsiridej, & Lertratanakul, 1991). Additional measures of adult shoulder function include DASH and its short version, QuickDASH (Beaton et al., 2005), Shoulder Pain and Disability Index (Roach et al., 1991), American Shoulder and Elbow Surgeons Society Standardized Shoulder Assessment form (Richards et al., 1994), Constant (Murley) score (Constant & Murley, 1987), Simple Shoulder Test (Brophy et al., 2009), Oxford Shoulder Score (Dawson, Fitzpatrick, & Carr, 1996), Shoulder Disability Questionnaire (van der Heijden, Leffers, & Bouter, 2000), Western Ontario Shoulder Instability Index (Salomonsson, Ahlström, Dalén, & Lillkrona, 2009), and Single Assessment Numeric Evaluation (Angst, Schwyzer, Aeschlimann, Simmen, & Goldhahn, 2011; Williams, Gangel, Arciero, Uhorchak, & Taylor, 1999).

Pathology of the Shoulder

Subluxations and dislocations of the shoulder occur most often in the anterior direction and are usually due to an external force that disrupts articulating joint surfaces. Sprains occur most frequently to the AC joint and are usually the result of a fall or direct blow to the joint or a fall on the elbow. There is pain with joint motion, tenderness, and varying degrees of deformity. The SC joint ligaments can be sprained by direct blows to the sternum or indirectly from a fall with the arm extended. Again, there will be localized pain over the joint, limited motion, and varying degrees of deformity.

Muscle strains frequently occur due to overuse, overfatigue, or weakness in specific muscles. Supraspinatus strain or tendonitis can be tested via the empty can test and the drop arm test. Subscapularis strain and function are assessed with the lift-off test (Gerber test), and Speed maneuver (biceps or straight-arm test) is used to test the biceps tendon instability or tendonitis. Tendonitis and strain usually precede bursitis and may be present simultaneously, and these are sometimes difficult to differentiate on physical exam. Pain that is elicited with both passive and resistance tests is likely due to bursitis and not tendonitis. Bursitis at the shoulder usually involves the subacromial bursa preceded by tendonitis/tenosynovitis of the rotator cuff. This occurs when weak rotator cuff muscles allow the humerus to move up into the acromion, pressing on the bursa and causing inflammation. Treatment for muscle and tendon strains and bursitis initially consists of ice, modalities, stretching, and friction massage followed by progressive eccentric strengthening.

If fibrosis of the joint capsule occurs, adhesive capsulitis may result, usually because of muscle strain, tendonitis, bursitis, or impingement. Onset is usually at age 40 to 60 years, and there are different types of adhesive capsulitis (Table 5-27). Treatment often involves stretching the capsule, use of modalities, joint mobilization techniques, and functional activities. Tests for labral lesions, neurological involvement, thoracic outlet syndrome, and ligamental pathology and assessment for the AC and SC joints are listed in Table 5-28.

The biomechanical treatment approach is commonly used to treat the orthopedic joint and muscle dysfunctions of the shoulder. Please see Chapter 11 for theoretic principles and treatment suggestions using this treatment approach.

In a systematic review of 22 studies of occupational therapy interventions for work-related shoulder conditions, the implementation of occupational therapy intervention is primarily in the realm of preparatory activities. The activities supported by this study include ROM and exercise, conservative management, joint mobilization, laser therapy, electromyogram (EMG) feedback, and Feldenkrais. Occupational therapy intervention was supported for shoulder instability, subacromial impingement syndrome and thoracic outlet syndrome. The authors advocate for additional research on occupation-based interventions for clients with shoulder limitations (von der Heyde, 2011).

Table 5-26

Descriptions of Shoulder Pain and Possible Affected Structures

Description	Structures That May Be Affected
Sharp	• Superficial muscles or tendon • Acute bursitis • Injury to the periosteum • Acute inflammatory response
Dull	• Tendon sheath • Deep muscle (serratus anterior or subscapularis) • Bone • Referred pain
Ache	• Deep muscle (subscapularis, teres minor) • Deep ligament (GH, coracoclavicular) • Tendon sheath or fibrous capsule • Chronic bursitis
Radiating ache	• Angina pectoris • Bursitis • Capsule adhesions • Fracture • Pancoast's tumor • Periarthritis • Rib subluxation • Complex regional pain syndrome • Subluxation (cervical or shoulder) • Neurological process
Pins and needles	• Peripheral nerve injury • Dorsal root of a cervical nerve
Tingling	• Circulatory or neural structure (thoracic outlet, brachial plexus, brachial artery, etc.)
Numbness	• Cervical nerve root • Peripheral cutaneous nerves
Twinges	• Subluxation • Muscle strain • Ligamentous sprain
Stiffness	• Capsular swelling • Arthritic changes • Muscle spasms
Timing of pain	• Night pain may suggest inflamed bursa, vascular, or metastatic disease • Sleeping postures can affect shoulder pain • Pain with specific movements suggests musculoskeletal problem, possible capsular or impingement problem
Swelling and tenderness (neck or shoulder)	• Arthritis • Cellulitis • Contusion • Dislocation • Fracture • Sprain • Strain • Subluxation (acute)

Table 5-27

SHOULDER PATHOLOGY

SENSATIONS	
Clicking	• Glenoid labrum tear • GH subluxation
Snapping	• Biceps tendon • Thickened bursa under acromion during abduction
Grating	• Osteoarthritic changes • Calcium in joint • Thickened bursa
Locking or catching	• Calcium in joint • Piece of articular cartilage fractured off humerus or labrum
Warmth	• Inflammation • Infection
CONTUSION	• AC joint most frequently affected • Frequent deltoid contusions if shoulder pad not worn in sports activities • Contusions on upper arm over biceps and triceps common because these are below shoulder pads • Deltoid mid-belly contusions in hockey and lacrosse where sticks are used • Coracoid process can be contused when marksman gun recoils
FRACTURE	
Clavicle	• Greenstick fracture of shaft frequent in children and preadolescents • Distal end of clavicle when acromion hits downward • Most common site of clavicular fracture is junction of middle and outer third of the clavicle • Acromion can fracture when there is a fracture of distal end of clavicle or due to a direct blow down over acromion
Scapula	• Fractures are rare • Direct blows, with the exception of glenoid rim fractures, which are usually in association with dislocations
Humerus	• Often due to a fall on outstretched arm, but can be direct blow • Concerns due to relation of the axillary nerve proximally and radial nerve in middle third as it passes through spiral groove • Hill-Sach's lesion, which is a compression fracture or defect in posterolateral humeral head due to repeated trauma • Humeral neck fracture or avulsion of greater tuberosity • Brachial plexus or axillary nerve damage may occur • Stress fractures are rare
SUBLUXATION	• May occur from traumatic injury or loose capsular ligaments

(continued)

Table 5-27 (continued)

Shoulder Pathology

Dislocation/ Separation	
GH	• Anterior dislocation frequent due to indirect force, such as fall on outstretched arm or elbow • Subscapularis is primary rotator cuff responsible for prevention of anterior displacement • Degenerative and traumatic injuries, especially sports • Often due to trauma to joint where there is excessive external rotation and abduction • Damage can be to anterior GH capsule or ligamental sprain or tear • Injury to the glenoid rim and anterior capsule ligaments detach and do not stabilize the humeral head when the anterior joint capsule becomes stretched and loose from the humerus
Glenoid labrum	• Usually labral pathology is associated with shoulder dislocations • Bankart lesion • Hill Sach's lesion • SLAP lesion
AMBRI dislocations—hyperlaxity of connective tissue	• A = atraumatic • M = multidirectional • B = bilateral • R = rehabilitation, not surgery • I = instability
AC	• Due to trauma to the acromion, which forces it under the end of the clavicle, resulting in a noticeable stepoff between the acromion and clavicle • If force is significant, the joint capsule may be disrupted and the coracoclavicular ligament ruptured • First-degree separation/type I: Involves stretching the ligaments; treatment is reduced activity and use of sling • Second-degree separation/type II: Involves rupture of the joint capsule and coracoclavicular ligament but joint continuity maintained; either conservative treatment or surgical repair • Third-degree separation/type III: Involves total disruption of the joint and rupture of the coracoclavicular and AC ligaments; treatment is open reduction and surgical repair • Types IV and V: Damage to trapezius and deltoid muscles; treatment is open reduction and surgical repair
SC	• Most common injury is anterior or superior displacement • If acute posterior dislocation occurs, requires emergency reduction due to proximity to trachea, subclavian artery and vein, aortic arch, and esophagus • Rarely dislocated due to position in body; if dislocation occurs, there is very little discomfort or dysfunction
Sprains	• Ligaments can be sprained or torn with displacement • Degenerative and traumatic injuries, especially sports • Fall on point of shoulder with arm adducted • Fall on outstretched arm • Fall on olecranon of elbow • Blow from behind with ipsilateral arm fixed on ground • Traction of humerus pulling acromion away from clavicle • Direct blow over acromion

(continued)

Table 5-27 (continued)

Shoulder Pathology

Strains	• Most common strains are to: ◦ Internal rotators: Subscapularis, latissimus dorsi, teres major, pectoralis major ◦ External rotators: Infraspinatus, supraspinatus, teres minor, long head of biceps at superior tip of labrum • Frequently seen with the varying grades of impingement or due to repetitive loading, muscle overuse and overfatigue
Supraspinatus tendonitis/strain	• Common sites are just before the insertion on the greater tuberosity and at the musculotendinous junction
Bicipital tendonitis/strain	• Often associated with tendonitis of the rotator cuff; cuff tendonitis can be misdiagnosed as biceps tendinitis • True tenosynovitis of the long head of the biceps is found under and just distal to the transverse humeral ligament • It is usually the result of overuse, a direct blow, or laxity of the transverse humeral ligament resulting in subluxation of the tendon
Overstretch injuries	• Often involve nerve damage or injuries and is due to overly forceful muscle contractions
Tendonitis	• Bankart lesion • Hill Sach's lesion • SLAP lesion • Painful arc with ROM and with isometric resistance and when muscle is stretched • Muscle contraction strong unless there is a tear • Tenderness over tendon when palpated
Bursitis	• Due to trauma or overuse so that the bursae become inflamed • Similar to acute tendonitis
Acute Conditions	• Rheumatoid arthritis (acute exacerbation) • Osteoarthritis • Trauma • Diabetes mellitus • Mircrotrauma from poor posture • Immobilization • Ischemic heart disease or stroke
Subacute and Chronic Conditions	• Osteoarthritis • Metastasis in acromion • Rheumatoid arthritis

(continued)

Table 5-27 (continued)

Shoulder Pathology

Frozen Shoulder: Capsular Pattern/ Adhesive Capsulitis	• Aged 40 to 60 years, unknown cause
	• Freezing = intense pain even at rest and limitation of motion 2 to 3 weeks following onset
	• Frozen = pain only with movement; substitute patterns to achieve motions of the scapula; atrophy of the deltoid, rotator cuff, biceps, and triceps muscles occurs
	• Thawing = no pain but significant capsular restrictions
	• Spontaneous recovery occurs in an average of 2 years after onset
	• Inappropriately aggressive treatment will prolong this condition, and treatment at the wrong time may prolong symptoms
	• If there is no external rotation, abduction is limited to 75 degrees and flexion to 100 degrees = severe
	• If there is 30 degrees external rotation, abduction to 100 degrees and flexion to 120 degrees = moderate impairment
	• Types:
	  ◦ Primary: Idiopathic, spontaneous onset of painful shoulder; insidious for no reason
	  ◦ Progressive: Women more than men; symptom is pain, nontraumatic, and the condition runs its course; steroids help a little but don't change rate of recovery
	  ◦ Secondary/traumatic adhesive capsulitis. Other injury leads to immobilization; shoulder becomes stiff and joint tissues shortened

Overuse Injuries Shoulder Impingement	• Impingement syndromes as seen in overhand tennis stroke, front crawl, butterfly swimming strokes and side arm and overhand throwing actions
	• Process: Microtrauma and inflammation → instability → subluxation → impingement
	• Biceps tendon and rotator cuff often affected as these pass through the acromial space
	• May be due to an insufficiently stabilized humeral head (due to weakened rotator cuff or biceps, which allows more movement; weak supraspinatus or infraspinatus)
	• May be inflammation, tendon damage, bony malformations, poor posture
	• Impingement classification
	  ◦ Grade I: Reversible inflammation and edema, frequently of the long head of the biceps or supraspinatus tendon
	    ▫ Pain is in a specific arc of movement
	    ▫ Most common in people between the ages of 16 to 20 years
	  ◦ Grade II: Inflammation with slight tearing/fraying of the rotator cuff and occasionally a subacromial bursitis
	    ▫ May be degenerative changes, such as osteophyte formation
	    ▫ Usually involves people between the ages of 30 and 45 years
	  ◦ Grade III: Severe fraying or a complete tear of the tendon of the supraspinatus or, less frequently, the long head of the biceps
	    ▫ Bone spurs present
	    ▫ More often seen in people older than 45 years

Neurological	
Thoracic outlet syndrome	• Compression, irritation, or direct injury of major structures within the thoracic outlet such as the subclavian vein, subclavian artery, and the brachial plexus • May be neurogenic, venous (effort induced or Paget Schroetter's syndrome), or arterial • Symptoms often develop due to poor posture and muscle tone • Burning, numbness in shoulder and ulnar side of forearm and hand, and decreased radial pulse

Table 5-28

Tests of Shoulder Pathology and Tests for Specific Joints

Neurological Involvement	• Upper limb tension test (brachial plexus tension) • Tinel's sign (at the shoulder)
Thoracic Outlet Syndrome	• Roos test (elevated arm stress test) • Wright test or maneuver • Costoclavicular syndrome (military brace) test • Provocative elevation test • Shoulder girdle passive elevation • Adson maneuver • Halstead maneuver
Fracture	• Comolli sign
Bursitis	• Dawburn's test
Ligament Pathology	• Crank test • Posterior inferior glenohumeral ligament test • Coracoclavicular ligament test
Labral Lesions	• Clunk test • Anterior slide test • The SLAP prehension test • Biceps tension test • Posterior labral tear • Push-pull test • Jahnke jerk test • Biceps load test 1 • Biceps load test 2 • Pain provocation test
Acromioclavicular Joint	• Acromioclavicular shear test • Anterior/posterior acromioclavicular shear test • Acromioclavicular crossover, crossbody, or horizontal adduction test • Ellman's compression rotation test • Alternate test for the acromioclavicular joint/shoulder depression test (for sprains) • Cross-chest adduction (scarf/forced adduction) test • Cross-arm test • Forced adduction test on hanging arm • Dugas test • Acromioclavicular distraction (bad cop) test • Paxino's test • O'Brien's test
Sternoclavicular Joint	• Sternoclavicular joint test/sternoclavicular squeeze test (sprains) • Sternoclavicular joint stress test • Scapula pinch/retraction test (for scapula stability) • Thompson and Kopell horizontal flexion test
Cervical Spine	• Spurling's test

Summary

- The shoulder is a complex joint with multiple articulations that enable movement in all planes and axes.
- The sternocostal and vertebrocostal joints enable full shoulder flexion and abduction due to gliding of the ribs on the sternum and vertebra.
- The suprahumeral articulation is a functional joint serving in a protective capacity, preventing trauma from above, upward dislocation of the humerus, and limiting abduction of the humerus.
- The scapulothoracic joint is also a functional joint that provides a movable base for the humerus, permitting wide ranges of movement of scapula and thorax. This joint also provides stability in the GH joint during overhead activities.
- The GH articulation is an incongruous joint because the bony surfaces are not in direct contact for most movements. Stability is achieved by the joint capsule and muscles of the joint as well as ligaments. Surface motion is mainly rotational but also includes some rolling and gliding. Shoulder motion, especially elevation, is governed by force couples, with the interaction of the deltoid muscle and oblique rotator cuff muscles a good example. Because this is a ball-and-socket joint, all motions are possible.
- The AC joint is also considered an incongruent joint, and the weak joint capsule is reinforced by ligaments and muscles adding to the stability of the joint.
- The SC joint is the only true articulation of the shoulder girdle with the trunk. Motions possible at this joint include elevation and depression and protraction and retraction. These motions demonstrate a reciprocal movement pattern between the SC and AC joints.
- All of the joints work together smoothly and synchronously with scapulohumeral rhythm. Generally, a ratio of 2:1 is accepted as the degree of contribution of the GH articulation and the contributions of the scapulothoracic articulations.
- Shoulder flexion/extension, and abduction/adduction occur in phases with differing levels of contribution of different joints during different phases.
- Many muscles contribute to the movement and stability of the shoulder. How much contribution a specific muscle makes to a particular movement is dependent on the axis and plane of motion, the position of the humerus, the other muscles that are involved, the resolution of the angle of pull of the muscle fibers, and the size of the muscle.
- Evaluation of the shoulder would include an assessment of pain; observation for changes in soft tissue, stability, symmetry, and alignment; active and passive ROM; and the client's participation in areas of occupation.

Figures 5-1, 5-3, 5-4, 5-5, and 5-6 are adapted from Biel, A. (2001). *Trail guide to the body*. Boulder, CO: Books of Discovery.

Figures 5-11 and 5-27 are adapted from Neumann, D. A. (2002). *Kinesiology of the musculoskeletal system: Foundations for physical rehabilitation*. St. Louis, MO: Mosby.

Figure 5-16 is adapted from Bowen, M. K., & Warren, R. F. (1991). Ligamentous control of shoulder stability based on selective cutting and static translation experiments. *Clinical Sports Medicine*. *10*(4), 757-782.

Figures 5-18, 5-20, and 5-21 are adapted from Muscolino, J. E. (2006). *Kinesiology: The skeletal system and muscle function*. St. Louis, MO: Mosby.

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6

The Elbow

Melinda F. Rybski, PhD, MS, OTR/L

The elbow joint and motion of the forearm are important in enabling proper positioning of the hands and fingers in space and permitting height and length adjustments to be made during activities. Rotation of the forearm helps to place the hand closer to the face and to position the arm to enable the most beneficial length-tension relationships in muscles. The elbow joint assists the shoulder with force distribution and in stabilizing the upper extremity for both power and fine coordination.

The elbow joint is not one joint, but three: the humerus articulates with the radius (humeroradial or radiohumeral) and the ulna (humeroulnar or ulnohumeral), and the ulna and radius articulate with each other (the superior/proximal radioulnar articulation; Figure 6-1).

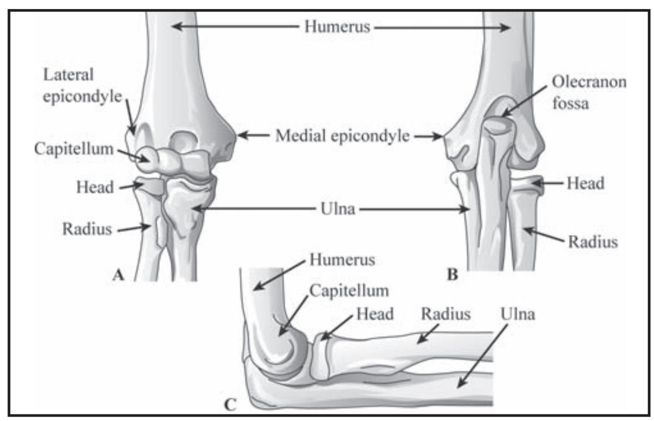

Figure 6-1. Articulations of the elbow.

Bones of the Elbow and Palpable Structures

The bones of the elbow include the humerus, ulna, and radius (Figure 6-2). Many of the bony structures are easily palpated.

Humerus

Epicondyles

These are the distal enlargements of the humerus. When the humerus is externally rotated, the medial epicondyle lies close to the body and is found easily as you move medially from the olecranon. It is large, superficial, and rounded. The medial epicondyle is known as the *flexor epicondyle* because many of the wrist and fingers attach here.

The lateral epicondyle points to the back when the humerus is externally rotated and can be found by moving laterally from the olecranon. The lateral epicondyle is known as the *extensor epicondyle* and is smaller than the medial epicondyle (Figure 6-3; Biel, 2016; Houglum & Bertoti, 2012).

The two epicondyles and the tip of the olecranon form an equilateral triangle when the elbow is flexed to 90 degrees and a straight line when the elbow is in extension (Figure 6-4).

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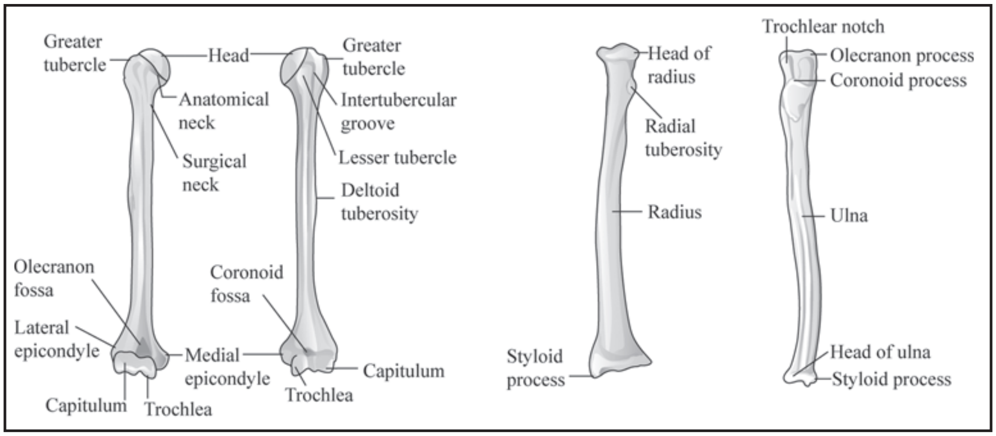

Figure 6-2. Bones of the elbow.

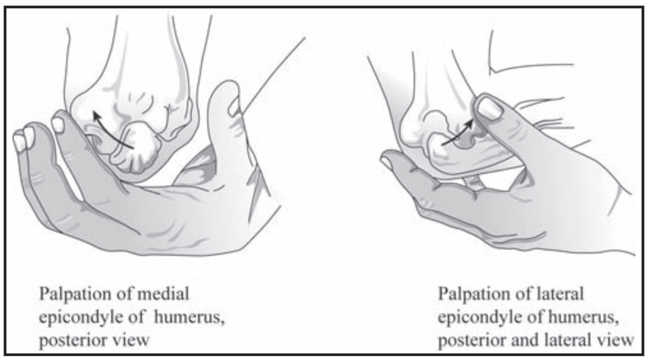

Figure 6-3. Palpation of the epicondyles of the humerus.

Ulna

Olecranon Process

This is the point of the elbow or the upper and posterior aspect of elbow, which is easily felt when the forearm is flexed to 90 degrees. The ulnar nerve runs in this area, which, when compressed, produces the tingling sensation and is referred to as the *funny bone*. This is the attachment site for the triceps brachii muscle. The olecranon fossa can also be felt around the top of the olecranon process as a small "crescent-shaped ditch" as you press through the triceps tendon (Figure 6-5; Biel, 2016).

Body of the Ulna

On the dorsal surface of the forearm, you can palpate the shaft of the ulna from the olecranon process to the distal end or head.

Head of the Ulna

This is the rounded projection on the dorsal surface of the forearm just proximal to the wrist. It is visible along the posterior and medial side of the forearm when in pronation (Figure 6-6).

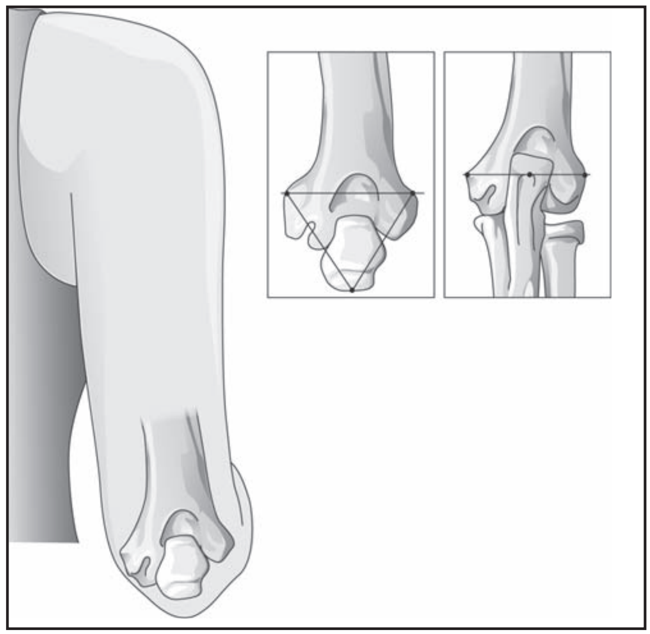

Figure 6-4. Equilateral triangle formed by the epicondyles and olecranon process.

Styloid Process of the Ulna

A small projection located on the posterior and medial aspect of the head of the ulna is the styloid process of the ulna, which is seen pointing distally off of the head of the ulna (Figure 6-7; Biel, 2016).

Radius

Head of the Radius

The head of the radius is distal to the lateral epicondyle of the humerus. With the elbow in extension, palpate the dorsal surface just distal to the lateral epicondyle of the humerus. Supinating and pronating the forearm will help in identifying this structure (Figure 6-8). Even minor effusions or mild synovitis can be palpated in the triangle formed by the lateral epicondyle, radial head, and olecranon (Figure 6-9).

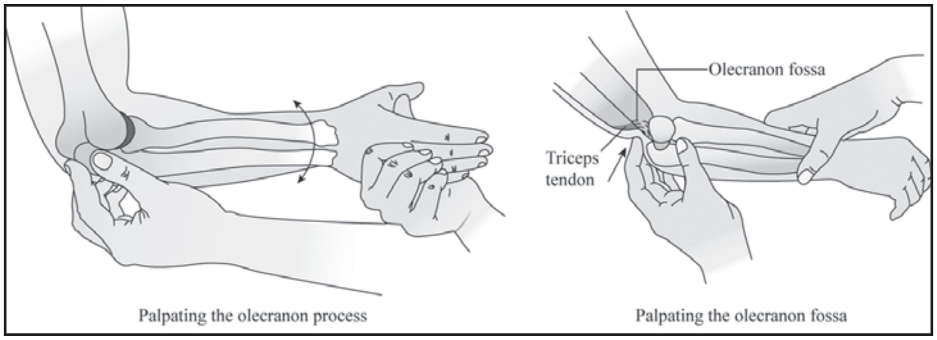

Figure 6-5. Palpation of the olecranon process and fossa.

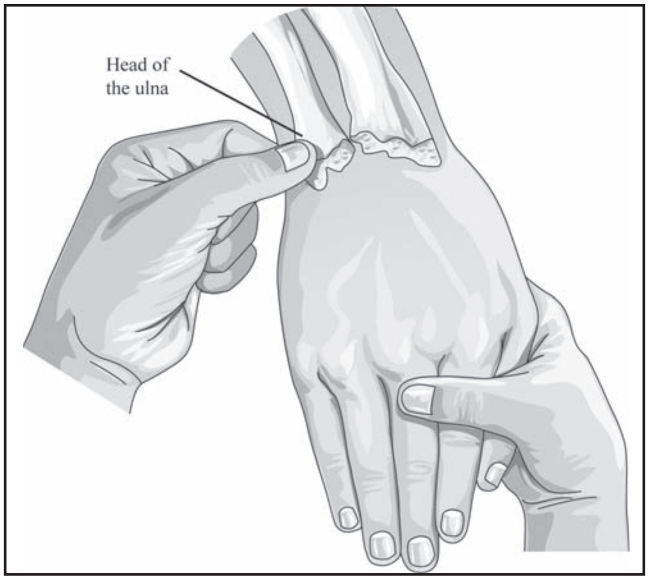

Figure 6-6. Palpation of the head of the ulna.

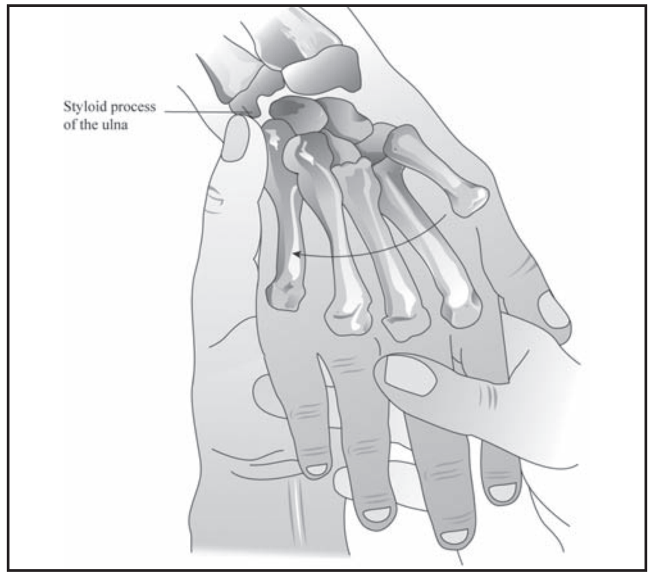

Figure 6-7. Palpation of the styloid process of the ulna.

Styloid Process of the Radius

Both the radius and ulna have styloid processes at their distal ends, but the radial styloid process extends further distally and is wider than the styloid process of the ulna.

The styloid process of the radius is located on the lateral aspect of the wrist proximal to the first metacarpal. It can be felt by following the distal radial shaft along the lateral side of the forearm, is surrounded by extensor tendons, and is the attachment site for the brachioradialis muscle (Figure 6-10; Biel, 2016).

Shaft of the Radius

You can feel the radial shaft on the lateral side of the forearm in the lower half of the forearm. Most of the shaft of the radius is located beneath muscle tissue and needs to be palpated at the distal portion of the shaft.

Lister's Tubercle

Lister's tubercle is located on the dorsum of the radius, about 1 inch laterally from the head of the ulna. The tendon of the extensor pollicis longus lies on the ulnar side of this prominence. It can be found by palpating on the dorsal surface of the radius moving toward the head of the ulna, and you will feel a superficial ridge. This tubercle can serve as a landmark to help in identifying the lunate and capitate carpal bones (Figure 6-11; Biel, 2016).

Non-Palpable Structures

The following are structures that are either too deep in the forearm to palpate or are difficult to differentiate due to overlying muscles and tendons (Houglum & Bertoti, 2012):

- Neck of radius
- Radial tuberosity
- Trochlear notch
- Capitulum of humerus
- Coronoid process of ulna

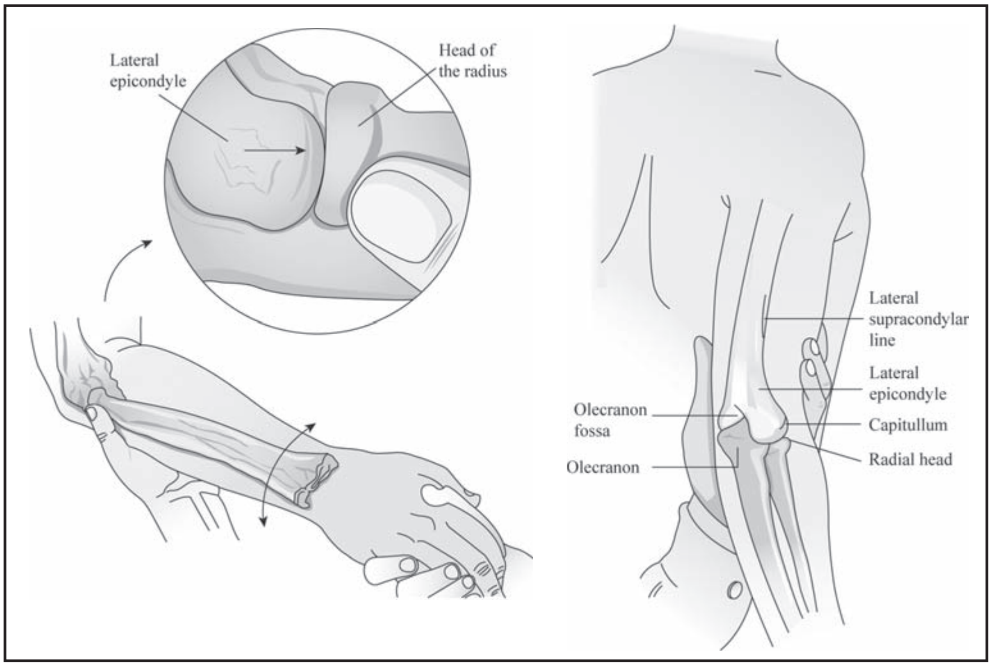

Figure 6-8. Palpation of the head of the radius.

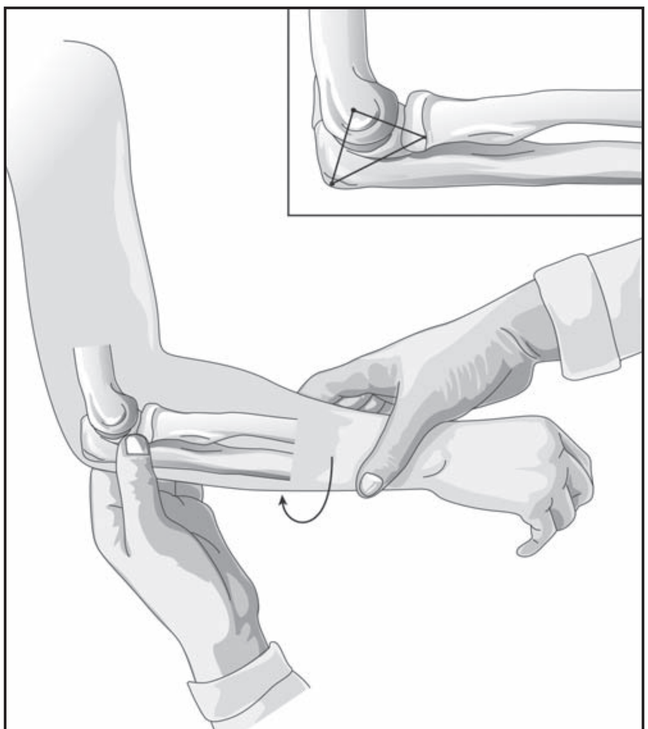

Figure 6-9. Palpation of the head of the radius, lateral epicondyle, and olecranon.

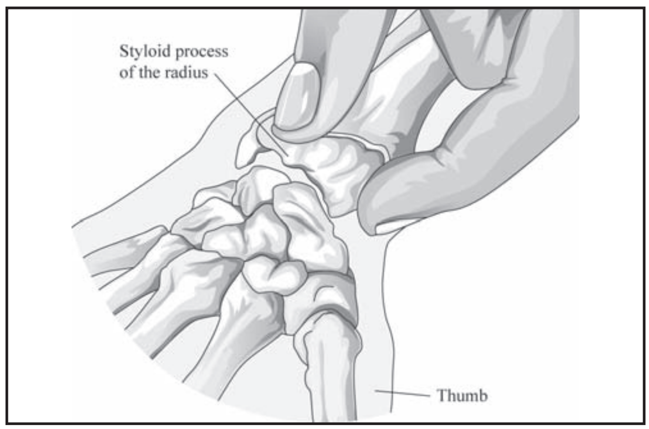

Figure 6-10. Palpation of the styloid process of the radius.

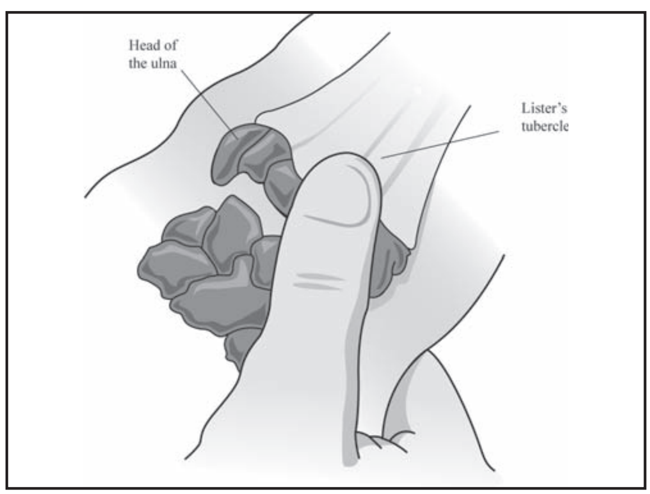

Figure 6-11. Palpation of Lister's tubercle.

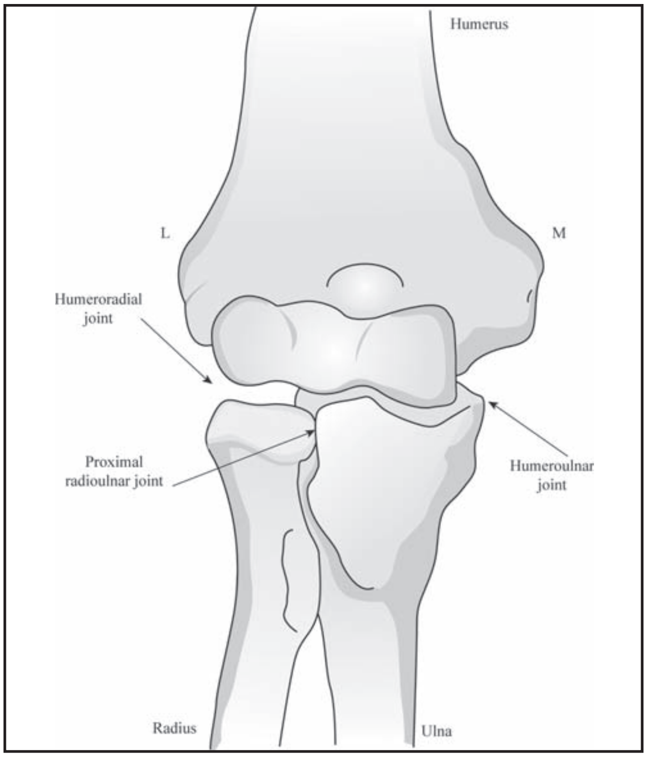

Figure 6-12. Separate joints of the elbow complex.

Articulations of the Elbow

The elbow joint has been classified as a compound uniaxial synovial hinge joint (Gench, Hinson, & Harvey, 1995; Jazrawi, Zuckerman, Young, & Day, 2012), as a multiarticulating biaxial joint (Hamill, Knutzen, & Derrick, 2015), and as a "composite trochleoginglymoid joint" (Jazrawi et al., 2012). The articulations of the humerus with the ulna and radius are uniaxial hinge/ginglymus joints, whereas the articulation of the ulna with the radius is a uniaxial pivot/trochoid joint (Figure 6-12). The articulations together provide 2 degrees of freedom at the elbow with the movements of flexion and extension and of pronation and supination.

Of the three articulations of the elbow, it is the humeroulnar and humeroradial joints that produce flexion and extension of the elbow. While the humeroulnar and humeroradial joints are generally seen to be uniplanar hinge joints, there are slight axial and side-to-side rotational movements that occur during flexion and extension (Magee, 2014; Neumann, 2010). Prosthetists need to consider these accessory motions in fabrication of elbow joint prostheses to avoid premature loosening of the orthotic device (Neuman, 2010).

Humeroradial Joint (Radiocapitular)

This joint is composed of the articulation of the capitulum and capitulotrochlear groove of the distal humerus with the head of the radius. In full extension, there is no contact between the capitulum and the radial head. In full flexion, the rim of the radial head slides into the capitulotrochlear groove and contacts the radial fossa. This joint is important in transmitting axial loads imposed on the elbow and accounts for about 60% of the loads imposed on the elbow (40% through the humeroulnar joint; Dumontier, 2010).

Table 6-1

Osteokinematics of the Humeroradial Joint

Functional Joint	Diarthrotic, uniaxial
Structural Joint	Synovial, hinge
Close-Packed Position	90 degrees elbow flexion, 5 degrees supination
Resting Position	Full elbow extension, full supination
Capsular Pattern	Flexion more limited than extension
Primary Muscles	Biceps brachii, brachialis, and pronator teres

Osteokinematics

The humeroradial joint is a uniaxial ginglymus (hinge) joint that allows for flexion and extension of the elbow in a sagittal plane around a frontal axis. The joint is structurally a synovial joint and, functionally, it is a diarthrosis uniaxial joint. This joint has 1 degree of freedom, and the resting position is with the elbow extended and the forearm fully supinated. When the joint is in full extension, there is no contact between the radius and humerus. The position of greatest stability, the close-packed position, is with the elbow flexed to 90 degrees and supinated to 5 degrees. In this position, the head of the radius is pulled against the capitulum and slides in the capitulotrochlear groove and into the radial fossa (Levangie & Norkin, 2011). The muscles primarily producing movement at this joint are the biceps, brachialis, and pronator teres. When there is synovitis or capsulitis of the elbow joint, the capsular pattern is that flexion will be more limited and painful than extension. A summary of the osteokinematics of the humeroradial joint is provided in Table 6-1.

Arthrokinematics

There are small accessory motions of the elbow but fewer than at shoulder, wrist, and fingers since there is stability due to congruence of the trochlea and capitulum and strong ligamental support.

Flexion and extension of the humeroradial joint occur as the concave proximal head of the radius glides and rolls with the convex capitulum of the distal humerus. As the elbow flexes and extends, the concave radial head slides on the convex capitulum in the same direction (Houglum & Bertoti, 2012; Kisner & Colby, 2012). The surface of the moving bone is concave, so sliding occurs in the same direction as the movement of the bone (see convex-concave rule #2 from Chapter 2). A summary of the arthrokinematics of the humeroradial joint is provided in Table 6-2.

Table 6-2

ARTHROKINEMATICS OF THE HUMERORADIAL JOINT

MOVEMENT OF CONCAVE RADIUS ON CONVEX HUMERUS	DIRECTION OF SLIDE OF RADIUS ON CAPITULUM	RESULTANT MOVEMENT
Flexion	Anterior roll, anterior slide	Movement in same direction
Extension	Posterior roll, posterior slide	Movement in same direction

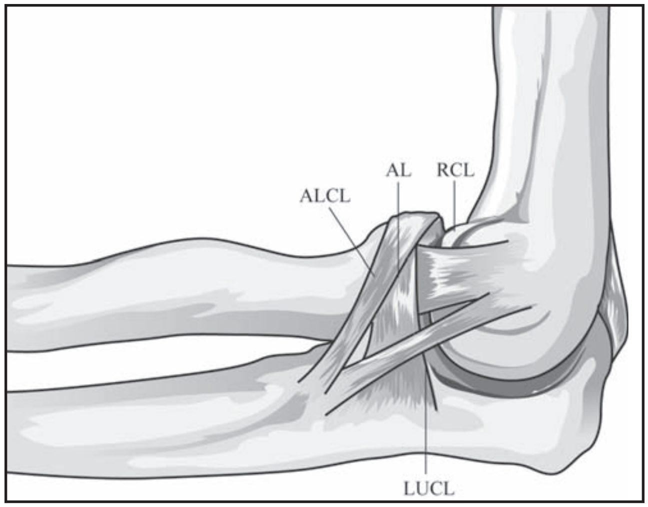

Figure 6-13. Supporting structures of the humeroradial joint. AL = annular ligament, ALCL = accessory lateral collateral ligament, LUCL = lateral ulnar collateral ligament, RCL = radial collateral ligament.

Supporting Structures

The primary supporting structures of the humeroradial joint are the lateral (radial) collateral ligament complex, articular capsule, and anconeus muscle (Figure 6-13). The anconeus muscle, which covers the joint capsule and collateral ligaments on the lateral side of the joint, acts as an active joint stabilizer against varus stress (Levangie & Norkin, 2011). It is often torn when the lateral collateral ligament complex is ruptured, but the role of this muscle is controversial (Dumontier, 2010).

Lateral (Radial) Collateral Ligament Complex

On the lateral side of the forearm, there are no discrete collateral ligaments, such as those that are found on the medial side. Instead, the lateral collateral ligament complex is composed of four ligaments: the lateral (radial) collateral ligament, lateral (ulnar) collateral ligament, annular ligament, and accessory lateral collateral ligament. These components vary widely among individuals (Carrino et al., 2001). The complex stabilizes the joint against varus forces and combined varus and supination forces and provides some resistance to longitudinal distraction. In addition, it reinforces the humeroradial joint, stabilizes the radial head for rotation, and prevents subluxation of the humeroulnar joint (Levangie & Norkin, 2011).

Lateral (Radial) Collateral Ligament

The lateral (radial) collateral ligament is a short, narrow fibrous band that attaches to the lateral epicondyle of the humerus and to the annular ligament below and inserts into the lateral margin of the ulna. The origin of the lateral (radial) collateral ligament lies over the center of rotation for the elbow so the ligament is tight throughout flexion and extension (Carrino et al., 2001; Gray & Lewis, 2000). This ligament provides reinforcement for the humeroradial joint and some protection against varus stress and longitudinal distraction of the joint, prevents subluxation of humeroulnar articulation, and maintains integrity of radioulnar articulation (Houglum & Bertoti, 2012; Levangie & Norkin, 2011). The lateral (radial) collateral ligament can be palpated as it extends from the lateral epicondyle of the humerus to the annular ligament and lateral surface of the ulna.

Lateral (Ulnar) Collateral Ligament

The lateral (ulnar) collateral ligament is a thick triangular band consisting of two portions: an anterior and posterior united by a thinner intermediate portion. It attaches anteriorly to the lateral epicondyle of the humerus above. Anterior fibers also attach to the medial margin of the coronoid below, while posterior fibers attach to the medial margin of the olecranon below (Gray & Lewis, 2000; Muscolino, 2006). The lateral (ulnar) collateral ligament reinforces the humeroradial joint and is seen as the primary lateral stabilizer, and injury to this ligament results in posterolateral rotatory instability of the elbow (Ellenbecker, Shafer, & Jobe, 2010), although this is debated (Jazrawi et al., 2012).

Annular Ligament

The annular ligament is a thick, strong band of fibers that attaches to the anterior and posterior radial notch, and a few of the fibers continue around the head of the radius to form a complete fibrous ring. It makes up four-fifths of the fibro-osseous ring that encircles the head of the radius (Gray & Lewis, 2000). The annular ligament provides stability to the radius against distal dislocation and maintains the integrity of the radioulnar joint. It prevents excessive radial distraction and is the main support of the radial head in the radial notch of the ulna (Jazrawi et al., 2012). It can be palpated distal to the lateral epicondyle and can be palpated around the radial head. Pronating and supinating the forearm will facilitate finding these structures.

Accessory Lateral Collateral Ligament

The accessory lateral collateral ligament arises from the distal fibers of the annular ligament and attaches distally on the lateral ulnar collateral ligament. The role of the accessory lateral collateral ligament is poorly understood, but because it is taut only with varus stress, it may act as a stabilizer of the annular ligament when a varus stress is imposed upon the joint (Dumontier, 2010).

Humeroulnar Joint (Ulnotrochlear)

The humeroulnar joint is the articulation of the trochlea and trochlear groove of the distal humerus with the trochlear (semilunar) notch and trochlear ridge of the ulna. It is the primary joint in the elbow complex for flexion and extension.

Table 6-3

Osteokinematics of the Humeroulnar Joint

Functional Joint	Diarthrotic, uniaxial
Structural Joint	Synovial, hinge
Close-Packed Position	Extension with supination
Resting Position	70 degrees elbow flexion, 10 degrees supination
Capsular Pattern	Flexion, then extension
Primary Muscles	Brachialis, triceps, and anconeus

During extension, the olecranon process of the ulna slides into the olecranon fossa of the humerus. During flexion, the coronoid process of the ulna articulates with the coronoid fossa of the humerus. Some people are able to hyperextend the elbow, which may be due partially to either a smaller olecranon process or a larger olecranon fossa.

Osteokinematics

Like the humeroradial joint, the humeroulnar joint is a uniaxial hinge joint permitting the motions of flexion and extension in the sagittal plane around a frontal axis. The resting position of this joint is with the elbow flexed to 70 degrees and the forearm supinated to 10 degrees. The close-packed position is extension with the forearm in supination, and the capsular pattern of limitation and pain is seen first in flexion and then in extension. The primary muscles acting at the humeroulnar joint are the brachialis, triceps, and anconeus (Table 6-3).

Humeroulnar Joint Axis

The axis of the humeroulnar joint is not horizontal but is directed in a downward and medial direction due to the protrusion of the trochlea. This valgus (outward) position of the elbow and forearm in full extension and supination is known as *cubitus valgus* or *carrying angle*. This outward deviation is not apparent when the forearm is pronated in extension or in full flexion. With the elbow extended and the forearm supinated, the carrying angle in males is 5 to 10 degrees, with a slightly larger lateral deviation angle of 10 to 15 degrees in females (Figure 6-14). While it has been suggested that the purpose of the carrying angle is to prevent objects that are held in the hand from contacting with the body. It has been suggested that the wider angle in women is to accommodate the female pelvis or that the medial aspect of the trochlear grows longer in shorter people, but a definitive function of this angle has not been identified (Hamill et al., 2015; Levangie & Norkin, 2011). Roy, Baeyens, Fauvart, Lanssiers, and Calrijs (2005) cite other examples of the functional significance of this outward deviation of the extended elbow, which includes pulling a wagon, skipping rope, increasing the reach of the arms, and providing a role in the muscular lever arms.

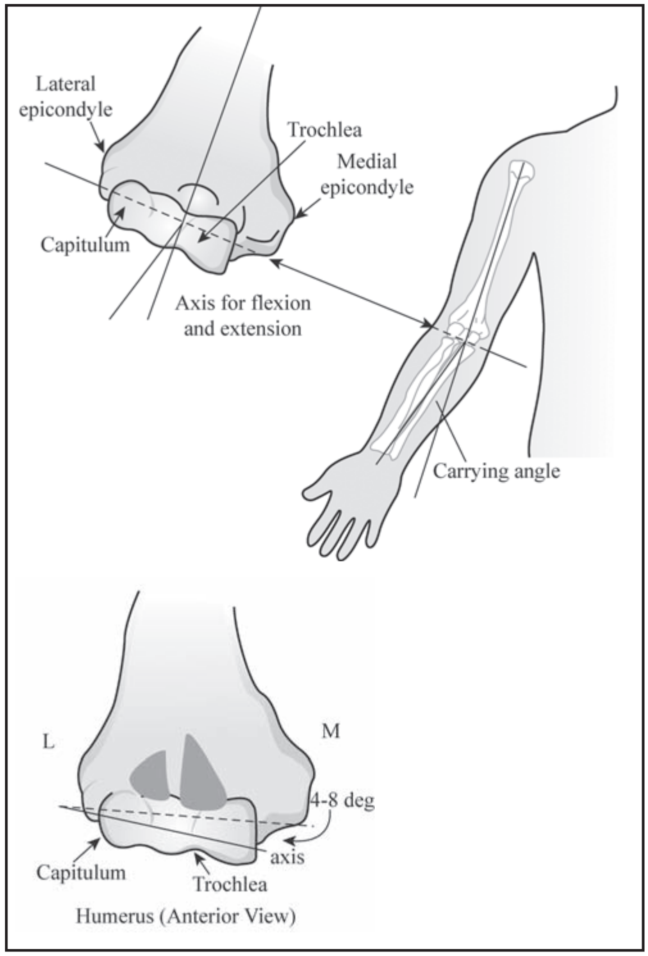

Figure 6-14. Axis of the humeroulnar joint and the carrying angle.

A deformity of the elbow where the forearm deviates toward rather than away from the midline when the elbow is extended is called *cubitus varus* or *gun stock deformity*. This may be due to condylar fracture (Figure 6-15).

Arthrokinematics

Because the trochlea at the distal end of the humerus is convex and articulates with the concave trochlear notch on the proximal ulna, the concave notch slides in the same direction in which the ulna moves. The sliding motion is primarily of the ulnar trochlear ridge on the humeral trochlear groove (Levangie & Norkin, 2011). In flexion, the trochlear notch rolls anteriorly over the trochlear groove of the humerus and into the coronoid fossa of the humerus. In extension, the trochlear notch rolls and slides in the same direction posteriorly over the trochlea. There is also a slight medial and lateral sliding of the ulna (see Table 6-4 for a summary of the humeroulnar joint arthrokinematics).

Supporting Structures

The primary supporting structures of the humeroulnar joint are the medial ulnar collateral ligament and the articular capsule, while much of the joint stability is derived from bony congruence.

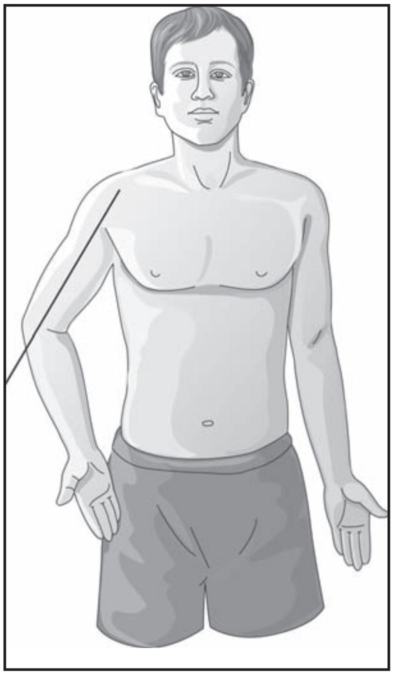

Figure 6-15. Gun stock deformity (cubitus varus).

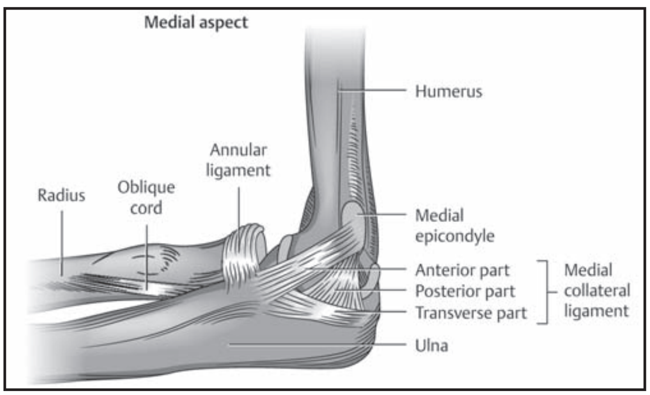

Figure 6-16. Medial collateral ligament.

Medial (Ulnar) Collateral Ligament

The medial (ulnar) collateral ligament attaches the medial epicondyle of the humerus to the coranoid and olecranon process of the ulna. It is a triangular shape and runs anteriorly, posteriorly, and obliquely (Figure 6-16). The humeral origin of the medial (ulnar) collateral ligament lies posterior to the axis of elbow flexion, resulting in stress to the anterior fibers in extension, and posterior fibers are stressed in flexion. This ligament serves as the primary constraint of the elbow joint to valgus stress with the radial head as a secondary constraint (Ellenbecker et al., 2010; Morrey, Tanaka, & An, 1991). In addition, the medial (ulnar) collateral ligament functions to prevent abduction of the forearm at the elbow and lateral movement of the proximal ulna in all positions, and supports the medial side of the joint. It is the strongest ligament in the elbow complex. Medial (ulnar) collateral ligament laxity most often results from repetitive valgus loading, such as in throwing activities. The medial (ulnar) collateral ligament can be palpated as it traverses from the medial epicondyle to the medial margin of the coronoid process anteriorly and to the olecranon process posteriorly (Magee, 2014).

Table 6-4

Arthrokinematics of the Humeroulnar Joint

Movement of Concave Ulnar Trochlear Notch and Convex Humeral Trochlea	Direction of Slide	Resultant Movement
Flexion	Anterior roll, anterior/distal slide	Movement in same direction
Extension	Posterior roll, posterior/proximal slide	Movement in same direction

Anterior Medial Collateral Ligament

The anterior medial collateral ligament is taut in extension and is considered the primary stabilizer to valgus stress in elbow flexion from 20 to 120 degrees (Regan, Korinek, Morrey, & An, 1991; Schwab, Bennett, Woods, & Tullos, 1980).

Posterior Medial Collateral Ligament

The posterior medial collateral ligament is a weak, fan-shaped thickening of the medial portion of the joint capsule. It arises at the posterior aspect of the medial epicondyle and inserts over the olecranon, forming the floor of the cubital tunnel. It is taut when the elbow is in a flexed position and is less significant in valgus (outward) stability than the anterior medial collateral ligament.

The oblique (transverse) portions of the medial collateral ligament run between the olecranon and the ulnar coronoid process and assist in valgus stability and in keeping the joints aligned (Levangie & Norkin, 2011).

Proximal (Superior) Radioulnar Joint

This is the articulation of the radial notch of the ulna with the radial head and rim. The joint is encircled by the annular ligament, which takes up to approximately four-fifths of the joint, and the radial head rotates around the annular ligament (Magee, 2014). In supination, the radius and ulna lie parallel to each other, but in pronation, the radius crosses over the ulna diagonally at this joint. When the distal extremity is fixed and not free to move (a closed kinetic chain movement, such as when you put weight on your hand and rotate the forearm), a reverse action can occur in which the ulna moves instead of the radius at the superior radioulnar joint (Muscolino, 2006).

Table 6-5

OSTEOKINEMATICS OF THE PROXIMAL RADIOULNAR JOINT

FUNCTIONAL JOINT	Diarthrotic, uniaxial
STRUCTURAL JOINT	Synovial, pivot
CLOSE-PACKED POSITION	5 degrees supination
RESTING POSITION	35 degrees supination, 70 degrees elbow flexion
CAPSULAR PATTERN	Equal limitation in pronation and supination
PRIMARY MUSCLES	Supinator, pronator quadratus

Osteokinematics

The proximal radioulnar joint provides the second of the 2 degrees of freedom possible at the elbow joint by enabling pronation and supination at this uniaxial pivot/trochoid joint. This joint is considered a uniaxial joint, meaning that the proximal and distal radioulnar joints function as one joint. This joint plays no part in producing the movements of flexion or extension at the elbow or in providing additional stability to the joint. The radial head rotates within the annular ligament and spins on the capitulum to produce pronation and supination.

The resting position of the proximal radioulnar joint is 35 degrees of supination and 70 degrees of elbow flexion. The position of greatest stability (close-packed position) is in 5 degrees of supination. The primary muscles involved at the radioulnar joint are the supinator and the pronator quadratus. The interosseous membrane between the radius and ulna helps to transmit some of the forces from the radius to the ulna. This prevents forceful contact of the radial head with the capitulum of the humerus (Table 6-5; Ellenbecker et al., 2010).

Arthrokinematics

With pronation and supination of the forearm, the direction of slide of the proximal radius on the ulna is opposite to the motion (Figure 6-17). This is because the convex rim of the radial head articulates with the concave radial notch on the ulna. With rotation of the radius, the convex rim moves opposite to the bone motion (Houglum & Bertoti, 2012; Kisner & Colby, 2012).

However, Baeyens and colleagues (2006) found that there was anterior spinning with anterior gliding during pronation, which is in contrast to the convex-concave rule. While their study included only three people, they reported consistent findings of anterior translation of the radial head about the ulna, which "gives strong evidence to revise concave-convex rule for pronation-supination of the forearm" (Baeyens et al., 2006, p. S12). Further research is needed to validate this. Table 6-6 provides a summary of the arthrokinematics of the proximal radioulnar joint.

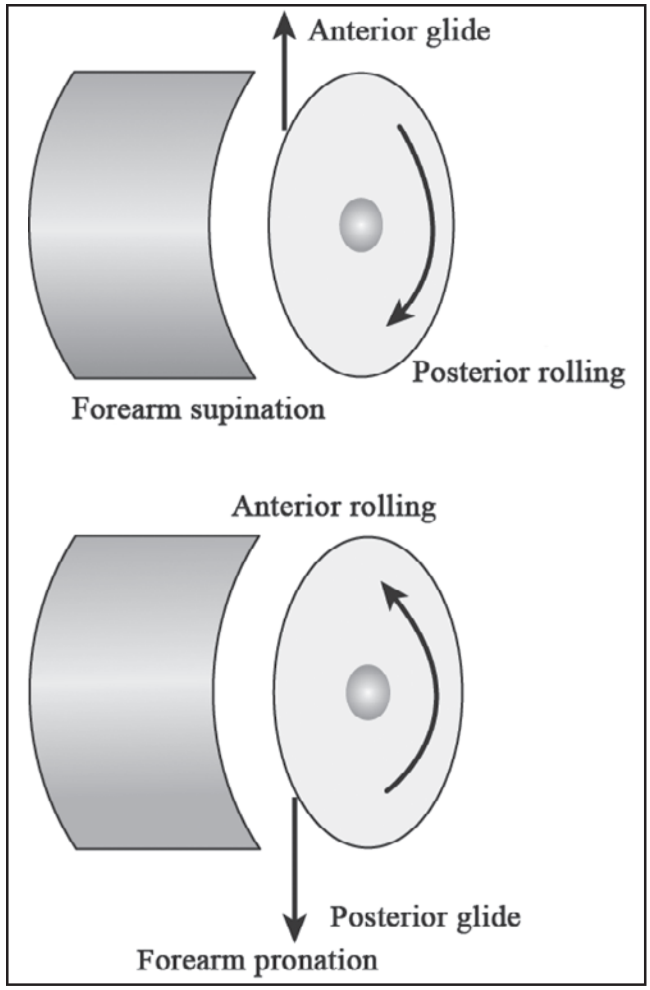

Figure 6-17. Diagrammatic representation of rotation at the proximal radioulnar joint.

Supporting Structures

The supporting structures for the proximal radioulnar joint include the annular ligament, fibrous capsule, oblique cord, and proximal portion of the interosseous membrane. The interosseous membrane not only connects the ulna and radius, but also prevents proximal displacement of the radius on the ulna (Ellenbecker et al., 2010). The quadrate ligament limits radial head spin and reinforces the inferior portion of the joint capsule (Houglum & Bertoti, 2012).

Middle (Intermediate) Radioulnar Joint

The middle (intermediate) radioulnar joint is not a true joint, but it is a fibrous, ligamentous synarthrodial articulation of the shaft of the radius with the shaft of the ulna and the interosseous membrane and oblique cord. There is no movement at this joint, but the interosseous membrane is tense in neutral position, helping to prevent proximal displacement of the radius on the ulna (Magee, 2014). The interosseous membrane serves to stabilize the elbow and radioulnar joints, to transmit forces from the hand to the humerus, and as a surface

Table 6-6

Arthrokinematics of the Proximal Radioulnar Joint

Movement of Convex Radial Head on Ulnar Notch	Direction of Slide of Proximal Radius on Ulna	Resultant Movement
Pronation	Anterior roll, posterior/dorsal slide	Movement in opposite direction
Supination	Posterior roll, anterior/volar slide	Movement in opposite direction

Table 6-7

Osteokinematics of the Distal Radioulnar Joint

Functional Joint	Diarthrotic, uniaxial
Structural Joint	Synovial, pivot
Close-Packed Position	5 degrees supination
Resting Position	10 degrees supination
Capsular Pattern	Pain at extremes of rotation
Primary Muscles	Pronator quadratus

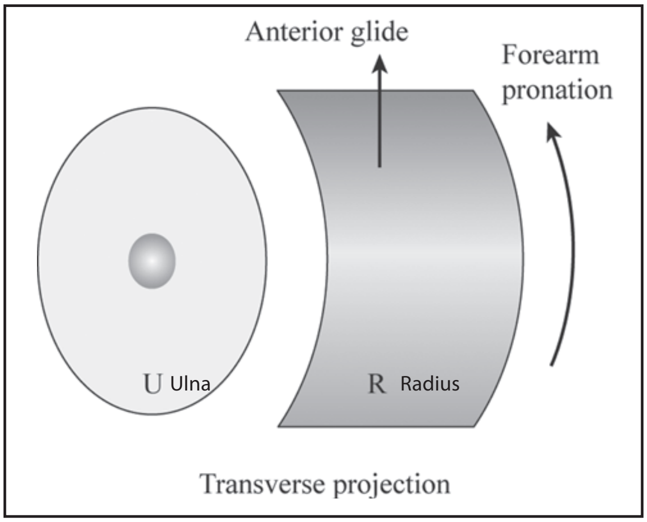

Figure 6-18. Diagrammatic representation of rotation at the distal radioulnar joint.

for attachment of deeper muscles (Magee, 2014; Muscolino, 2006; Premkumar, 2003).

Distal (Inferior) Radioulnar Joint

This joint is at the distal end of the forearm near the wrist, where the head of the ulna articulates with the ulnar notch and articular disc of the radius. This is an extremely stable joint due to the articular disc, triangular fibrocartilage, interosseous between the radius and ulna, and pronator quadratus muscle. This is an important joint in the transmission of load via the triangular fibrocartilage and is an intricate part of wrist function (Ozer & Scheker, 2006; Palmer & Werner, 1984; Shaaban et al., 2004). Further information about the distal (inferior) radioulnar joint will also be covered in Chapter 7.

Osteokinematics

Like the proximal radioulnar joint, the distal (inferior) radioulnar joint is a uniaxial pivot joint. To produce pronation and supination, the distal end of the radius must be free to move about the ulna at its distal end as well as at the proximal portions (Table 6-7). Rotation of the lower end of the radius around the head of the ulna occurs at the distal radioulnar joint. The resting position is in 10 degrees of supination, and the close-packed position is in 5 degrees of supination.

Arthrokinematics

The articulating surface of the radius slides in the same direction as the bone motion because the concave ulnar notch on the distal radius articulates with the convex portion of the head of the ulna (Figure 6-18; Kisner & Colby, 2012). The ulnar head, in a rolling, sliding motion, moves from the dorsal to the volar rim of the sigmoid notch as the joint moves from pronation to supination.

There is slight movement of the ulna at the distal radioulnar joint. The ulnar head moves laterally in a direction opposite to the movement of the distal radius of up to 8 degrees. The ulna moves slightly dorsally in pronation and slightly toward the palm in pronation (Palmer & Werner, 1984; Shaaban et al., 2004). A summary of the arthrokinematics of the distal radioulnar joint is provided in Table 6-8.

Supporting Structures

The distal radioulnar joint is supported by the anterior/posterior radioulnar joint capsule and the interosseous membrane, as well as the dorsal and palmar radioulnar ligaments. The articular disc, which attaches to the ulnar notch and styloid process of the ulna, helps to hold the distal ends of the radius and ulna together as well as separate the ulna from the carpal bones.

The articular disc at the distal radioulnar joint is also known as the *triangular fibrocartilage*. The lateral side of the disc attaches along the rim of the ulnar notch of the radius, and the main body of the disc spreads into a triangular shape. The anterior and posterior edges of the disc join with the palmar and dorsal radioulnar joint capsule ligaments, which hold the head of the ulna in the ulnar notch of the radius. The disc plus several wrist ligaments form the triangular fibrocartilage complex (TFCC), seen as a primary stabilizer of the distal radioulnar joint. Further discussion of the TFCC is in Chapter 7. The dorsal and palmar radioulnar ligaments reinforce the joint capsule and stabilize the radioulnar articulation (Houglum & Bertoti, 2012).

Table 6-8

ARTHROKINEMATICS OF THE DISTAL RADIOULNAR JOINT

MOVEMENT OF DISTAL RADIUS ON HEAD OF ULNA	DIRECTION OF SLIDE OF DISTAL RADIUS ON ULNA	RESULTANT MOVEMENT
Pronation	Anterior roll, anterior slide	Movement in same direction
Supination	Posterior roll, posterior slide	Movement in same direction

ELBOW STABILITY

The elbow joint is an inherently stable joint due to the bony configuration as well as ligamental support. The role of each of these structures varies with the degree of flexion or extension of the elbow (Dumontier, 2010). Overall, the three primary static constraints in the elbow are the humeroulnar joint, medial collateral ligament, and lateral collateral ligament complex. Other structures that provide secondary restraints include the radial head and joint capsule; flexor-pronator muscles; extensor-supinator muscles; and anconeus, triceps, and brachialis muscles (Table 6-9; Gray & Lewis, 2000; Yallapragada & Patko, 2009).

Bone Support

The bony support is attributed to the articulation of the trochlea of the humerus with the trochlear fossa of the ulna and the head of the radius with the capitulum of the humerus. The amount of contact of the bony surfaces of the elbow increases from full extension to full flexion, which puts the radius in more contact with the capitulum, providing greater stability for the joint, especially in flexion (Figure 6-19).

The elbow is more stable when in flexion than in extension because there is more contact of the bony surfaces. In flexion, the coronoid process locks into the coronoid fossa, while the medial rim of the radial head engages in the trochleocapitellar groove. The lateral part of the olecranon process of the ulna is not in contact with the trochlea of the humerus during full flexion. In full extension, the medial part of the olecranon process is not in contact with the trochlea, but the apex of the olecranon is held in the olecranon fossa of the humerus. In full extension, there is no contact between the capitulum and radial head. Posterior displacement of the elbow is prevented by the coronoid process of the ulna and by the humeroradial articulation.

Elbow stability is improved by the congruency between the radial head and the radial notch of the ulna, which accounts for approximately 50% of the mediolateral stability of the elbow (Dumontier, 2010; Yallapragada & Patko, 2009).

Bony stabilization to valgus stress is provided by the proximal portion of the trochlear notch of the ulna, and varus stability is primarily a function of the distal part of the trochlear notch. Bony stability is also provided by the coronoid process during extension (Dumontier, 2010).

Ligamental and Soft Tissue Supports

The joint capsule is continuous for all three articulations, and the capsule is fairly large, loose, and weak, which allows for free movements. Anteriorly and posteriorly, the capsule is protected by muscles, but medially and laterally, it is reinforced by ligaments (Hartley, 1995; Jazrawi et al., 2012). The joint capsule is important for joint support but also because it is highly innervated and is the "neurologic link between shoulder and hand" (Ellenbecker et al., 2010, p. 237).

Both of the collateral ligaments (medial and lateral) are strong fan-shaped thickenings of the fibrous joint capsule. The medial and lateral collateral ligaments provide a stabilizing force to medial and lateral stresses of the joint.

Valgus stability of the elbow is provided to a large extent by the medial collateral ligament. The bony surfaces of the humeroradial joint have only an accessory function in resisting valgus elbow stresses and only in less than 20 degrees and greater than 120 degrees of flexion (Morrey & Sanchez-Sotelo, 2009).

The roles of the different ligamentous structures in resisting varus stress are not as clear as for valgus stability. The lateral collateral ligamental complex as a whole stabilizes to varus and extension loads. The lateral collateral ligament prevents excessive supination in addition to its role in varus stability. It was initially thought that the annular ligament was responsible for resistance to varus stress between 40 and 60 degrees of elbow flexion, but this has been contested, and it appears as though the primary role of the annular ligament is for stabilization of the radioulnar joint (Dumontier, 2010; Jazrawi et al., 2012; Morrey & Sanchez-Sotelo, 2009).

The stability of the proximal and distal radioulnar joints is accomplished by the interosseous membrane, annular ligament, and TFCC. Dynamic stabilization of the elbow is achieved by the synergistic actions of the biceps, brachialis, brachioradialis, triceps, and anconeus muscles (Ellenbecker et al., 2010).

Table 6-9

PRIMARY AND SECONDARY STABILIZERS OF THE ELBOW

PRIMARY STABILIZERS	• Humeroulnar joint	• Provides bony stability
	• Medial collateral ligament	• Stabilizes against valgus stress
	• Lateral collateral ligament	• Stabilizes against varus stress
	• Radial head and joint capsule	• Prevent hyperextension of the elbow
SECONDARY STABILIZERS	• Flexor-pronator muscles	• Stabilizes against valgus stress
	• Extensor-supinator muscles	• Stabilizes against varus stress
	• Anconeus, triceps, and brachialis muscles	• Dynamic stabilizers that cross the joint provide compressive forces to the joint

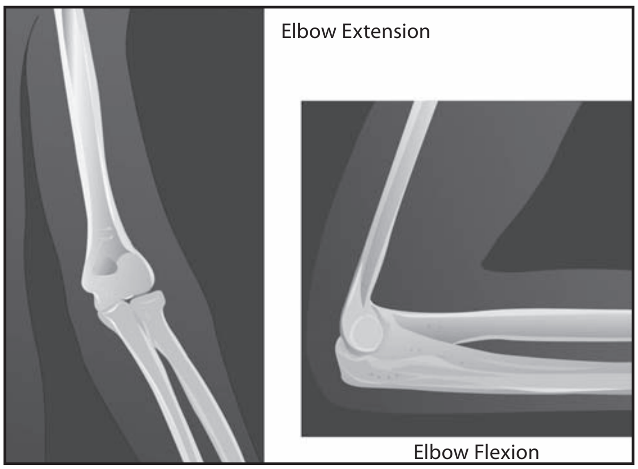

Figure 6-19. Bony contact during flexion and extension of the elbow.

MOVEMENTS AT THE ELBOW JOINT

Flexion and Extension

The flexion and extension movements that occur at the humeroradial and humeroulnar joints are primarily gliding motions until the last 5 to 10 degrees, when the joint surface motion changes to rolling. During flexion, there is distal (inferior) glide of the ulna in the trochlea. The trochlear ridge glides inferiorly on the trochlear groove until the coronoid process comes into contact with the coronoid fossa of the humerus. The lateral part of the olecranon is not in contact with the trochlea. The lack of full contact of the olecranon with the humerus during flexion and extension permits the small amount of joint play necessary for full pronation and supination (Magee, 2014). The rolling in flexion occurs when the coronoid process of the ulna contacts the floor of the coronoid fossa of the humerus. Supination and adduction of the ulna in the trochlea and pronation of the radius on the humerus also occur at the same time (Hamill et al., 2015). The capsule limits flexion more than extension, and total range of elbow flexion ranges from 135 to 146 degrees.

Normal limitations for flexion are due to the apposition of the anterior forearm and upper arm soft tissue, the posterior joint capsule, extensor muscles, and, ultimately, the coronoid process contacting coronoid fossa. This produces the normal soft end feel for elbow flexion, which is due to compression of forearm against upper arm. If there is little muscle bulk, the end feel may be hard due to contact of the radius and radial fossa of the humerus and contact of the coronoid process with the coronoid.

In extension, the gliding motion occurs until the olecranon process of the ulna goes into the olecranon fossa of the humerus. The rolling that occurs in extension takes place when the olecranon of the ulna is received by the floor of the olecranon fossa of the humerus (Esch, 1989; Levangie & Norkin, 2011). The movements occurring during elbow extension are proximal glide of the ulna on the humerus, pronation and abduction of the ulna on the humerus, and pronation of the radius on the humerus (Hamill et al., 2015). The medial part of the olecranon is not in contact with the trochlea in full extension. In addition, 10 to 15 degrees of hyperextension of the elbow may occur and may be due to a shortened olecranon process, enlarged fossa, or lax ligaments.

The normal limiting factor of elbow extension is the olecranon process contacting the olecranon fossa that results in a hard end feel. Occasionally, the end feel may be firm due to the anterior joint capsule, anterior band of the middle collateral ligament, and tension in the biceps and brachialis muscles.

The joint axis for flexion and extension goes through the middle of the trochlea and the capitulum, which bisects the longitudinal angle of the forearm. It is possible to feel this axis by grasping the elbow from side-to-side distal to the lateral and medial epicondyle. If muscles are located posterior to this axis, the muscles are extensors; if the muscles are anterior to the axis, they are flexor muscles.

If elbow motion is restricted, compensatory motion is provided by increased shoulder motion. This can lead to shoulder pain and overuse, so it is important to consider both the shoulder and elbow when assessing shoulder complaints (Jazrawi et al., 2012). Elbow flexors are the brachialis, biceps (when supinated), and brachioradialis (when rapid flexion and when weight is lifted during slow flexion). The extensor carpi radialis and pronator teres also assist with flexion movements. Primary extensor muscles are the triceps and anconeus (especially in

Table 6-10

FLEXION AND EXTENSION MOVEMENTS

MOTION	JOINT	PLANE/AXIS	NORMAL LIMITING FACTORS (TENSION IN)	END FEEL	PRIMARY MUSCLES	NORMATIVE ROM/ FUNCTIONAL ROM (IN DEGREES)
Flexion	• Humeroulnar • Humeroradial	• Sagittal/ frontal	• Soft tissue • Posterior joint capsule • Extensor muscles • Coronoid process contacting coronoid fossa	• Soft	• Biceps brachii • Brachialis • Brachioradialis	• 0 to 150/ 30 to 130
Extension	• Humeroulnar • Humeroradial	• Sagittal/ frontal	• Olecranon process contacting olecranon fossa	• Hard	• Triceps • Anconeus	• 150 to 0/ 130 to 30

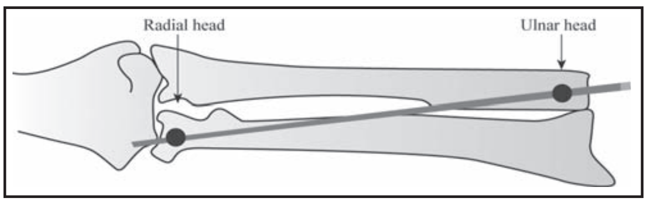

Figure 6-20. Axis for forearm rotation.

initiating and maintaining extension), with some assistance from the extensor carpi ulnaris muscle (Levangie & Norkin, 2011). Generally, flexor muscles are 30% stronger than extensor muscles (Table 6-10; Jazrawi et al., 2012).

Pronation and Supination

During pronation and supination, the distal and proximal radioulnar joints work together to enable the head of the radius to spin, roll, and glide in the radial notch. The axis line for pronation and supination goes through the center of the head of the radius proximally and through the center of the head of the ulna distally (Smith, Weiss, & Lehmkuhl, 1996). It does not run parallel to the longitudinal axis of the forearm (Figure 6-20). Therefore, the axis is oblique to the longitudinal axis center of the radius and ulna (Levangie & Norkin, 2011). The muscles that cross anterior to this axis are pronators; those crossing posterior to the joint axis are supinators (Figure 6-21; Gench et al., 1995).

It is important to realize that, although the radius rotates over the ulna, the ulna moves as well. The ulna moves laterally during pronation and medially during supination (Palmer & Werner, 1984; Shaaban et al., 2004).

Tension in the pronator muscles, palmar radial ligament of the distal radioulnar joint, oblique cord, and interosseous membrane restrict further motion in supination as normal limiting factors. This results in a firm end feel. Primary muscles producing supination include the supinator muscle and biceps (during fast and resisted motion; Levangie & Norkin, 2011).

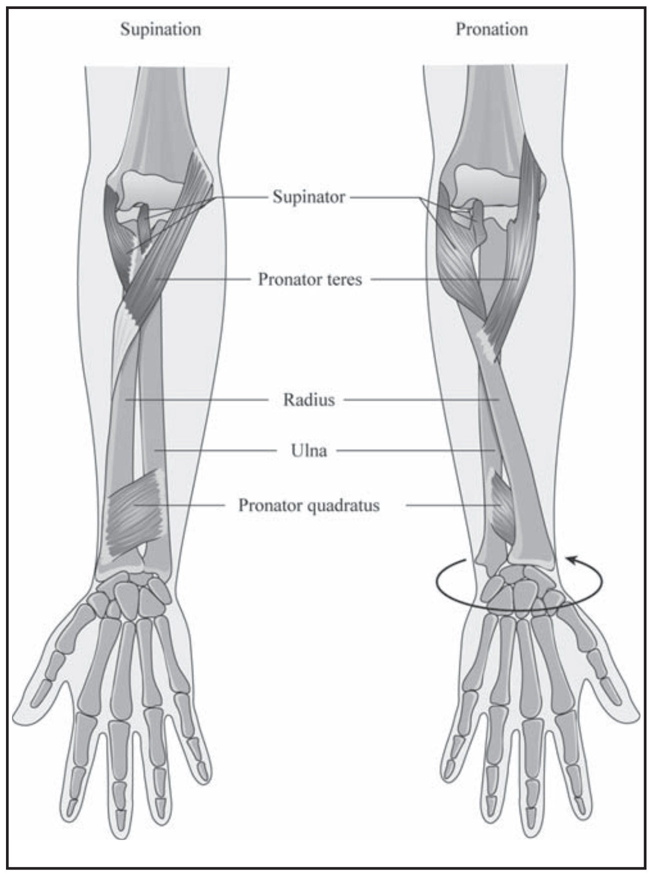

Figure 6-21. Muscles of forearm rotation relative to joint axis.

Due to contact of the radius on the ulna and tension in the dorsal radioulnar ligament of the distal radioulnar joint, interosseous membrane, and biceps muscle, further pronation

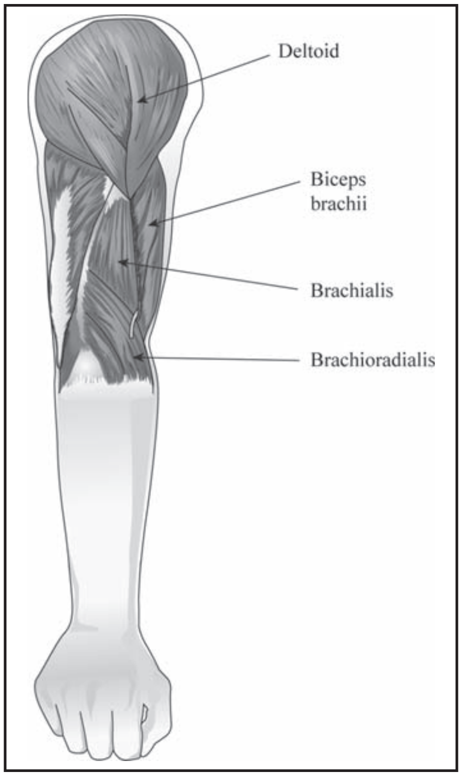

Figure 6-22. Muscles that flex the elbow.

is prevented. The dorsal and volar radioulnar ligaments at the perimeter of the TFCC provide primary constraints to the distal radioulnar joint (Linscheid, 1992). The dorsal and palmar radioulnar ligaments are the primary stabilizers of the joint and aid in wrist stabilization. Each of these ligaments also consists of deep and superficial portions. The deep portions originate from the radius and conjoin to insert into the fovea. The superficial portions also originate from the radius, but separately insert into the base of the styloid. In supination, deep portions of the palmar radioulnar ligament and a superficial portion of the distal radioulnar ligament become taut. In pronation, deep portions of the distal radioulnar ligament and a superficial portion of the palmar radioulnar ligament are under tension. This produces a firm end feel due to tension in the ligamentous structures. Primary muscles involved in pronation are the pronator quadratus and pronator teres (during fast or resisted movements), with secondary contributions from the flexor carpi radialis and anconeus muscles (Figure 6-22).

Range of motion (ROM) values for pronation range from 0 to 71 degrees to 0 to 90 degrees for pronation and from 0 to 80 degrees to 0 to 90 degrees for supination. Functional ROM for both supination and pronation for most activities is 0 to 50 degrees (Vasen, Lacey, Keith, & Shaffer, 1995). A summary of pronation and supination is provided in Table 6-11.

Internal Kinetics: Muscles

According to Levangie and Norkin (2011, p. 287), there are 10 factors that influence motion at the elbow:

1. Location of muscles
2. Position of the elbow and adjacent joints
3. Position of the forearm
4. Magnitude of applied force
5. Types of muscle contraction
6. Speed of motion
7. Number of joints crossed by the muscle
8. Moment arm at different joint positions
9. Fiber types
10. Physiologic cross-sectional area

The location of the muscles has a direct relationship with the motion possible at the joint. For example, pronators cross the joint axis anterior to the axis, whereas supinators cross posteriorly to the joint axis of rotation. Location of muscles as well as the position of the forearm and other joints help to determine the line of pull of the muscles, which influences the power of the force generated by the muscle due to length-tension relationships. In addition, some of the forearm muscles are active only when the movement is unresisted or when there is external load and only in certain positions. For example, the pronator quadratus will pronate the forearm regardless of forearm position or amount of flexion of the elbow, whereas the pronator teres contributes to pronation where there is an external load or when rapid pronation is required.

The nervous system uses efficient economy of energy when determining which muscles will produce specific movements. Unskilled movements waste energy because muscles that are not needed also contract. As skill increases, the selection of muscles improves, and the gradation of contraction becomes more refined, which results in smoother movements (Houglum & Bertoti, 2012). The number of muscles is determined by the effort needed, and the nervous system prefers only one muscle to perform the task if possible. For example, if flexion of the elbow and supination of the forearm is the desired motion, the biceps would be a good choice because the biceps muscle both flexes the elbow and supinates the forearm. The two actions could also be done by the brachialis and supinator, but at the expense of energy required to produce contractions of two muscles rather than just one (Smith et al., 1996). Likewise, if only flexion without supination or pronation was the required motion, the biceps would be wasteful because the supination function of biceps would need to be neutralized by pronator muscles.

The stresses applied to the elbow vary based on the load applied, resultant force vector, and length of the lever arm (Dumontier, 2010). Small loads applied to the hand dramatically increase the elbow joint reaction force. Common activities, such as supporting oneself when pushing up out of a chair, generates loads of more than twice the body weight, which may challenge the view that the elbow is not a load-bearing joint (Grünert-Plüss, Hufschmid, Santschi, & Gruenert, 2008; Levangie & Norkin, 2011). Compressive loads are observed during simple activities of daily living (ADL), such as dressing or feeding, and the use of crutches transfers 40% to 50% of the body weight onto the upper extremity (Dumontier, 2010).

At the elbow joint, there are two muscles that are multijoint muscles (i.e., muscles that cross two or more joints). The biceps is a multijoint muscle that can develop active insufficiency when the elbow is in full flexion while the shoulder is in full humeral flexion and the forearm is supinated. This puts the

Table 6-11

PRONATION AND SUPINATION MOVEMENTS

MOTION	JOINT	PLANE/AXIS	NORMAL LIMITING FACTORS (TENSION IN)	END FEEL	PRIMARY MUSCLES	NORMATIVE ROM/ FUNCTIONAL ROM (IN DEGREES)
Pronation	• Horizontal longitudinal	• Radioulnar (proximal, middle, distal)	• Dorsal radioulnar ligament • Interosseous membrane • Biceps muscle • Radius on ulna	• Firm	• Pronator quadratus • Pronator teres	• 0 to 90/ 0 to 50
Supination	• Horizontal longitudinal	• Radioulnar (proximal, middle, distal)	• Pronator muscles • Palmar radial ligament • Oblique cord • Interosseous membrane	• Firm	• Supinator • Biceps	• 0 to 90/ 0 to 50

biceps muscle in a shortened position, resulting in marked loss of force and some leverage loss. Passive tension in triceps may also limit elbow flexion (Levangie & Norkin, 2011). The triceps, also a multijoint muscle, is actively insufficient when the elbow is in full extension with the shoulder in extension (shortened position). Passive tension in the long head of the biceps brachii by passive shoulder hyperextension may limit full elbow extension (Levangie & Norkin, 2011). The significance of this as it pertains to intervention is to provide activities or adaptations that will not cause muscle shortening over the multiple joints, resulting in decreased strength and force production.

Muscles must act in synergistic ways to produce motion. For biceps to supinate at the radioulnar joint without flexing the elbow, it works in synergy with the triceps. For biceps to flex the elbow without supinating, it works in synergy with an elbow pronator. For pronation, the humeral head of the pronator teres works in synergy with an elbow extensor to counteract the flexion function of the pronator teres muscle. Overshortening and loss of force production in the biceps is prevented by the synergistic action of the triceps muscle and, similarly, the synergy of the triceps with the biceps muscle prevents overshortening and loss of force production in the triceps brachii (Thompson, 2001).

The location of muscles and position of the forearm, elbow, and adjacent joints, as well as the angle of the pull of muscle fibers, all contribute to the actions of the muscles of the elbow joint.

Flexors of the Forearm

Primary flexors of the elbow are the brachialis, biceps (when supinated), and brachioradialis (when rapid flexion and a load is lifted during slow flexion; Jazrawi et al., 2012). The greatest force of elbow flexion is produced when there is 90 degrees of flexion accompanied by supination of the forearm. The dominant side produces higher flexion torque, work, and power, but there is no difference between right and left for extension, pronation, or supination. Flexor muscles are stronger than extensor muscles, and flexion force is 20% to 25% higher in a supinated position due to the increased flexor moment arm of the biceps and brachioradialis (Magee, 2014; Vasen et al., 1995).

Brachialis

The brachialis is considered the primary flexor of the elbow and, as such, is always a flexor regardless of whether there is an external load and whether the rate of movement is fast or slow. An appropriate nickname is "workhorse of elbow," as this muscle has the greatest work capacity of the elbow flexors. Because this fusiform, one-joint, spurt (mobility) muscle crosses the elbow closer to the flexion and extension axis than the brachioradialis and biceps, it is less favorably located to produce force. The moment arm is greatest at about 100 degrees of elbow flexion, so the greatest torque is produced in this position (Houglum & Bertoti, 2012). However, the distal attachment is on the ulna rather than the radius, which means that arm position is inconsequential to flexion and extension (Gench et al., 1995).

The brachialis also contributes to pronation and supination, but the contribution is weak. The brachialis works well eccentrically but better concentrically (Gench et al., 1995; Hinkle, 1997; Houglum & Bertoti, 2012; Jenkins, 1998; Smith et al., 1996). The brachialis muscle is being used when you bring food to your mouth, pick up books, or carry a baby car seat (Biel, 2016).

The brachialis can be palpated just lateral to the biceps when resistance is applied to the wrist (Figure 6-23). If the examiner places the palpating fingers laterally and medially to the biceps and flexes the elbow with minimal effort, contraction of the brachialis may be felt. Quick contraction in a small range will result in a stronger contraction by this muscle (Esch,

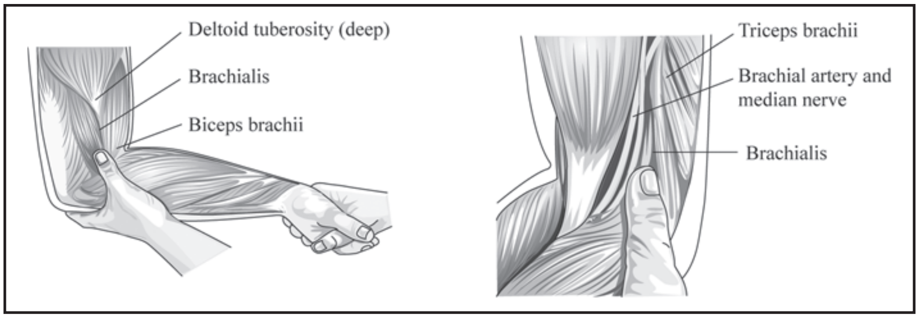

Figure 6-23. Palpation of the brachialis muscle.

1989; Houglum & Bertoti, 2012; Lumley, 1990; Magee, 2014). You may also feel this muscle by sliding about 1/2 inch from the distal biceps in a relaxed arm. The edge of the brachialis can be felt as you roll your fingers across the surface (Biel, 2016).

Biceps Brachii

This fusiform, spurt (mobility) muscle is a multijoint muscle whose contraction produces shoulder flexion, elbow flexion, and forearm supination. The force components of the pull of the biceps muscle can vary in length so that, at full extension, the biceps is accompanied by a strong stabilizing component, while at full flexion there is a strong dislocating component. It is for this reason that the biceps is most efficient as an elbow flexor when in 90 degrees of flexion because the only component is an angular one and the moment arm is greatest between 90 and 100 degrees of elbow flexion.

The biceps muscle creates an isolated, unopposed contraction when there is simultaneous flexion of the shoulder and elbow, and supination. The biceps does not function in slow flexion with the arm pronated, but rather in slow flexion with the forearm supinated as well as in fast flexion with and without an external load. As the speed of the movement increases and as the load increases, the biceps may act even in pronation. When the elbow is flexed with the forearm in pronation, the biceps is nearly inactive (Greene & Roberts, 1999). An example of how to use the actions of the biceps in a therapeutic situation is provided by Greene and Roberts (1999):

> When Mary Smith arrived at Maple Grove Skilled Care Facility, she held her right arm (elbow) flexed tightly against her body. She refused to let any nurses or aides move her arm through passive ROM, so the nursing supervisor contacted the occupational therapy department. The occupational therapy assistant who went to see Mary explained that putting her arm through ROM probably would help her not to feel so stiff and sore all of the time.
>
> The occupational therapy assistant promised to try some new techniques that would make ROM less painful than it had been in the past. First, the OT assistant gave Mary's right arm a gentle rubdown to gain Mary's trust and then slowly pronated her forearm to inhibit the biceps. The OT assistant explained to Mary that in the past, medical practitioners may have attempted to extend her elbow with her palm up in supination, a position associated with increased activity in the biceps. By pronating the forearm first, the OT assistant inactivated the biceps and made elbow extension easier and more comfortable. The OT assistant continued to explain that elbow extension in pronation stretches the tight biceps tendon even further because both of the biceps' antagonistic movements—extension and pronation—occur simultaneously. (Greene & Roberts, 1999, pp. 89-90)

The biceps muscle also often works eccentrically in a protective capacity to slow down the rate of elbow extension. An example of the biceps working eccentrically would be when a person who is on a ladder slips and the fall necessitates a quick, forced extension of the elbow. The biceps is contracting while lengthening to slow the fall (Konin, 1999).

With the forearm in supination and the elbow flexed, the tendon of insertion can be felt anterior to the elbow joint (Jenkins, 1998). When one "makes a muscle" by bending the elbow, it is the biceps muscle that is seen (Esch, 1989; Lumley, 1990; Magee, 2014). Alternate pronation and supination while palpating the biceps muscle belly against resistance to feel the biceps contraction upon supination (Biel, 2016).

Brachioradialis

This fusiform, shunt (stability) muscle has its distal attachment farther from the elbow than other elbow flexors. This means that the force arm and moment arm are increased. Because the proximal attachment is closer to the axis and the muscle lies close to the joint axis, there is a small angular component at the distal attachment when compared to a larger stabilizing component.

The brachioradialis tends to pronate as it flexes, so the angular component can be increased by placing the forearm in neutral (midposition between pronation and supination), which will lead to a stronger contraction (Gench et al., 1995). The brachioradialis is active during rapid flexion or when an external load is lifted during slow flexion, adding speed and power to elbow flexion.

The brachioradialis lies between the triceps and brachialis muscles. At and just below the elbow, the brachioradialis forms the lateral border of the antecubital fossa (Figure 6-24; Gench et al., 1995; Houglum & Bertoti, 2012). The brachioradialis is seen when the elbow is flexed to 90 degrees and the forearm is placed in neutral position. When resistance is applied to the wrist, the brachioradialis contracts and may be visible as a bulge on the lateral side of the elbow. Another way to see the muscle is to press your fist up into a table, and the brachioradialis will be visible. When bringing a glass to your mouth, turning a screwdriver, or whisking cream in a bowl, you are using the brachioradialis muscle (Biel, 2016).

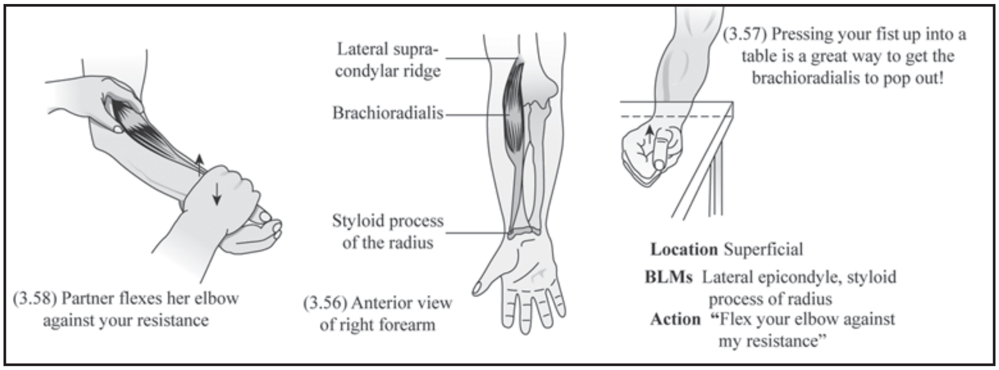

Figure 6-24. Palpation of the brachioradialis muscle.

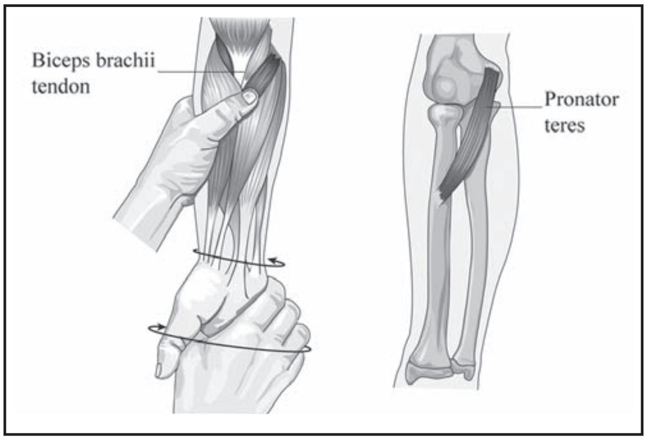

Figure 6-25. Palpation of the pronator teres muscle.

Pronator Teres

This muscle lies quite close to the axis throughout the ROM, making it inefficient as an elbow flexor, and it may actually serve to neutralize the supination action of the biceps rather than actually flex the elbow. The pronator teres may not be able to flex the extremity alone against gravity.

The pronator teres forms the medial margin of the antecubital fossa, and the fibers can be identified when the forearm is pronated while the elbow is flexed (Figure 6-25). When resistance is applied to the forearm in this position, the pronator teres can easily be identified. Place one finger on the humeral medial epicondyle and one on the midpoint of the radius, and the ridge of this muscle will be seen running obliquely between the two fingers (Gench et al., 1995; Houglum & Bertoti, 2012). More distally, the pronator crosses to the radial side and is covered by brachioradialis. If the forearm is pronated with little effort, the pronator teres will contract.

Extensor Carpi Radialis Longus

Due to the anterior location and origin on the humeral epicondyle, both the extensor carpi radialis longus and pronator teres may assist with elbow flexion. However, because the extensor carpi radialis longus arises too low on the humerus, attaches too close to the flexion axis, and produces a short moment arm, this muscle fails to be too important in flexion of the forearm.

Extensor Carpi Radialis Brevis

Due to this muscle crossing the elbow anterior to the axis, this muscle may serve to assist in elbow flexion (Gench et al., 1995); however, because the muscle's proximal attachment is on the epicondyle and therefore very close to the elbow's axis, it is questionable what effect this muscle has on elbow flexion.

Flexor Carpi Radialis, Palmaris Longus, and Flexor Carpi Ulnaris

These muscles were also identified as having assistive actions with elbow flexion (Gench et al., 1995; Lumley, 1990; Smith et al., 1996).

Extensors of the Forearm

Primary extensors of the elbow are the triceps and anconeus (Figure 6-26).

Triceps

The triceps muscle has three heads, with the medial head being the primary extensor of the forearm. The size of the muscle as well as the angle of attachment on the olecranon give the triceps power despite poor leverage.

The long head of the triceps is affected by positions of the shoulder because this portion crosses both the shoulder and elbow joints. This long head can become actively insufficient when the elbow and shoulder are both extended because this

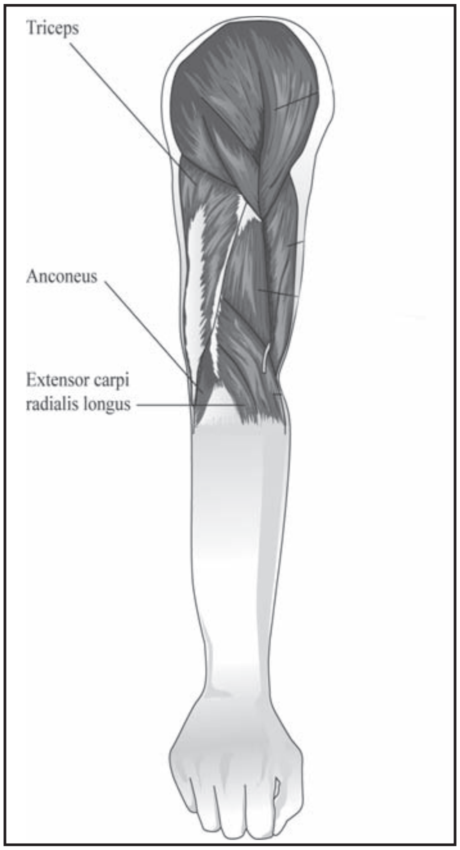

Figure 6-26. Muscles that extend the elbow.

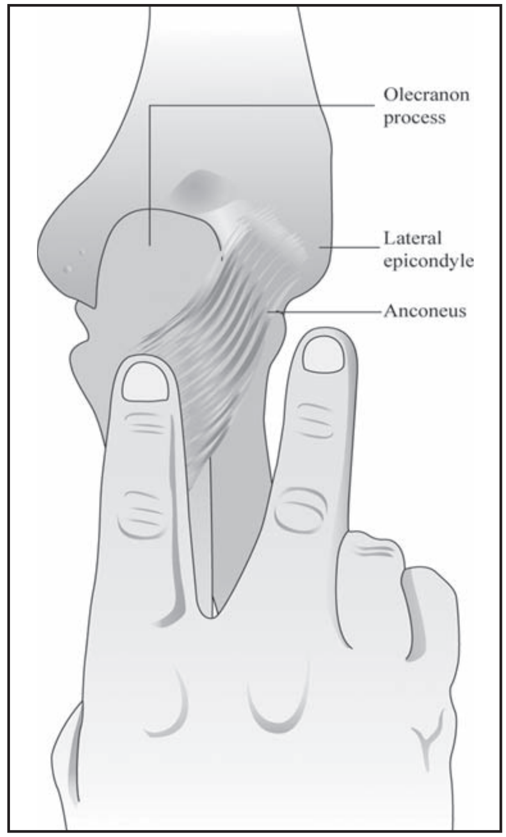

Figure 6-27. Palpation of the anconeus muscle.

shortens the muscle over both joints. The middle and lateral heads of the triceps muscle are not affected by shoulder position. All three heads of the triceps muscle extend the elbow when there is heavy resistance or when quick extension is required.

Frequently, the triceps muscle works eccentrically, as when one lowers the body to the floor with the elbows flexed and the triceps lengthen (Gench et al., 1995; Hinkle, 1997; Houglum & Bertoti, 2012; Konin, 1999; Loth & Wadsworth, 1998; Smith et al., 1996).

The lateral head can be palpated between the posterior deltoid and the lateral epicondyle. It appears separated from the deltoid by a groove. The long head can be palpated between the axilla and the olecranon process. This is the contour at the lower portion of the arm. The long head of the triceps is the only band of muscle on the posterior surface that runs superiorly along the proximal and medial aspect of the arm (Biel, 2016).

The medial head is located beneath the long head and is difficult to palpate. It is best palpated in its distal portion near the medial epicondyle. By placing the dorsum of the wrist on the edge of a table and applying resistance downward, the medial head may be felt contracting when extension is resisted (Esch, 1989; Houglum & Bertoti, 2012; Lumley, 1990; Magee, 2014). It can also be felt by placing the subject prone and having him or her extend the elbow as you apply resistance toward flexion. You can palpate the medial and lateral heads on either side of the broad distal triceps tendon (Biel, 2016).

Anconeus

This small, triangular muscle is active in initiating and maintaining extension and in joint stabilization. Because it is very close to the axis and is small, it is weak in these actions. Thompson and Floyd (1994) stated that the chief function of the anconeus was to pull the synovial membrane out of the way of the advancing olecranon process during extension of the elbow.

By placing the thumb and index finger on the olecranon process and lateral epicondyle, one can feel the base of this equilateral triangular muscle (Figure 6-27; Gench et al., 1995). The extensor carpi ulnaris lies close to the anconeus, and while the two muscles may appear as one, identification can be made by keeping in mind that the direction of the line of muscle pull varies and that the anconeus lies more proximally and is very short.

Pronators of the Forearm

The primary pronators of the forearm are the pronator quadratus (primary) and pronator teres (when there is rapid or resisted pronation; Figure 6-28). Other muscles that may contribute to pronation include the brachioradialis, flexor carpi radialis, palmaris longus, and extensor carpi radialis longus.

Pronator Quadratus

A rhomboidal or quadrangular muscle, pronator quadratus muscle is considered to be the primary pronator. Due to the size of the muscle and the pull of the fibers, this muscle is a

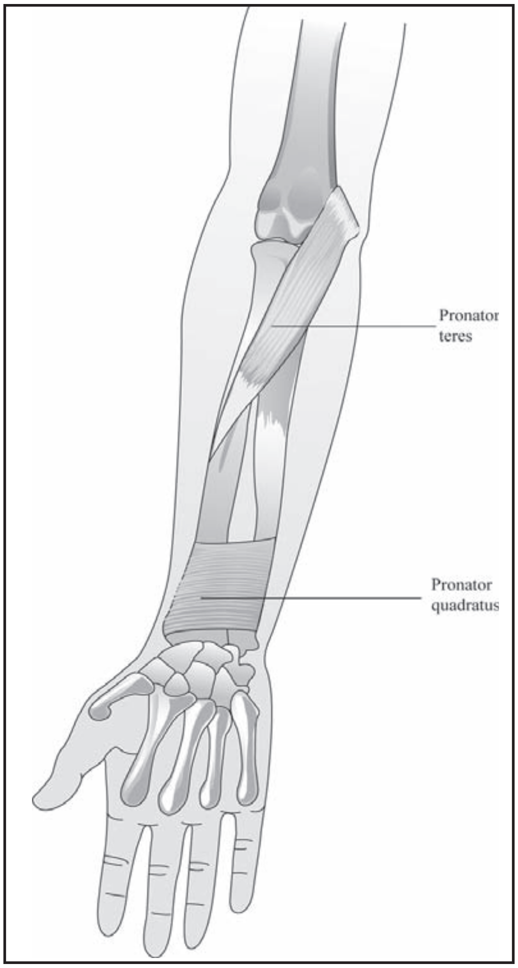

Figure 6-28. Muscles that pronate the forearm.

pronator of the radioulnar joint without help and in movements that are slow and unresisted. With the triceps muscle, it extends and pronates the elbow. The action of pronator quadratus can be seen in using a screwdriver to remove a screw and in throwing a screwball in baseball (Gench et al., 1995; Hamill et al., 2015; Hinkle, 1997; Houglum & Bertoti, 2012; Jenkins, 1998; Smith et al., 1996).

Because it is too deeply located, palpation is not possible except for the most lateral portion, which is located near the radial artery.

Pronator Teres

This muscle lies anterior to the axis at the proximal radioulnar joint and has a long angular component. Due to its strength and efficiency, the pronator teres does not participate in pronation in slow or unresisted motion but instead contracts during rapid pronation or in pronation against resistance. It is considered to be a secondary pronator (Levangie & Norkin, 2011). If the pronator teres were to act alone, it would bring the back of the hand to the face as it contracts (Houglum & Bertoti, 2012). When you turn a doorknob or arrange cups in a dishwasher, you are using the pronator teres muscle (Biel, 2016).

See the palpation description in the earlier section on elbow flexors.

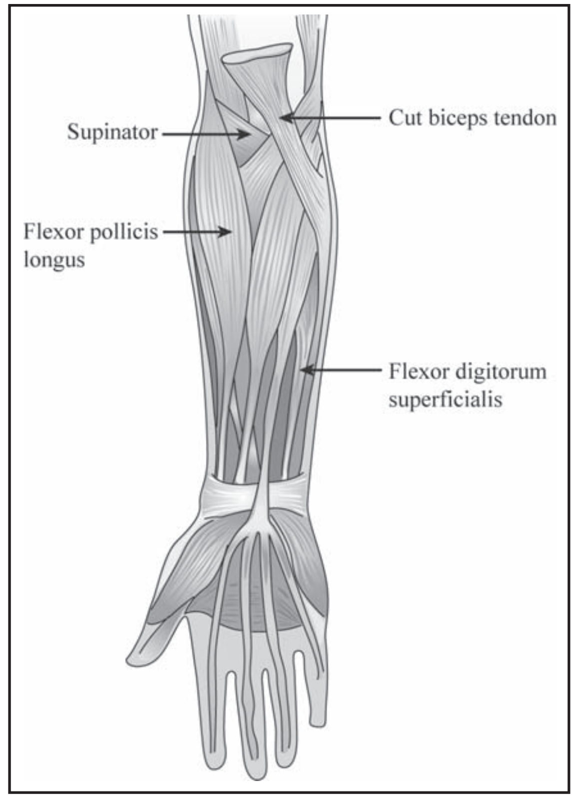

Figure 6-29. Muscles that supinate the forearm.

Brachioradialis

While primarily a flexor, the brachioradialis muscle is also a weak pronator. The brachioradialis directs a force volar to the joint axis, pulling the radius toward the ulna in pronation. In other words, the brachioradialis acts in pronation from a position of supination, with the ability to pronate decreasing as the forearm rotates to neutral.

Flexor Carpi Radialis

The flexor carpi radialis assists with pronation because the tendon passes obliquely across the wrist.

Palmaris Longus and Extensor Carpi Radialis Longus

These muscles may assist with pronation (Gench et al., 1995; Hinkle, 1997; Houglum & Bertoti, 2012; Jenkins, 1998).

Supinators of the Forearm

The primary supinator of the forearm is the biceps, with secondary contributions from the supinator muscle and brachioradialis (Figure 6-29). The force of the muscles that produce supination is 25% stronger than elbow flexors, which helps to explain why we use a clockwise motion when using a screwdriver to tighten a screw (Jazrawi et al., 2012).

Supinator

The supinator muscle (see Figure 6-29) is in the best position to supinate the radioulnar joint when the elbow is extended, and this position puts the muscle on more stretch than other positions (Gench et al., 1995). Two common examples of how this muscle may be seen are turning a screwdriver or throwing a curve ball in baseball. The primary function of this muscle is supination of the forearm, and it contracts when supination occurs slowly and without resistance. The supinator requires assistance from the biceps with resisted motion. The supinator is located deeply, and the slender muscle belly is difficult to palpate. When scooping ice cream or folding clothes, you are using your supinator muscle (Biel, 2016).

Biceps

The biceps is the strongest and most efficient supinator, especially when the elbow is flexed to 90 degrees. The biceps is four times more efficient than the supinator muscle in this flexed position and only twice as effective as the supinator muscle with the elbow extended and supinated. The triceps is needed to counteract the flexor action of the biceps when the muscle is recruited as a supinator. The biceps assists with rapid, unresisted supination with the elbow flexed or with any supination against resistance.

Brachioradialis

In addition to flexing the elbow, the brachioradialis can function as both a pronator and a supinator. As the forearm pronates, the brachioradialis directs a force on the dorsal side of the axis, and supination of the forearm occurs. The brachioradialis can supinate the forearm from a position of pronation, with the ability to supinate decreasing as the joint moves toward neutral.

Other Assistive Supinators

The abductor pollicis longus, extensor pollicis brevis, extensor indicus proprius, and flexor carpi ulnaris were also identified by some sources as assistive supinators (Houglum & Bertoti, 2012; Jenkins, 1998).

Assessment of the Elbow

Assessment of the elbow includes an understanding of the client as a person so that treatment goals match the occupational performance needs of the client. Observation and palpation of the structures of the elbow can provide information about pathologic conditions, such as inflammation and edema. Both active and passive ROM provide information about joint movement and about the contractile and non-contractile elements of the joint. ROM and strength testing can be quickly assessed with screens unless more formal testing is warranted. An appraisal of the client's pain is also a vital part of the evaluation as pain can invalidate tests, cause the client discomfort, and result in functional limitations in the use of the elbow (Figure 6-30).

Occupational Profile

The essential first step in evaluation is to understand the client's occupational history, experiences, patterns of living, interests, values, and needs (American Occupational Therapy Association, 2014). It is crucial to establish what the client's priorities are for treatment so that these are integrated into the treatment plan because it is the client's perspective about his or her priorities that drive any intervention. How limitations in elbow function affect occupational performance is the goal of assessment of the elbow. Does the client now use the non-dominant extremity for activities? If so, this reversal of natural dominance may indicate that function has been severely impaired. It is also important to establish the duration of the complaint and the time since onset of elbow-related symptoms.

How well the person can move the elbow joint and the quality of movement are vital to understanding how the limitations will interfere with functional activity. Observe how the person uses the elbow and arm in activities. Does the client seem willing to move the joint, and does the client use the arm automatically in activities and without discomfort? Does the client support one arm or use one arm more than the other? Look at how well the wrist, elbow, and shoulder all work together, and observe for lack of symmetry or muscle imbalance.

Several quantitative measures of elbow function are available. The American Shoulder and Elbow Surgeons-Elbow Score (ASES-e) has four assessment sections, including ROM, strength, stability, and physical findings, in addition to a self-evaluation section containing visual analog scales for pain and questions related to function (King et al., 1999). The Patient-Rated Elbow Evaluation (PREE) asks if there are any limitations in functional and usual activities and asks about pain under different conditions (MacDermid, 2001). The Oxford Elbow Score (OES) asks 12 multiple choice questions about pain, social psychology, and disability in daily activities (Dawson et al., 2008) but no physical factors related to the elbow. The Broberg and Morrey rating system assesses motion, strength, stability, and pain (Broberg & Morrey, 1986) and the Mayo Elbow Performance Score (MEPS) evaluates pain intensity, motion, stability, and function (Morrey & Sanchez-Sotelo, 2009). The Elbow Self-Assessment Score (ESAS) was developed by Beirer et al. (2017) based on several established measures of elbow function to provide a self-assessment tool that is both subjective and objective. The Disabilities of the Arm, Shoulder and Hand (DASH) and Quick DASH have also been used to assess elbow function. The Quick DASH contains 11 items to measure physical function and symptoms and is seen to be a more efficient version of the DASH outcome measure yet still appears to retain its measurement properties (Beaton et al., 2005). The Liverpool Elbow Score includes both a clinical and client assessment section. The clinical assessment includes ROM, strength, and assessment of ulnar nerve function, while the client section asks questions about specific daily tasks (Sathyamoorthy, Kemp, Rawal, Rayner, & Frostick, 2004). Other outcome measures for the elbow include the Ewald Scoring System (Ewald, 1975), Hospital for Special Surgery Scoring System (Figgie, Inglis, Mow, & Figgie, 1989), Flynn Criteria (Flynn, Matthews, & Benoit, 1974), Pritchard Score (Morrey & Sanchez-Sotelo, 2009), Nevaiser Criteria (Nevaiser & Wickstrom, 1977), Jupiter Score (Morrey & Sanchez-Sotelo, 2009), and Khalfayan Score (Khalfayan, Culp, & Alexander, 1992).

Cusick et al. (2014) tested the reliability of the MEPS and compared it with ASES-e. Pearson coefficients for MEPS scores at two time points averaged 0.82 and between MEPS and ASES-e averaged 0.83, indicating that the MEPS has

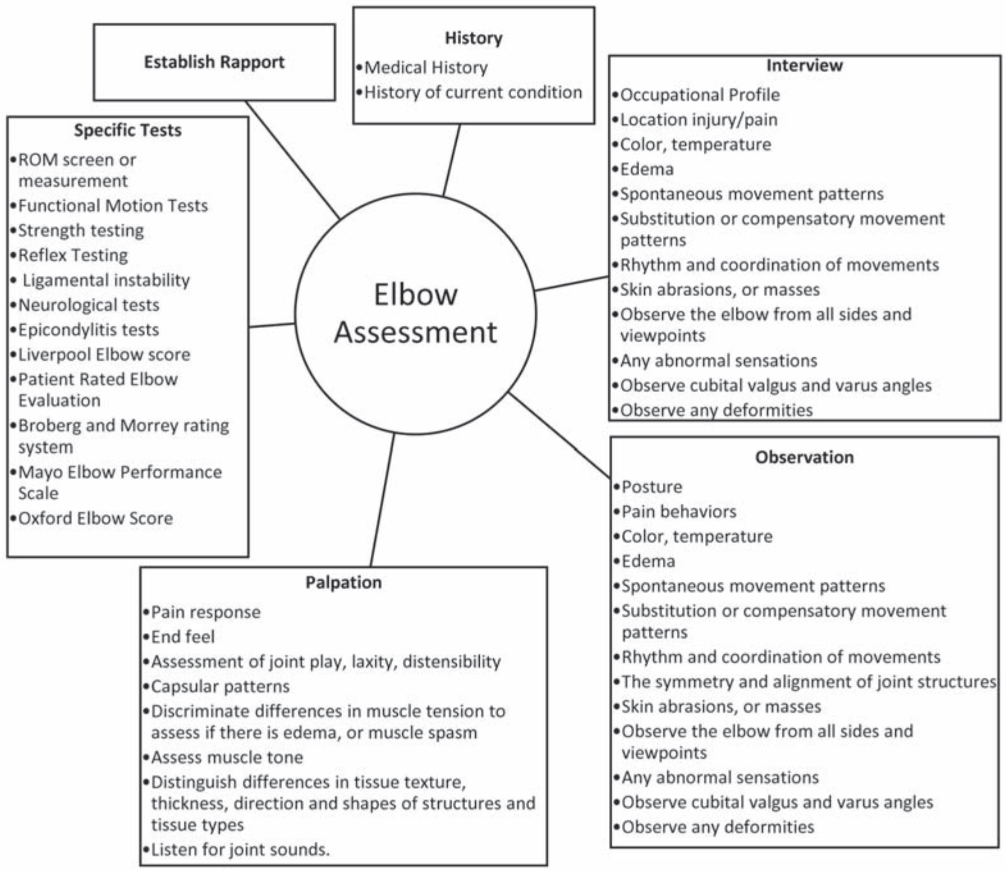

Figure 6-30. Evaluation of the elbow and forearm. (Adapted from Cooper, C. [Ed.]. [2007]. *Fundamentals of hand therapy: Clinical reasoning and treatment guidelines for common diagnoses of the upper extremity.* [p. 74]. St. Louis, MO: Mosby.)

strong reliability at different times and when compared with the ASES-e. Beirer et al. (2017) conducted a study to determine the construct validity and responsiveness of ESAS as compared to the Broberg and Morrey rating system, PREE, MEPS, OES, and Quick DASH. Construct validity and responsiveness were confirmed and correlation coefficients of the ESAS and other rating systems were between 0.70 and 0.90 ($P < .05$). The OES elbow function and pain domains correlated highly with the MEPS elbow performance clinical scale, the DASH, and with relevant domains of the generic 36-item Short Form Health Survey. The OES social-psychological domain also correlated with the DASH and Short Form Health Survey and, in the context of clients undergoing elbow surgery, the OES was highly responsive with a large effect size (Dawson et al., 2008). MacDermid (2001) asked a group of 50 clients with a diverse range of elbow pathologies to self-rate themselves using the PREE and ASES-e and did so again within one week. The test-retest reliability was calculated and both questionnaires were shown to be reliable (MacDermid, 2001; Nuttall et al., 2010). Using the Consensus-Based Standards for the Selection of Health Measurement Instruments checklist criteria to assess the validity, reliability, and responsiveness of 12 different elbow-specific measures, The, Reininga, Moumni, and Eygendaal (2013) concluded that the OES is the only system that is validated using high-quality methodology.

Observation and Palpation

Many of the disorders of the elbow can be detected by observation and palpation. Observe the client's position in extension and supination. The cubitus valgus (carrying angle) should not be more than 15 to 20 degrees, and the cubitus varus should not exceed 5 degrees. The cubitus valgus angle has been found to be greater in athletes in unilaterally dominant upper extremity sports (e.g., baseball, tennis) and may also have more osseous changes, such as bone spurs and osteophytes, which would limit motion and present with abnormal end feel (Dumontier, 2010; Ellenbecker et al., 2010). Changes in the carrying angle may also be indicative of elbow instability or malunion (Dumontier, 2010).

Many of the landmarks will be more easily seen by standing or sitting behind the client. The prominence of the olecranon is a sign of posterior subluxation of the elbow, which is not uncommon in clients with rheumatoid arthritis (Dumontier, 2010; Magee, 2014). Subcutaneous nodules are also common and can be found on the posterior aspect (extensor surface) of the elbow. Note the location, number, size, and other characteristics of these nodules (e.g., freely moveable, hard, tender). Bursitis may also be seen and is sometimes described as a "goose egg" formation at the back of the elbow. Other conditions that may cause nodular swelling of the elbow include rheumatoid arthritis; gout; and, rarely, systemic lupus erythematosus, rheumatic fever, and sarcoidosis.

Table 6-12

Structures to Palpate During Assessment of the Elbow

Location	Structure
Anterior	• Biceps tendon • Median nerve • Anterior capsule
Posterior	• Triceps tendon • Olecranon fossa
Medial	• Medial epicondyle • Forearm flexor and pronator tendons • Medial collateral ligament • Ulnar nerve
Lateral	• Lateral epicondyle • Radiocapitellar joint • Radial head • Radial nerve

Table 6-13

Edema and Abnormal Sensations of the Elbow

Swelling	
Type	• Local: May be due to bursae, muscle strains or contusions to tendons, muscle bellies; or may be due to intracapsular effusion • Diffuse: May be due to severe hematoma, dislocations, or fractures
Time	• Immediate to within first 2 hours: Damage to a structure with rich blood supply • 6 to 24 hours: Suggests synovial irritation as may occur with bone chips, capsular sprains, ligament sprains, or joint subluxation • After activity: Chronic bursitis or repeated trauma to bursae
Sensations	
Locking	• May occur if loose body is in the joint
Warmth	• May suggest inflammation or infection
Tingling, numbness	• May suggest C5 to C8 nerve root compression, thoracic outlet syndrome, injury to peripheral nerves, or neuritis or neuropathy
Grating	• Osteoarthritic changes or damage to articular surface (chondromalacia, osteochondritis, osteoarthritis)

Typical structures that are palpated during a physical examination of the elbow are included in Table 6-12. When palpating the anatomic landmarks, look for points of tenderness and compare these with the opposite extremity. Palpate the radial and ulnar margins, noting any synovial thickening that may be present or that may appear as a bulge on either side of the olecranon process (Magee, 2014). Lateral epicondylitis (tennis elbow) will be suggested if there is pain when the wrist is extended against resistance with the elbow in extension. Medial epicondylitis (golfer's elbow) is tested by resisted flexion of the wrist with the elbow in extension. Bicipital tendonitis is found by flexing the supinated forearm against resistance while palpating the tendon insertion.

Look for normal bony and soft tissue contours anteriorly and posteriorly. Swelling in the elbow is not uncommon, especially because all three joints share the same joint capsule. Swelling may be most evident in the triangular space between the radial head, tip of the olecranon, and lateral epicondyle. Because the elbow joint is so superficial, swelling and redness of the olecranon bursa are easy to observe. It is important to ascertain when the swelling started and make note of the location of the swelling. Additional information that can be gleaned from the physical assessment of the elbow is if any locking occurs during movement, the temperature of the skin, client descriptions of paresthesias, and any abnormal sound (e.g., grating or grinding; Table 6-13).

Distal radioulnar pathologies are also visible. The "piano key" sign is seen when the client places the palm flat on the table and is asked to press to the table using shoulder depression with the forearm in pronation. If the head of the ulna is elevated, this is considered a positive sign and suggests destabilizing dysfunction of the TFCC (Ellenbecker et al., 2010). Distal radioulnar subluxation or dislocation may only be noticeable by the swelling. There would also be functional changes, such as painful wrist motions or restricted pronation if there is volar dislocation, and supination is affected if there is dorsal dislocation (Ozer & Scheker, 2006).

Hypermobility of joints can be assessed by observation or more formally by using standardized elbow assessments or the Brighton Hypermobility Criteria. One point is added for moving into certain positions, such as hyperextension of the elbow (one point each for right and left), thumb touching the forearm, little finger bending backward past 90 degrees, hyperextension of the knee, and placing flat hand on the floor with straight legs (Grahame, Bird, & Child, 2000). The Brighton Scale is a simple system to quantify joint laxity and hypermobility, with higher scores representing greater laxity. Scores for young adults range from 4 to 6. Hypermobility syndrome may cause other conditions as a result of their unstable joints, which might include joint instability causing frequent sprains, tendonitis, or bursitis; early-onset osteoarthritis; frequent subluxations or dislocations; pain; crepitus in the joints; and increased nerve compression disorders.

Hypomobility of joints (those with decreased ROM) may be more susceptible to muscular strains, overuse tendonitis, chronic tendinosis, and nerve entrapment syndromes.

Range of Motion

ROM testing can begin with a screening test as simple as asking the client to bend and straighten the elbow (flexion and extension), turn the forearm so the palm faces up (supination), and turn the forearm so the palm faces down (pronation). Functional testing of the elbow can also be done in which you ask the client to perform certain motions such as reach into a back pocket, rise from a chair, wash the opposite axilla, eat with a utensil, comb hair, carry 10 to 15 pounds, dress, pull, throw, do usual work, and do usual sports (Morrey & Sanchez-Sotelo, 2009). Other functional assessments include an assessment of strength and ROM and quantify the observations by using weights or determining a number of repetitions (Palmer & Epler, 1998).

Active ROM is assessed first because a loss of elbow extension is a sensitive indicator of intra-articular pathology (Magee, 2014). Loss of active elbow flexion is seen as more disabling due to the amount of flexion required for many daily activities, such as eating, grooming, and hygiene. The biceps brachii two-joint muscle affects elbow ROM if the long head is excessively shortened over both the shoulder and elbow (Levangie & Norkin, 2011).

Passive movement assesses the capsule, ligaments, bursa, cartilage, and nerves. Passive movements can be done to assess end feel, sequences of pain and resistance, and capsular patterns. End feels that are not appropriate for the specific movement or that occur sooner in the range than should normally occur are indicative of joint pathology. In the two-muscle triceps brachii, passive tension may limit full elbow flexion when the shoulder is also simultaneously flexed (Levangie & Norkin, 2011).

Joint-play movements can be assessed. Deviations of the ulna and radius on the humerus are examined by having the examiner stabilize the elbow, placing the other hand above the wrist, and abducting/adducting the forearm. The end feel should be hard. Distraction of the olecranon from the humerus can be done by having the subject flex the elbow to 90 degrees and applying a distractive force (but with no rotation). Additional joint-play movements of anteroposterior glide can also be tested.

While there are normative data available for ROM for elbow flexion/extension, pronation, and supination, variance from these norms should be considered for intervention only when the limitations prevent the client from successful engagement in work, play, or self-care.

The useful arc of motion (or functional range) is between 30 and 130 degrees of elbow flexion (Jazrawi et al., 2012; Morrey, Askew, & Chao, 1981; Morrey & Sanchez-Sotelo, 2009). Most ADL require an arc of only 60 to 120 degrees (Dumontier, 2010; Vasen et al., 1995). Gates, Walters, Cowley, Wilken, and Resnik (2016) assessed the amount of ROM necessary for eight upper extremity ADL, and all tasks could be completed with 121 degrees of elbow flexion; van Andel, Wolterbeek, Doorenbosch, Veeger, and Harlaar (2008) found a minimum of 85 degrees was used for all functional tasks they studied. Flexion values range from 57 degrees to open a door to 136 degrees to use a telephone (Magee, 2014; Vasen et al., 1995). Elbow flexion had significant correlations (Spearman correlation coefficients $P < .001$) with functional tasks such as combing hair, using a telephone, putting a fork to mouth, feeding, and putting a glass to mouth (Nuttall et al., 2010).

Most tasks did not require forearm pronation, and all could be performed with 53 degrees of supination (Gates et al., 2016). Pronation values can range from 10 degrees needed to drink from a glass to 49 degrees to read a paper. Supination is not needed at all for cutting meat or rising from a chair, but approximately 52 degrees is needed to put a fork into the mouth (Magee, 2014; Vasen et al., 1995).

Reliability for ROM and strength for the elbow is good to excellent (intraclass correlation coefficient [ICC] = 0.87-1.00, standard error of measurement [SEM] = 0.00) using standardized testing positions and reliable instruments (Fieseler et al., 2015).

Stability Assessment

Instability is defined as an abnormal path of articular contact occurring during or at the end of the ROM (Ozer & Scheker, 2006). Instability may be due to changes in joint surface congruence, in ligamental pathology, or both.

Instability testing of the elbow requires rotationally stabilizing the humerus. From full extension to about 20 degrees of elbow flexion, the collateral ligaments cannot be isolated due to bony contributions to stability. Mediolateral varus stability is tested by having the client move into slight elbow flexion (20 to 30 degrees), which disengages the olecranon from the fossa and allows testing of the collateral ligaments. The humerus is in maximum internal rotation, and the forearm is also pronated. Stress is applied and, if there is instability, the client will report pain on the medial side.

Mediolateral valgus stability is tested in full external rotation (Dumontier, 2010) and with the forearm pronated to test the medial collateral ligament. Continue testing the valgus stability by slightly flexing the elbow, with the humerus in external rotation and with the forearm supinated to test the lateral collateral complex (Andersson, Nordin, & Pope, 2006; Dumontier, 2010). Apply radial compression and, if there is valgus instability, there will be tenderness 4 to 5 cm distal to the lateral epicondyle. The tenderness experienced due to valgus instability is distal to the epicondyle, while lateral epicondylitis tenderness is adjacent to the lateral epicondyle (Andersson et al., 2006). For assessing anteroposterior stability, the elbow is flexed to 90 degrees and is held by the examiner while applying an anteroposterior stress to the joint.

Instability can lead to dislocations. Dislocations can be either acute (e.g., an isolated injury, fracture of radial head, distal radius, ulna, or radius) or chronic (e.g., an isolated injury, distal radius malunion, incongruent distal radioulnar articulations, or unstable radiocarpal or ulnocarpal ligaments).

If the distal radioulnar joint subluxes or is dislocated as an isolated injury, only swelling may become apparent with painful wrist motions. The rotation of the forearm is always restricted. Complex distal radioulnar dislocations usually involve the ruptured triangular fibrocartilage ligaments, extensor digiti minimi tendon, extensor carpi ulnaris tendon, and extensors of the ring and little fingers and are frequently associated with ulnar styloid fracture. Chronic instability of the distal

Table 6-14

Strength Screen for the Elbow and Forearm

Muscle Action Tested	Instructions to the Client/Ask the Client to ...	Therapist's Action
Elbow flexion	Bend the elbow to 90 degrees. Tell the client, "Do not let me straighten your arm."	Apply resistance toward elbow extension
Elbow extension	Bend the elbow to 90 degrees. Tell the client, "Do not let me push your arm."	Apply resistance toward elbow flexion
Forearm supination	Bend the elbow to 90 degrees with the forearm in neutral position. Tell your client, "Do not let me turn your palm down."	Apply resistance in a downward (pronated) direction
Forearm pronation	Bend the elbow to 90 degrees with the forearm in neutral position. Tell your client, "Do not let me turn your palm up."	Apply resistance in an upward (supinated) direction

Table 6-15

Special Tests for the Elbow and Forearm

Reflex Testing	• Biceps brachii reflex	• Tests integrity of reflex innervated by C5 nerve root
	• Brachioradialis reflex	• Tests integrity of reflex innervated by C6 nerve root
	• Triceps reflex	• Tests integrity of reflex innervated by C7 nerve root
Ligamental Instability	• Valgus stress test	• Rupture of medial ulnar collateral ligament complex
	• Varus stress test	• Rupture of lateral radial collateral ligmament • Associated with radial head dislocation and annular ligament disruption
	• Valgus extension overload test	• Aids in identifying an osteophyte or loose body causing pain
Neurological Tests	• Tinel's sign	• Assesses ulnar nerve in ulnar groove between olecranon process and medial epicondyle
	• Pinch grip test	• Anterior interosseous nerve
	• Elbow flexion test	• Cubital tunnel syndrome/ulnar nerve entrapment
	• Test for pronator teres syndrome	• Median nerve entrapment
	• Wartenberg's sign	• Ulnar nerve neuropathy
Epicondylitis Tests	• Lateral epicondylitis tests	• Inflammation
	• Medial epicondylitis tests	• Inflammation

radioulnar joint can also occur as an isolated injury or may be associated with the distal radius malunion. Chronic instability of the distal radioulnar joint can progress toward osteoarthritis of the joint (Andersson et al., 2006; Ozer & Scheker, 2006).

Strength Assessment

Assessment of strength can occur by observing the client perform daily tasks or by resisted manual muscle testing. Elbow strength significantly correlated with several daily activities (Spearman correlation coefficients, $P < .001$), including doing heavy household chores, cutting with a knife, lifting a heavy pan, opening a door, rising from a chair, pouring from a jug, washing, and dressing (Nuttall et al., 2010). A strength screen for the elbow can be found in Table 6-14. More discrete testing can be done either with muscle groups or individual muscles. In general, resisted testing of muscle groups includes medial (epicondyle) flexors and pronators and lateral (epicondyle) extensors and supinators. Daily tasks such as drinking from a glass or self-feeding require fair plus elbow flexor strength and pulling up knee-high socks requires poor plus strength for elbow extensors. Fair supinator strength is required for brushing teeth, and fair pronator strength is necessary for locking a door with a key (Gutman & Schonfeld, 2003).

In addition, Table 6-15 shows special tests that can be done to assess reflexes, ligamental stability, epicondylitis, and neurological status of the elbow.

Pain Assessment

An assessment of the elbow should include gathering information about the client's level of pain. Determining the location of the pain can help to identify the cause of the pain. For example, if the pain is localized, it may be indicative of bursitis or epicondylitis; if the pain is more diffuse, it may signify a subluxation or fracture (Table 6-16). Ask the client when the pain was first noticed, when it occurs, and if there was an immediate onset of pain or if the onset was gradual. Differentiating the type of pain the client is experiencing as well as eliciting descriptions about sensations being felt is also helpful. Getting an idea of the experience of the pain for the client is often done by asking the client to rate his or her pain on a scale from 1 to 10, with 1 indicating no pain and 10 being the worst pain the person has ever experienced. Visual analog scales may also be used to represent the client's perception of his or her pain. Elbow pain was found to correlate with difficulties in performing daily activities and required modification of behavior for task completion (Nuttall et al., 2010).

The elbow has to be considered as part of the entire kinetic chain of the upper extremity. Pain can be referred to the elbow from the neck, shoulder, or wrist. For example, a client may complain of elbow pain due to cervical nerve root irritation or even due to metastatic cancer. Elbow pain can come from a variety of conditions and pathologies that include ligamental and bursa inflammation, sprains, arthritis, acute rheumatic fever, tuberculosis, gonorrhea, dislocations and subluxations, fractures, osteosarcoma, and hemarthrosis. A partial list of elbow pathology is included in Table 6-17.

Table 6-16

DESCRIPTIONS OF ELBOW AND FOREARM PAIN

LOCALIZED VS. DIFFUSE	If pain is easily localized, it is more likely to due to a superficial structure (olecranon bursitis, lateral epicondylitis, medial epicondylitis) or due to muscle or ulnar or radial collateral ligamental sprains. Deeper structures elicit pain that is more difficult to localize or radiates. Diffuse pain may be due to referred pain from dermatomes or cutaneous nerves, joint subluxations, severe hematoma, or fractures. Localized pain may be due to: • Olecranon bursitis • Lateral epicondylitis • Medial epicondylitis • Muscle strains (biceps, triceps, wrist flexors or extensors) • Ulnar or radial collateral sprains Diffuse pain may be due to: • Referred pain from dermatomes or cutaneous nerves • Nerve injuries • Joint subluxations or dislocations • Severe hematoma • Fractures	
LOCATION	• Anterior	• Rupture of distal biceps tendon • Brachialis muscle tear • Anterior capsule tear • Disruption of the annular ligament and radial head dislocation • Acute thrombophlebitis
	• Posterior	• Triceps tendonitis • Triceps rupture • Valgus extension overload syndrome • Stress fracture of the olecranon • Olecranon bursitis
	• Medial	• Medial epicondylitis • Rupture of flexor forearm • Rupture or injury to the medial (ulnar) collateral ligament • Medial epicondylar fracture • Acute ulnar neuropathy • Epitrochlear lymphadenitis
	• Lateral	• Lateral epicondylitis • Rupture of the lateral extensor muscle group • Disruption of the annular ligament and anterior radial head dislocation • Entrapment of the musculocutaneous or lateral antebrachial cutaneous nerve • Osteochondral fracture of the radial head
ONSET	• Immediate	• Suggests acute injuries such as hemarthroses, fractures, subluxations, or severe sprains or tears
	• Gradual	• Suggests overuse injuries or epicondylitis; ulnar neuritis pain 6 to 24 hours after an activity may suggest a more chronic condition
TYPE		May suggest injury to:
	• Sharp	• Skin, fascia, superficial muscle or ligaments, inflammation of bursa or periosteum
	• Dull ache	• Subchondral bone, fibrous capsule, or chronic olecranon bursitis
	• Tingling	• Peripheral nerve damage, irritation of nerve roots C5 to C8, or a circulatory problem
	• Numbness	• Peripheral nerves or dorsal nerve roots affecting C6 to T1 dermatomes
TIME	• Morning	• Rest does not alleviate pain and may suggest that the injury is still acute, that there is an infection or is systemic in nature, or that rheumatoid arthritis may be present
	• Evening	• Suggests that activities aggravate the pain
	• Night	• May indicate bone neoplasm, local or systemic disorders

Adapted from Tan, J. C. (1998). *Practical manual of physical medicine and rehabilitation*. St. Louis, MO: Mosby.

Table 6-17

Elbow and Forearm Pathology

Contusions	• Olecranon contusion when one falls on tip of elbow • Lateral epicondyle and radial head frequently contused • Biceps and triceps often contused, especially in contact sports; can lead to myositis ossificans
Fractures	• Especially in children and adolescents due to epiphyseal plates that are not closed and ligamental structures that are stronger than cartilaginous plates; condylar and epicondylar fractures, especially on the medial aspect • Medial epicondylar fractures usually avulsion fractures due to excessive force on ulnar collateral ligaments • Lateral epicondylar fracture often avulsion through growth center often due to excessive force through the common extensor origin • With all fractures of the elbow, disruption of arterial supply may cause Volkman's ischemic contractures, which are a medical emergency • Supracondylar fracture, usually in children, is very serious due to nearness of brachial artery and median nerve; occurs often due to a fall on an outstretched hand or forced elbow hyperextension without dislocation • Monteggia fracture-dislocation is a fracture of the ulna just distal to the olecranon due to fall on the outstretched hand • Head of radius may fracture • Osteochondritis of the capitulum (Panner disease) may occur due to direct trauma or inadequate circulation through the elbow joint
Bursitis	• Olecranon bursitis due to fall on tip of elbow or direct blow causing swelling into the bursa • Radiohumeral bursa can occur due to a direct blow or extensor muscle overuse; not to be confused with lateral epicondylitis
Overstretch Injuries	• Hyperextension due to falls on outstretched arm with elbow extended and forearm supinated, potentially causing damage to biceps, brachialis, brachioradialis, anterior portion of medial and/or lateral collateral ligaments, elbow capsule • In children or young adolescents, hyperextension usually causes a supracondylar fracture • In older athletes, fractures occur in ulna or radius • Very common in gymnasts and in wrestling
Sprain/Strain	• Valgus force causing medial collateral ligament sprain or tear and damage to anterior capsule; often associated with ulnar nerve paresthesias • Forced pronation can cause posterior subluxation of ulnar head • Forced supination can sprain the annular ligament or lateral collateral ligament • Swelling and pain are the presenting symptoms
Overcontraction: Acute Muscle Strain	• Common extensor tendon (lateral epicondyle) • Common flexor tendon (medial epicondyle)

(continued)

Table 6-17 (continued)

Elbow and Forearm Pathology

Overuse	• Wrist extensor-supinator overuse results in:
	  ◦ Lateral epicondylitis
	  ◦ Tendonitis
	  ◦ Radiohumeral bursitis
	  ◦ Radial head fibrillation
	  ◦ Radial tunnel syndrome
	  ◦ Annual ligament inflammation
	  ◦ Entrapment of posterior interosseous nerve
	  ◦ Lateral epicondylitis, especially with sports such as tennis and racquetball due to forceful contraction involving wrist extensors
	  ◦ Wrist flexion with a valgus force at extending the elbow and incorrect biomechanics
	  ◦ Medial epicondylitis or "little league elbow"
	• Repeated elbow extension with a valgus force
	• Repeated wrist flexion (e.g., golfers at medial epicondyle; tennis players and athletes who are in throwing sports)
	• Repeated elbow flexion

Myositis Ossificans	• Brachialis muscle may be affected following trauma to the elbow; most often seen with supracondylar fracture, posterior dislocation, or tear of the brachialis tendon • Resisted elbow flexion causes pain; flexion is limited and palpation of distal brachialis muscle is tender
Tendinitis	• Pain and swelling in elbow region and pain and weakness of wrist muscles with forceful movements of wrist and fingers; due to repeated or excessive use of the muscle or incorrect biomechanics • Common extensor tendon = lateral epicondylitis or tennis elbow • Common flexor tendon = medial epicondylitis or golfer's elbow
Specific Joint Problems	
Humeroulnar	• Passive flexion is more limited than extension; capsular end feel
Humeroradial	• Flexion and extension limited only in prolonged immobilization or arthritis, and then pronation and supination will also be limited
Proximal subluxation of the radial head	• May be limited flexion or extension, limited wrist flexion, or limited pronation
Distal subluxation of the radial head (pulled elbow)	• Limited supination with pain following forceful traction to forearm; tennis elbow
Proximal radioulnar joint	• Limited pronation and supination with pain when overpressure applied
Distal radioulnar joint	• May be limited pronation or supination and pain in distal forearm with overpressure

Summary

- The elbow joint consists of the articulations between the ulna, radius, and humerus.
- The elbow joint is actually made up of three articulations: the humeroulnar, humeroradius, and superior radioulnar joints.
- The superior radioulnar joint does not contribute to the uniaxial hinge motions of flexion and extension at the elbow joint.
- The superior and inferior radioulnar joints produce pronation (crossing of radius and ulna) and supination (ulna and radius parallel).
- Stability of the elbow is provided by the ligaments surrounding the joint and the congruence of the distal humerus, proximal radius, and proximal ulna.
- Flexors of the elbow (biceps, brachialis, brachioradialis) are, as a group, most efficient in supination and when the elbow is flexed (also the position of greatest stability). Extensors of the elbow (triceps, anconeus) are most efficient when the elbow is flexed to 20 to 30 degrees.

- Contact areas of the radius and ulna on the humerus change as one moves in flexion and extension.
- Posterior displacement of the elbow is prevented by the coronoid process of the ulna and the humeroradial articulation.
- Assessment of the elbow should include how the client moves, the goals of the client, amount of edema, and client's pain. Observation of how the client uses the elbow in activities is an important aspect of evaluation.

> Figures 6-3, 6-5, 6-6, 6-7, 6-8, 6-9, 6-10, 6-11, 6-23, 6-24, 6-25, and 6-27 are adapted from Biel, A. (2001). *Trail guide to the body*. Boulder, CO: Books of Discovery.

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7

The Wrist

Melinda F. Rybski, PhD, MS, OTR/L

The wrist allows for incremental changes in location and orientation of the hand relative to the forearm, allows placing the hand in space, and permits fine gradations of prehension as well as powerful grasp. The wrist makes a dynamic contribution to a skill or movement or to stabilization (Hamill, Knutzen, & Derrick, 2015) and contributes to expression and non-verbal communication. The wrist serves a kinetic function in transmitting loads and forces from the hand to the forearm and from the forearm to the hand, as well as providing stability for the hand. Linscheid (1986) considered the wrist to be mechanically the most complex joint in the body. These positional adjustments are essential for augmenting fine motor control of fingers and in allowing optimal length-tension of long finger muscles so maximal finger movement can be attained (Figure 7-1; Barr & Bear-Lehman, 2012). The length-tension interactions between extrinsic hand muscles cannot be replaced by compensatory movement of the shoulder, elbow, or forearm (Levangie & Norkin, 2011).

The wrist is a multiarticulating, complex biaxial joint made up of two compound joints. Because this is a complex joint with many articulations, the joints do not act in isolation. When the hand is in a resting position, it assumes a slight ulnar and palmar posture because the dorsal surface is much longer than the palmar.

The position of one joint affects the action of others. For example, if the wrist is flexed, the interphalangeal joints cannot flex fully due to the insufficiency of the finger flexors as they cross both joints. The interplay of structures has implications not only for joint and muscle actions, but also is an influence in the pathology of the hand and wrist.

The wrist joint is capable of much mobility and has great structural stability. This highly complex area consists of 15 bones (8 carpal bones, ulna, radius, and 5 metacarpal bones), 17 joints, and an extensive ligamental system. The joint is formed by articulations of the hand and wrist and has four articular surfaces (Figure 7-2; Goss, 1976):

1. Distal surfaces of the radius and the articular disc
2. Proximal surfaces of scaphoid, lunate, and triquetrum bones
3. An S-shaped surface formed by the inferior surfaces of the scaphoid, lunate, and trapezium carpal bones
4. The reciprocal surface of upper surfaces of the carpal bones of the second row

These four surfaces form the two joints of the wrist: the proximal portion is what is commonly thought of as the wrist joint (radiocarpal joint) and the distal portion forms the midcarpal joint.

Bones of the Wrist and Palpable Structures

The bones of the wrist include the ulna, radius, and eight carpal bones. The ulnar and radial styloid processes are the medial and lateral borders of the wrist with the carpal bones easily palpated between the two styloid processes. The two wrist creases on the volar surface of the wrist indicate the radiocarpal (proximal line) and midcarpal (distal line) joints and can be seen in Figure 7-3.

Rybski, M. F.
Kinesiology for Occupational Therapy, Third Edition (pp. 199-222).

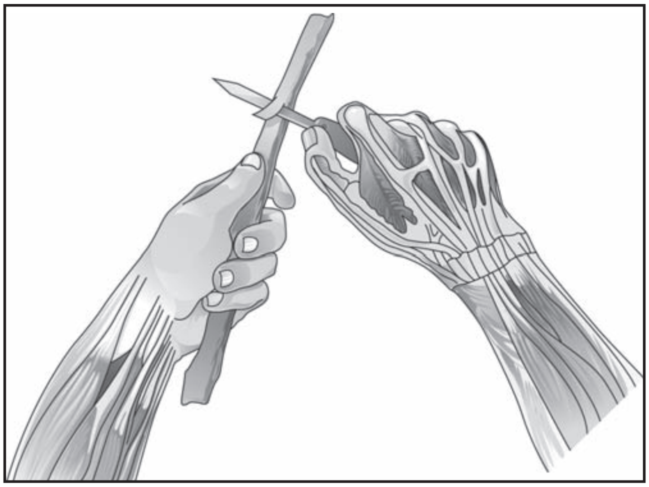

Figure 7-1. The wrist in action.

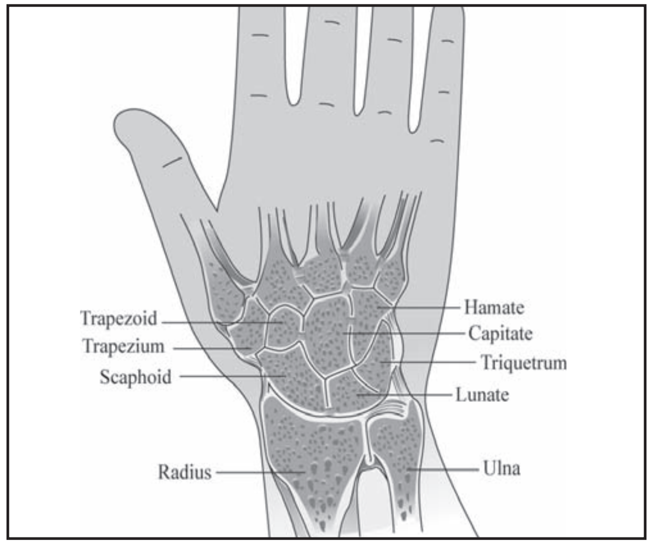

Figure 7-2. Articulating surfaces of the wrist.

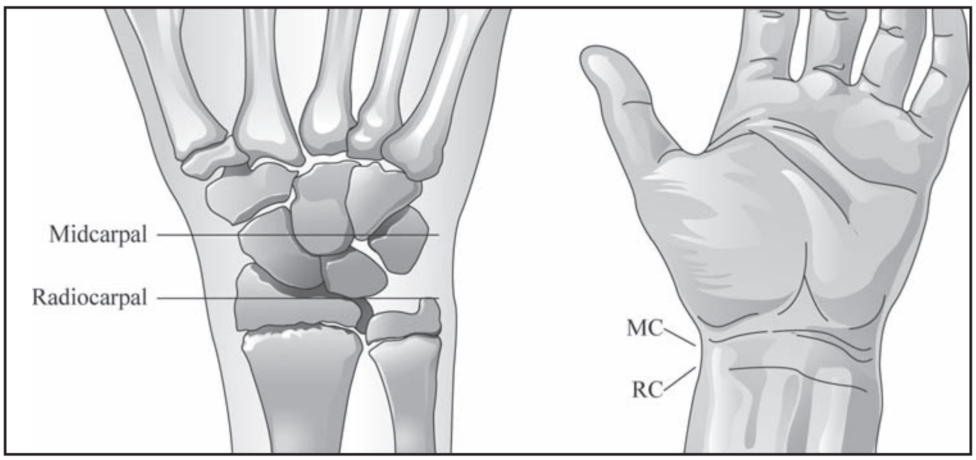

Figure 7-3. Flexor wrist creases indictating the midcarpal (MC) and radiocarpal (RC) joints.

Ulna

Head of the Ulna

This can be grasped from side to side at its narrowest portion. This is the rounded projection proximal to the index finger and on the dorsum of the wrist. In a pronated position, this eminence can be seen beneath the skin. If the fingertip is placed on the highest part and the forearm is supinated, the head of the ulna can no longer be palpated because, during supination, the distal portion of the radius rotates around the head of the ulna.

Styloid Process of the Ulna

This is a small projection on the medial aspect of the head of the ulna, and it feels smaller and sharper than the head of the ulna. It may be palpated in pronation or supination. If the extensor carpi ulnaris (ECU) tendon interferes with palpation, slide the index finger over this tendon in a palmar direction, and the styloid will be more accessible (Biel, 2016).

Radius

Styloid Process of the Radius

This is located at the lateral aspect of the wrist, proximal to the first metacarpal, and it extends more distally than the styloid process of the ulna. Note that the radial styloid extends further distally than ulnarly at an oblique angle.

Lister's Tubercle (Tubercle of the Radius)

This tubercle is located on the dorsum of the radius about 1 inch laterally from the head of the ulna. The extensor pollicis longus tendon lies on the ulnar side of this prominence, and the tubercle serves as a landmark for locating many tendons in this region (extensor carpi radialis brevis [ECRB], extensor indicus proprius, and the extensor digitorum to the index finger). Locate the radial styloid process and palpate the dorsal surface of the process directly across from the head of the ulna (Biel, 2016).

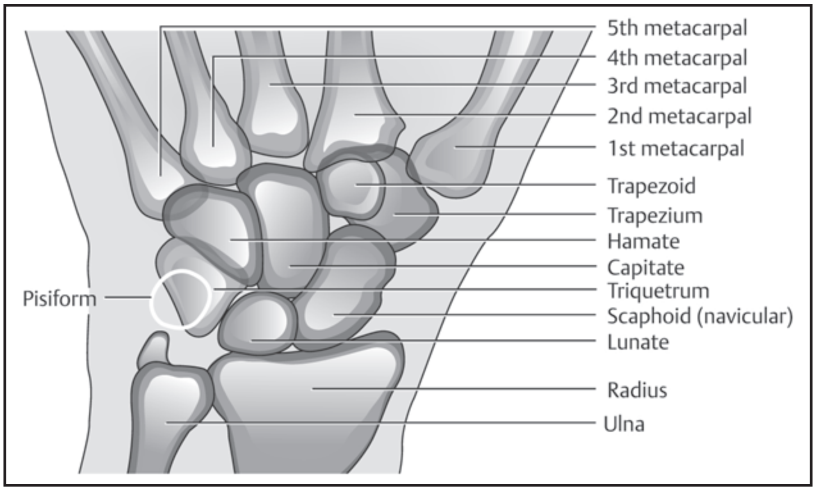

Figure 7-4. Carpal bones.

Carpal Bones

There is considerable passive accessory motion possible in the wrist with the forearm and wrist relaxed. If the distal radius and ulna are stabilized with one hand and the other hand is placed around the proximal carpal row, the carpals can move easily in dorsal, volar, medial, and lateral translatory glides and can be distracted several millimeters (Biel, 2016). Due to overlying tendons and compact arrangement of the carpal bones, isolating all of the carpal bones is difficult (Biel, 2016). As a group, you can feel the shifting of the carpal bones, particularly on the dorsum of the hand just above the radius and ulna and between the proximal and distal flexor creases of the wrist.

A mnemonic to remember the carpal bones is "She Looks Too Pretty, Try To Catch Her" with the scaphoid, lunate, triquetrum, and pisiform in the proximal row laterally to medially and trapezium, trapezoid, capitate, and hamate in the distal row laterally to medially (Provident & Houglum, 2012). Figure 7-4 identifies the carpal bones.

Capitate

This bone is in the central position in the wrist in line with the middle finger. It is best approached from dorsum and is seen as a slight depression. The capitate serves as the axis for deviation motions of the wrist (Smith, Weiss, & Lehmkuhl, 1996).

Scaphoid (Navicular)

The scaphoid is an important bone for wrist and hand function as it bridges and moves with the two carpal rows on the radial side. Because of this, the scaphoid helps to support the weight of the arm, transmits forces received from the hand to the forearm, and is important in wrist movements (Magee, 2014). It is also the most frequently fractured carpal bone.

This can be palpated distally to the styloid process of the radius. When in ulnar deviation, the bone becomes prominent and can be palpated, but while in radial deviation, the bone recedes. The scaphoid and trapezium make up the floor of the anatomic snuffbox (fovea radialis).

Trapezium (Greater Multangular)

This bone can be palpated proximal to the first carpometacarpal of the thumb and distal to the scaphoid.

Lunate

The lunate is distal to Lister's tubercle and proximal to the capitate. It is prominent as the wrist is passively flexed and recedes as the wrist is passively extended. This is the most frequently dislocated carpal bone.

Pisiform

This is a pea-shaped bone on the palmar side of the wrist near the ulnar border. It is located on the ulnar and palmar surface of the wrist just distal to the flexor crease. It can be grasped and moved from side to side when the wrist is flexed but is immobile when the wrist is extended due to tension of the flexor carpi ulnaris (FCU) muscle, which attaches on this bone (Biel, 2016).

Triquetrum (Triangular)

The triquetrum is located on the dorsal surface of the pisiform, distal to the styloid process of the ulna. This bone is just below the ulnar styloid and is accessible for palpation when the wrist is abducted.

Hamate

The hamate has a palpable hook on the palmar surface on which the flexor retinaculum attaches. It is located distally and laterally to the pisiform, which is often tender when palpated. The flat surface of the hamate is accessible on the dorsal surface of the bases of the fourth and fifth metacarpals and will feel like a subtle mound at the base of first finger about 1/2 inch from the pisiform (Biel, 2016).

Anatomical Snuffbox

This indentation forms on the dorsum of the hand when the thumb is actively extended. The tendons between the extensor pollicis longus and extensor pollicis brevis form the medial and lateral borders of the snuffbox, with the scaphoid

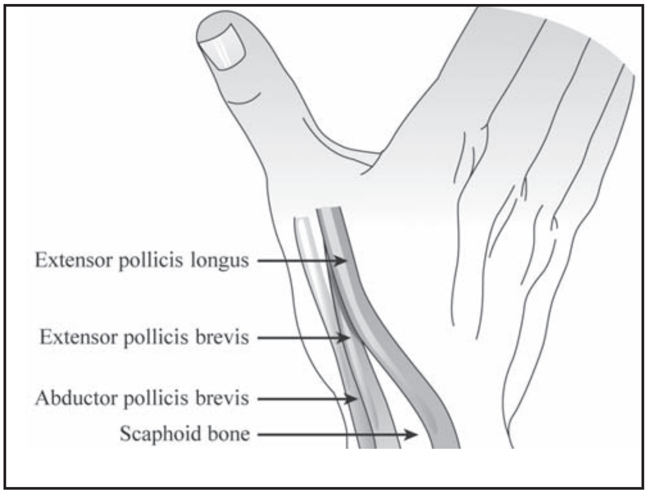

Figure 7-5. Structures of the anatomical snuffbox.

Table 7-1

OSTEOKINEMATICS OF THE RADIOCARPAL JOINT

FUNCTIONAL JOINT	Diarthrosis, biaxial
STRUCTURAL JOINT	Synovial, condyloid
CLOSE-PACKED POSITION	Extension
RESTING POSITION	Neutral with slight ulnar deviation
CAPSULAR PATTERN	Flexion and extension

bone inside as the floor of the snuffbox (Figure 7-5). The radial styloid is on the lateral aspect when in the anatomic position, and moving medially over the radius is Lister's tubercle. The ulnar styloid is on the medial aspect. The muscles of the anatomical snuffbox are involved in many daily activities including typing or texting, painting, throwing a ball, unlocking a door with a key, grasping the handle of a teacup, or writing with a pencil (Biel, 2016).

ARTICULATIONS OF THE WRIST

The articulations of the wrist include the radiocarpal joint, midcarpal joints, intercarpal joints, distal radiocarpal joint, and ulnocarpal joints. The wrist complex includes the radiocarpal and midcarpal joints, which act together in flexion and extension and radial and ulnar deviation.

Radiocarpal Joint

This joint is commonly referred to as the *wrist*. It is made up of the biconcave distal end of the radius and the distal surface of the radioulnar articulating disc, connecting with the biconvex proximal carpal bones (scaphoid and lunate). The radius articulates with the scaphoid and lunate, while the lunate and trapezium articulate with the disc, not the ulna (MacKenna & Callender, 1990). The distal radius and the disc form an elliptical, biconcave surface, and the superior articulating surfaces of the scaphoid, lunate, and trapezium form a smooth biconvex surface. The disc binds the radius and ulna together at their distal ends and separates the distal ulna from the radiocarpal joint. The joint surface is oblique and angled approximately 23 degrees slightly volarly and ulnarly due to greater length on the radial side than the ulnar. The distal radius is also tilted 11 degrees, with the posterior radius longer than the volar surface (Levangie & Norkin, 2011).

Osteokinematics

The radiocarpal joint is a biaxial, condyloid and synovial joint with 2 degrees of freedom capable of producing flexion and extension, abduction and adduction, and circumduction of the wrist. Circumduction is produced by the consecutive sequential combination of movements of adduction, extension, abduction, and flexion. This is a true condyloid joint with all motions except rotation. No active rotation is possible, but the effect of rotation is achieved by pronation and supination of the forearm at the radioulnar joints. Rotation is blocked by the bony fit of the radiocarpal joint and direction of fibers of the radiocarpal ligaments (Neumann, 2002). The motion at this joint is primarily gliding produced by movement of the proximal row of the carpal bones on the radius and radioulnar disc.

The close-packed position of extension with slight ulnar deviation occurs due to the elongation of the palmar radiocarpal ligament, palmar capsule, wrist, and finger flexor muscles. This stabilization allows greater stability when weightbearing on hands, such as when crawling on the hands and knees or doing a transfer from a wheelchair (Magee, 2012; Neumann, 2002). With the wrist in neutral and forearm and hand relaxed, the wrist is unstable with a substantial amount of joint plan possible. A summary of the osteokinematics of the radiocarpal joint is presented in Table 7-1.

Arthrokinematics

In open chain movement, the convex surfaces of the scaphoid, lunate, and trapezium move on the concave surfaces of the radius and ulna. Because the convex surface of the carpals moves on the concave distal radius, the glide of the carpals is in a direction opposite to the movement of the hand (Kisner & Colby, 2012; Provident & Houglum, 2012). In extension, the convex surface of the lunate rolls dorsally on the radius and simultaneously glides in a palmar direction; it moves similarly but in the reverse direction for flexion (Figure 7-6). There is a similar convex-on-concave movement of the carpals at the radiocarpal joint for ulnar and radial deviation (Table 7-2; Neumann, 2002). Computer modeling and cadaver studies have shown that radiocarpal extension is accompanied by increased contact dorsally rather than in a volar direction, which may contradict the current understanding of the convex-concave rule and our understanding of the complexity of the wrist (Levangie & Norkin, 2011).

Stability

The radiocarpal joint is formed by the radius and radioulnar disc proximally and by the scaphoid, lunate, and

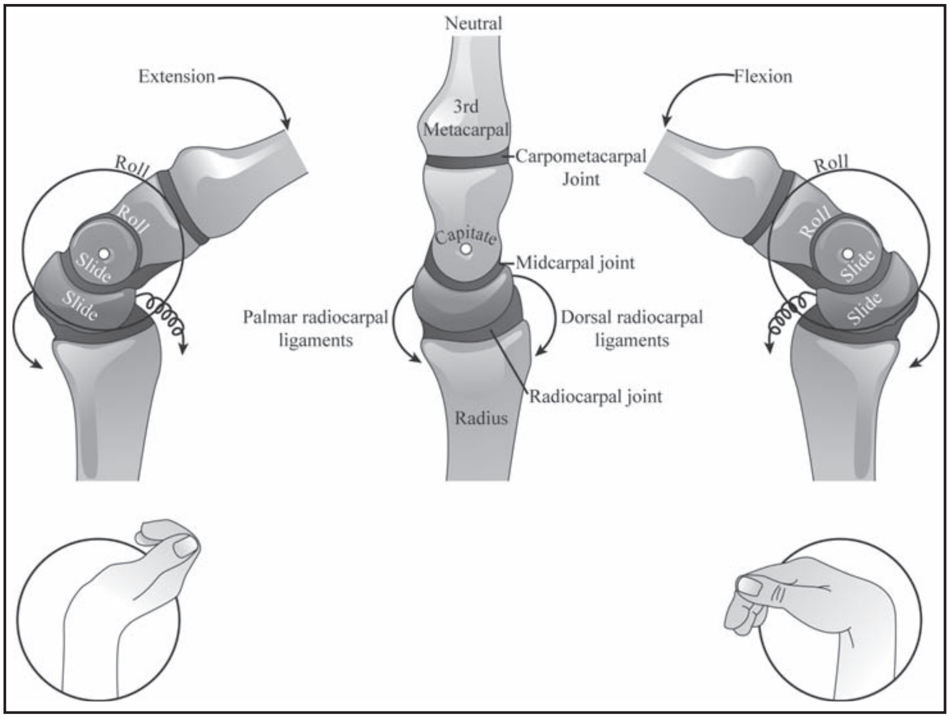

Figure 7-6. Arthrokinematics of wrist flexion and extension.

Table 7-2

ARTHROKINEMATICS OF THE RADIOCARPAL JOINT

MOVEMENT OF CONVEX CARPALS ON CONCAVE RADIUS	DIRECTION OF SLIDE OF CARPALS ON RADIUS	RESULTANT MOVEMENT
Flexion	Anterior (volar) roll, posterior (dorsal) slide	Movement in opposite direction
Extension	Posterior (dorsal) roll, anterior (volar) slide	Movement in opposite direction
Radial deviation	Radial roll, ulnar slide	Movement in opposite direction
Ulnar deviation	Ulnar roll, radial slide	Movement in opposite direction

Adapted from Kisner, C., & Colby, L. A. (2012). *Therapeutic exercise: Foundations and techniques* (6th ed.). Philadelphia, PA: F. A. Davis.

triquetrum distally. No muscle forces are applied directly to the bones of the proximal row, and this row serves as a link between the radial and distal carpals; it is considered an intercalated segment. When compressive forces are applied to the wrist, the middle segment tends to collapse and move in the wrong direction. This would happen at the wrist except for the intercarpal bridge formed by scaphoid and ligaments (Barr & Bear-Lehman, 2012).

The structures involved in the radiocarpal joint also include structures related to the distal radioulnar joint. The distal radioulnar and radiocarpal joints share the same joint fibrous, joint capsule, and radioulnar disc (triangular fibrocartilage), so these structures participate in movements at both the distal radioulnar joint and at the radiocarpal joint (Donatelli & Wooden, 2010).

The radioulnar disc (triangular fibrocartilage) runs from the distal radius to the distal ulna and blends into the capsular ligamentous structure of the distal radioulnar joint. The triangular fibrocartilage covers the distal end of the ulna, creating a smooth appearance of the wrist as the ulna articulates with the proximal carpal row via the disc. The disc accounts for just more than 11% of the articulating surfaces of the radiocarpal joint (Linscheid, 1986). The disc and connective tissue continue distally to attach to the triquetrum, hamate, and base of the fifth metacarpals and ulnar collateral ligament, radioulnar ligament, and sheath of the ECU.

The articular disc adds stability to the joint by maintaining a mechanical relationship that binds the distal ends of the radius and ulna as well as the carpal bones and ulna. With the disc intact, the radius takes on 60% of the axial load, and the ulna takes on 40%. If the disc is injured, the radius takes on 95% of the axial load (Ishii, Palmer, Werner, Short, & Fortino, 1998; Magee, 2014; Tang, Ryu, & Kish, 1998; Wheeless, 2010). This view was challenged by Markolf, Lamey, Yang, Meals, and Hotchkiss (1998), who found that the distal ulna only bore 3%

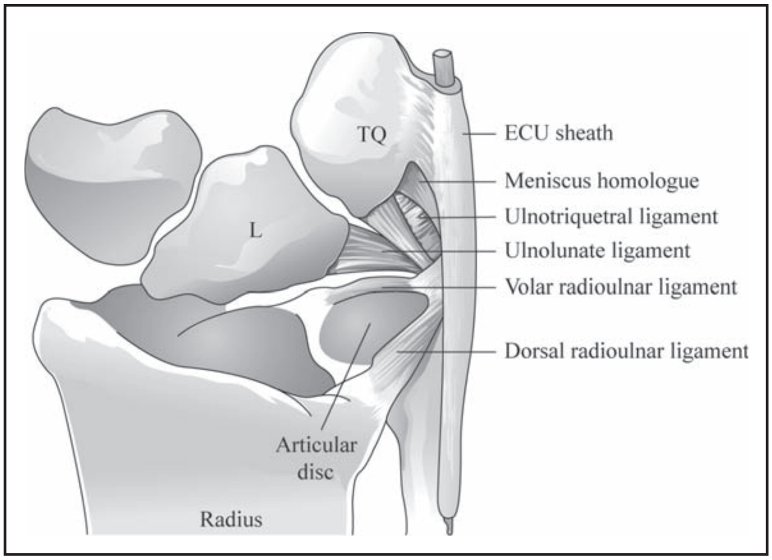

Figure 7-7. The TFCC. L = lunate, TQ = triquetrum.

of the forces and that the triangular fibrocartilage complex (TFCC) was too compliant to bear significant loads.

There is a wedge of connective tissue (meniscus homolog) that continues from the fibrocartilage that thickens medially and encloses the ulnar styloid, attaching to the articular capsule (Levangie & Norkin, 2011). The dorsal and palmar sections of the joint capsule thicken to form the dorsal radioulnar and palmar radioulnar ligaments.

Triangular Fibrocartilage Complex or Ulnocarpal Articulation

Konin (1999) asserted that these structures at the wrist would comprise an additional functional articulation of the wrist commonly called the *TFCC* (or *ulnocarpal*, *ulnar-meniscal-triquetrum*, or *ulnomeniscocarpal joint*; Figure 7-7). This articulation is a meniscal type of structure located between the distal ulna and the proximal part of the triquetrum bone that separates the radiocarpal joint from the distal radioulnar joint.

The TFCC consists of the radioulnar articular disc (triangular fibrocartilage), meniscus homologue (lunocarpal), ulnocarpal ligament (consisting of the ulnolunate and ulnotriquetral ligaments), dorsal and volar radioulnar ligaments, and ECU sheath.

This complex acts as a shock absorber and binds the distal radioulnar joint. The TFCC forms the ulnar aspect of the proximal articulating surface of the radiocarpal joint. Notice, too, that the ulna has no contact with the carpal bones because they are separated by this fibrocartilaginous disc; this allows the ulna to glide on the disc for pronation and supination without influence or interference of the carpal bones. The distal end of the ulna can be surgically removed without any impairment of wrist motion because the ulna does not influence wrist motion at this articulation (Magee, 2014).

The TFCC is a major stabilizer of the distal radioulnar joint and contributes to ulnocarpal stability. The volar portions of the TFCC prevent dorsal displacement of the ulna and are taut in pronation, while the dorsal portions prevent volar displacement of the ulna and are tight in supination (Wheeless, 2010). It has similar mechanics to the glenoid labrum of the shoulder and menisci of the knee.

Midcarpal Joints

The midcarpal joints are formed as a compound articulation between the proximal and distal rows of carpal bones (except for the pisiform bone). On the radial (lateral) side, the scaphoid articulates with the trapezoid and trapezium bones. The scaphoid is essentially a convex surface on which the concave surfaces of the trapezoid and trapezium slide. The central portion consists of the head of capitate and superior part of the hamate articulating with the deep cavity formed by the scaphoid and lunate (Goss, 1976). This forms a type of ball-and-socket joint where some axial rotation may be possible (Barr & Bear-Lehman, 2012).

The ulnar (medial) side of the joint is the articulation of the hamate with the triquetrum bone. The articulating surface of the hamate is convex as it slides on the concave articulating surface of the triquetrum.

Flexion and extension motions are possible at this joint, as is some rotation. The trapezium and trapezoid on the radial side and the hamate on the ulnar side glide forward and backward on the scaphoid and trapezium, while the head of the capitate and the superior surface of the hamate rotate in the cavity of the scaphoid and lunate (Goss, 1976). This joint is inherently stable because it is bound by the dorsal, palmar, ulnar, and radial ligaments.

The joint capsule of the midcarpal joint is separate from the radiocarpal joint capsule and is usually divided into the medial and lateral compartments. The medial compartment is larger with the concave proximal surface and convex distal surface. The smaller lateral compartment is oriented opposite to the medial surface with a proximal convex surface and concave distal surface (Muscolino, 2006).

The distal row of the carpal bones, with the metacarpals, move together, resulting in nearly equal distribution of forces across the carpal articulations. The union of the distal carpals also are the basis for the longitudinal and transverse arches of the hand (Levangie & Norkin, 2011).

Osteokinematics

This joint is predominantly described as a condyloid joint, although it was also cited as a *sellar (saddle-shaped) joint* (Gench, Hinson, & Harvey, 1995). The excursion of the articulating surfaces produces greater extension than flexion and radial deviation over ulnar, which is opposite to what occurs at the radiocarpal joint (Barr & Bear-Lehman, 2012). There are interosseous membranes between the scaphoid, trapezoid, and trapezium on the lateral side and the scaphoid, lunate, triquetrum with capitates, and hamate on the medial side, but none between the proximal and distal rows of bones, so there is greater movement at the midcarpal joint than between individual bones of the two rows of the intercarpal joint (Viegas, Patterson, Todd, & McCarty, 1993). The midcarpal joint is a biaxial, synovial joint, and the bony surfaces are in most contact in extension with slight ulnar deviation (Table 7-3).

Table 7-3

OSTEOKINEMATICS OF THE MIDCARPAL JOINTS

FUNCTIONAL JOINT	Diarthrotic, biaxial
STRUCTURAL JOINT	Synovial, condyloid
CLOSE-PACKED POSITION	Extension with ulnar deviation
RESTING POSITION	Neutral or slight flexion with ulnar deviation
CAPSULAR PATTERN	Equal limitation of flexion and extension

Arthrokinematics

The concave-convex relationship rules apply in the case of the midcarpal joints, but the relationships between these bones are more complex than is readily apparent. For example, in wrist flexion at the midcarpal joint, the convex capitate and hamate slide dorsally on the concave scaphoid, lunate, and triquetrum (opposite directions), and the concave trapezium and trapezoid slide in a volar direction (same direction). The relationship of the motion with the direction of movement of the distal carpal bones in respect to the proximal carpals is shown in Table 7-4. The distal row of the carpal bones moves in the same direction as the hand but in an opposite direction of the proximal carpal bones. Because of the movement at the carpal bones, there is significant range of motion (ROM) produced by only moderate movements of either the radiocarpal or midcarpal joints (Neumann, 2002; Provident & Houglum, 2012).

Intercarpal Joints

The intercarpal joints are those articulations between the individual bones in the proximal and distal rows of the carpal bones. It is the articulation of the scaphoid, lunate, and triangular (trapezium) bones that form gliding joints and are connected by dorsal, palmar, and interosseous ligaments, as well as the articulation of the bones of the distal row (trapezium, trapezoid, capitate, hamate) that also form gliding joints and are connected by the dorsal, palmar, and interosseous ligaments. The intercarpal joints are bound by the intercarpal ligaments and are capable of slight movements (Table 7-5).

Pisotriquetral Joint

This is a separate joint, and it does not take part in other intercarpal movements. The sesamoid bone forms an articulation in the pisiform with the triquetrum bone. This is capable of slight movement due to ligamental connections, serves to increase the contraction force of the FCU muscle, and serves as an attachment for the transverse carpal ligament (Muscolino, 2006).

WRIST STABILITY

The wrist joint is very stable due to the proximal radiocarpal and distal midcarpal joints, which act together as a double hinge (Barr & Bear-Lehman, 2012). In addition to the bony support and geometry of the sigmoid notch of the radius, wrist stability is maintained by an extensive system of ligaments. Not only do the wrist ligaments provide additional support at the wrist, but they also contribute to passive motion.

Primary stability of the joint comes from the radial and ulnar collateral ligaments, dorsal and volar radioulnar ligaments, and TFCC. The joint is enclosed by a strong but loose joint capsule and is reinforced by the dorsal radiocarpal, palmar radiocarpal, palmar ulnocarpal, and intercarpal ligaments and flexor and extensor retinaculum (Barr & Bear-Lehman, 2012).

Ligaments in the wrist have been classified as extrinsic (connecting the distal radius and ulna to the carpal bones) or intrinsic (with origins and insertions within the carpal bones; Kijima & Viegas, 2009).

Extrinsic Ligaments

The extrinsic ligaments tend to limit motion primarily at the radiocarpal joint. The radial and ulnar collateral ligaments provide significant passive control of radiocarpal motion in the frontal plane. The radial collateral ligament, which runs from the styloid process of the radius to the scaphoid and trapezium, limits ulnar deviation, while the ulnar collateral ligament, which runs from the styloid process of the ulna to the triquetrum, limits radial deviation (Muscolino, 2006). The radial collateral ligament, which runs from the lateral epicondyle of the humerus to the annular ligament and olecranon process, can be felt as a depression between the lateral epicondyle and the head of the radius. With the elbow flexed, the fibers of the ligament run parallel to the forearm (Biel, 2001). The triangular ulnar collateral ligament is deep to the common flexor tendon but superficial to the ulnar nerve. It can be found between the medial epicondyle and the medial aspect of the olecranon process (Biel, 2016).

Table 7-4

Arthrokinematics of the Midcarpal Joint

Movement of Convex Carpals on Concave Radius	Direction of Slide and Roll	Resultant Movement
Flexion of wrist	• Capitate and hamate dorsal slide on scaphoid; lunate and triquetrum, volar roll	• Opposite direction
	• Trapezium and trapezoid volar slide on scaphoid, volar roll	• Same direction
Extension of wrist	• Capitate and hamate volar slide on scaphoid; lunate and triquetrum, dorsal roll	• Opposite direction
	• Trapezium and trapezoid dorsal slide on scaphoid, dorsal roll	• Same direction
Radial deviation	• Capitate and hamate slide on scaphoid, lunate and triquetrum in ulnar direction, radial roll	• Opposite direction
	• Trapezium and trapezoid dorsal slide on scaphoid, radial roll	• Same direction
Ulnar deviation	• Capitate and hamate slide on scaphoid; lunate and triquetrum, volar roll	• Opposite direction
	• Trapezium and trapezoid volar slide on scaphoid, ulnar roll	• Same direction

Table 7-5

Osteokinematics of the Intercarpal Joints

Functional Joint	Multiaxial
Structural Joint	Gliding
Close-Packed Position	Extension
Resting Position	Neutral or slight flexion
Capsular Pattern	None

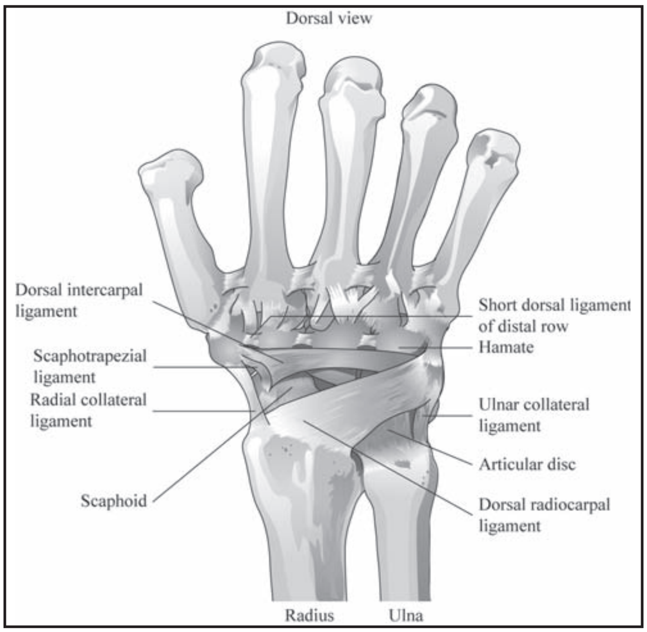

Figure 7-8. Dorsal ligaments of the wrist.

The dorsal radiocarpal ligament, which exists as a thickening of the capsule, attaches the radius to the capitate, lunate, and scaphoid. This ligament limits full flexion and allows the hand to follow the radius during pronation of the forearm (Levangie & Norkin, 2011). Figure 7-8 shows the dorsal ligaments of the right wrist.

The palmar radiocarpal ligaments are thick and strong and are the most important ligaments for motion and stability (Levangie & Norkin, 2011). The palmar radiocarpal ligament has three distinct portions that are named for their attachments. The first is the radiolunate (radiotriquetral or long radiolunate) ligament, which is the strongest and most distinct. This ligament allows the scaphoid to rotate as well as provides stabilization for the scaphoid at the extremes of movement (Magee, 2014). The second ligament is the radiocapitate (radioscaphocapitate) ligament, and the third is the radioscaphoid (short radiolunate) ligament. The radioscaphoid assists with joint motion and stability by checking movement of the joint surfaces and maintaining joint integrity (Levangie & Norkin, 2011). The palmar radiolunate and radiocapitate ligaments are the primary constraints to carpal translation (Linscheid, 1986). The radiocarpal ligaments ensure that the carpals follow the radius throughout forearm rotation.

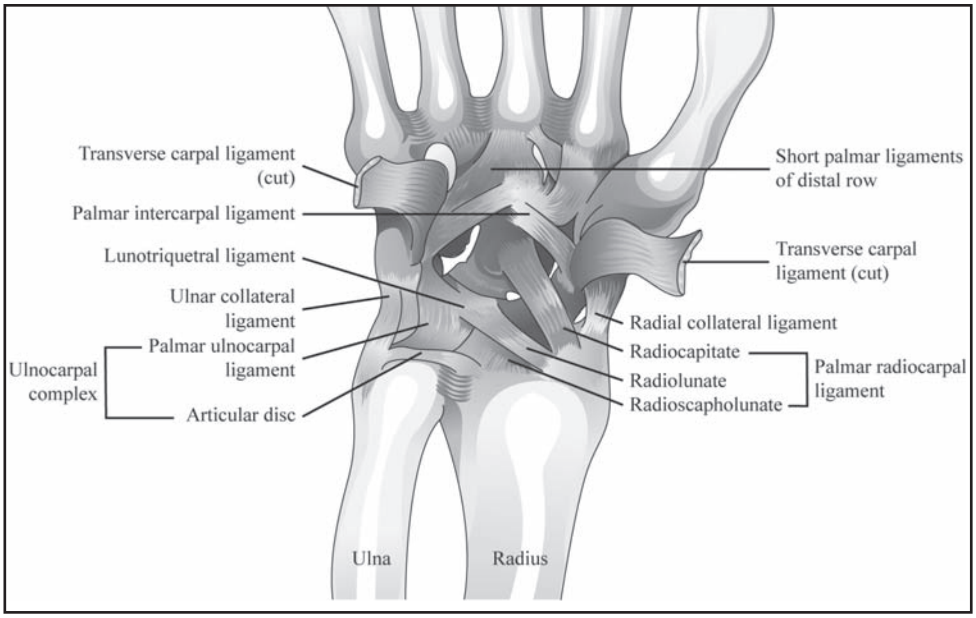

Figure 7-9. Palmar ligaments of the wrist.

Supination tightens the palmar ligaments, and the palmar radiocarpal ligament carries the wrist with the radius.

The ulnocarpal complex includes the ulnar collateral ligament, the radioulnar articular disc, and the palmar ulnocarpal ligament. These structures are part of the TFCC, which consists of the radioulnar articular disc, meniscus homologue (ulnocarpal), ulnocarpal ligament, dorsal and volar radioulnar ligaments, and ECU sheath. The ulnocarpal ligament is composed of the ulnolunate and ulnotriquetral ligaments of the meniscus homologue and is really portions of the medial palmar radiocarpal ligament. The ulnocarpal ligament prevents separation of the carpals to which they attach and prevents dorsal migration of the distal ulna to add to joint stability (Figure 7-9; Ishii et al., 1998; Wheeless, 2010).

Intrinsic Ligaments

Intrinsic ligaments stabilize and limit movement between carpals. There are short intrinsic ligaments that connect the distal row of the carpal bones and help to maintain the bones of the distal carpal row as an immovable unit. The intermediate intrinsic ligaments (lunotriquetral, scapholunate, and scaphotrapezial ligaments) connect the proximal row of the carpal bones. The long intrinsic ligaments connect the scaphoid, triquetrum, and capitate and include the dorsal intercarpal and palmar intercarpal ligaments.

The dorsal and palmar intercarpal ligaments strengthen the hand for any impact imposed on the knuckles (e.g., striking with a closed fist). Of these two ligaments, the palmar is seen to be more important and is called the *deltoid* or *V ligament*, which stabilizes the capitate. The dorsal intercarpal ligament and dorsal radiocarpal ligament work together to allow normal kinematics and stabilization of the proximal carpal row, and the scaphoid and these two ligaments together are also known as the *dorsal radioscaphoid ligament* (Kijima & Viegas, 2009; Viegas, 2001; Viegas, Yamaguchi, Boyd, & Patterson, 1999).

Dynamic Stability

Dynamic stability occurs only when the muscles are actively contracting. The pronator quadratus connects the ulna to the radius and depresses the ulna during pronation. The ECU has a moderate effect in depressing the ulna relative to the triquetrum during pronation, but the mechanical advantage of the muscle is small. The FCU also acts to depress the ulnar head, but only when the hand is fixed against resistance (Linscheid, 1992).

The proximal carpals act as a mechanical link between the radius and distal carpals to which forces are applied and acts as an intercalated segment. This relatively unattached middle segment tends to collapse and move in a direction opposite to the segments above and below when forces are applied, which adds to the stability of the joint. Rotation between the proximal and distal carpal rows adds to the joint stability due to ligamentous tension (Levangie & Norkin, 2011).

Movements of the Wrist

There is much variability from one person to another in the structure and movements of the wrist, which can produce differences in function. The proximal row is a link between the radius and distal carpals, the proximal row acts as an intercalated and relatively unattached middle section, and the distal radius and TFCC are relatively immobile (Levangie & Norkin, 2011).

Movements at the wrist include flexion, extension, abduction, adduction, and circumduction. The amount of movement varies considerably from person to person, varies due to the position of the forearm, and can even vary from one hand to the other of the same person (Jenkins, 1998). Movement of the carpal row on the radius and TFCC is a gliding translatory movement produced concomitantly with wrist movements (Hamill et al., 2015). As the hand flexes in the palmar

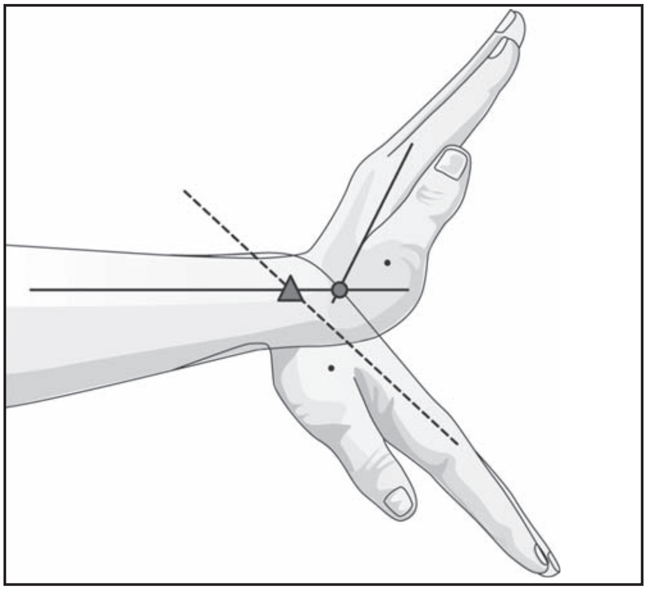

Figure 7-10. Wrist axis of motion for flexion (triangle) and extension (circle).

direction, the carpal row glides dorsally; in radial abduction, the proximal carpal row glides in the ulnar direction, but this must be accompanied by an elastic capsule and lax ligaments. Wrist motion is actively driven by muscles but is controlled by the passive tension of ligaments (Neumann, 2002).

The function that occurs at the wrist depends on the muscles relative to the axes of motion. The wrist does not move in a direct plane, but rather along a plane between radial extension (deviation) and ulnar flexion (deviation) and an opposite plane of ulnar extension and radial flexion due to direction of muscles and their tendons acting on the wrist (Caillet, 1996).

The amount of motion depends also on the shape of the articulating surfaces. The surface of the radioulnar articulation is less concave across the bony surfaces than anteroposteriorly, and the proximal row of carpal bones is more mobile than the distal. Plus, the curvature of the proximal carpal row is greater than the opposing curve of the radioulnar surface. The curvature of the proximal carpal row is greater than the opposing curve of the radioulnar surface. The distal end of the radius is concave and usually reaches further distally on the radial side than the ulnar side (although 60% of people have equal length). These discrepancies permit greater excursion of flexion and extension than of radioulnar motion. There is a greater degree of flexion as compared to extension and of ulnar abduction as compared to radial that is due to the angulation of the distal articular surface of the radius and due to the fact that dorsal wrist ligaments are less taut than is the palmar ligament (Caillet, 1996).

Grip strength is influenced by the position of the wrist. Hamill et al. (2015) cited a study by Nordin and Frankel (2012) that found that when the wrist is in 40 degrees of hyperextension (extension), grip was more than three times greater than if the wrist was in 40 degrees of wrist flexion. In addition, wrist flexion has more than twice the work capacity of extension, and radial deviation slightly exceeds ulnar deviation in work capacity (Baxter, 1998).

Flexion and Extension

The wrist has been conceptualized as being composed of three columns: rotational (triquetrohamate), flexional and extensional (capitolunate), and radial (scaphotrapezial; Taleisnik, 1985). The kinematic of flexion and extension is sagittal plane movement within the central column of the wrist (articulation of the radius, lunate, capitate, and third metacarpal). The axis for wrist flexion and extension of the wrist occurs in the sagittal plane and frontal or side-to-side axis through the wrist just distal to the styloid process of the radius and ulna through the capitate carpal bone (Patterson, Nicodemus, Viegas, Elder, & Rosenblatt, 1998). Smith and colleagues (1996) indicate that the axis migrates distally when moving from full flexion to extension, which is caused by translatory and rotational movements of the lunate and scaphoid (Figure 7-10). Of the three proximal carpal bones, the scaphoid moves the most and the lunate the least (Levangie & Norkin, 2011). These movements change the height of the bones of the wrist, which is necessary to maintain tension on the ligaments. Muscles that lie anterior to the wrist's flexion-extension axis are wrist flexors, whereas muscles lying posterior to the axis are wrist extensors.

Flexion of the wrist is produced when the carpals slide dorsally on the radius and disc. Normative values for wrist flexion ROM are between 60 to 85 degrees with 50 degrees of motion occurring at the radiocarpal joint and 35 degrees at the midcarpal, although the exact percentage of motion at each joint has been debated (Levangie & Norkin, 2011; Neumann, 2002). The movement of flexion is often accompanied by slight ulnar deviation and supination, and the primary wrist flexors are the flexor carpi radialis (FCR), FCU, and palmaris longus.

The FCR enables the second and third metacarpals to compress the capitate and trapezoid, minimizing their movement. The capitate flexes on the scaphoid and lunate, resulting in metacarpal joint flexion, and the scaphoid flexes and pronates on the radius while the lunate flexes and supinates on the radius. The FCU enables the proximal portion of the fifth metacarpals to glide dorsally on the hamate, and the hamate will then rotate anteriorly on the triquetrum (metacarpal joint flexion). Secondary wrist flexor muscles include the flexor digitorum profundus, flexor digitorum superficialis, and flexor pollicis longus. The proximal portion of the triquetrum will flex on the TFCC, resulting in radiocarpal joint flexion (Prosser & Conolly, 2003). End feel for wrist flexion is firm secondary to tautness of the dorsal radiocarpal ligament and dorsal joint capsule.

Wrist extension also has a firm end feel secondary to the tautness of the palmar radiocarpal ligament and palmar joint capsule. It has been estimated that 35 degrees of the movement of extension occurs at the radiocarpal joint while 50 degrees of motion occurs at the midcarpal (Barr & Bear-Lehman, 2012; Sarrafian, Melamed, & Goshgarian, 1977). The motion of extension is initiated by the distal carpals, with the capitate at the center as the axis, which glide on the relatively fixed proximal row of the carpal bones. Extensor force, via the ECU and extensor carpi radialis, moves the distal carpal row and scaphoid on the relatively fixed lunate and triquetrum. At 45 degrees of wrist extension, the scapholunate interosseous ligament draws the lunate and scaphoid together, which increases the extensor force and unites the carpals, which now will act as

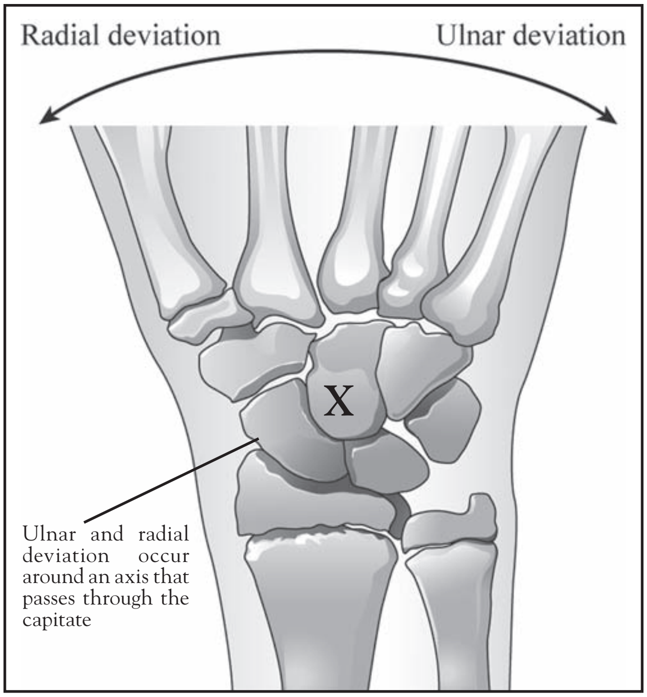

Figure 7-11. Wrist axis of motion for radial and ulnar deviation.

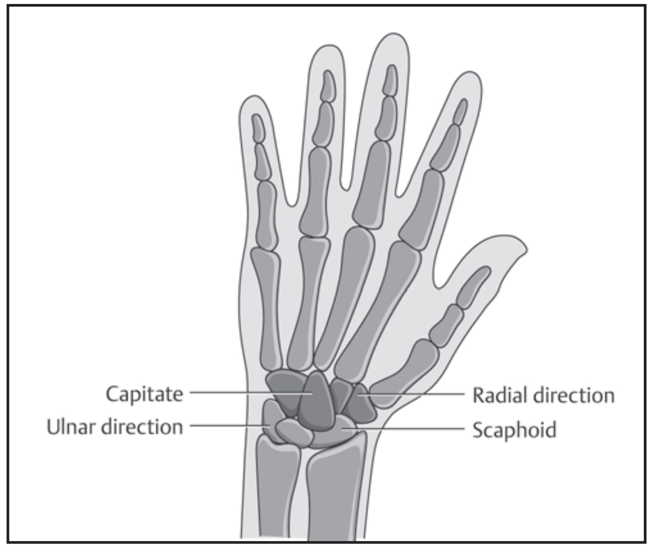

Figure 7-12. Radial deviation.

a single unit. Midcarpal motion, estimated at 33% of the joint motion (Barr & Bear-Lehman, 2012; Sarrafian et al., 1977), occurs with the distal carpals gliding on the proximal carpals (lunate and triquetrum), which are relatively fixed.

Full wrist extension requires a slight spreading of the distal radius and ulna, and if these two bones were grasped together, complete wrist extension would not be possible (Smith et al., 1996). Wrist extension is usually accompanied by slight radial deviation and forearm pronation. Pure extension (without deviation) is dependent on the ulnar and radial extensors working together for balance.

The most powerful extensors are the extensor carpi radialis longus (ECRL), ECRB, and ECU. These muscles are active in activities requiring wrist extension or stabilization against resistance, especially if pronated, as occurs when doing the backhand stroke in racquet sports (Hamill et al., 2015). The ECU enables the proximal portion of the fifth metacarpal to glide on the hamate. The hamate then will rotate posteriorly on the triquetrum (metacarpal joint extension), and the proximal portion of the triquetrum will glide on the TFCC (radiocarpal joint extension). The extensor carpi radialis produces forces that enable the second and third metacarpals to compress the capitate and trapezoid, limiting movement. The capitate extends on the scaphoid and lunate, resulting in metacarpal joint extension. This leads to scaphoid extension and supination on the radius while the lunate extends and pronates on the radius (Prosser & Conolly, 2003). Secondary wrist extensors include the extensor digitorum communis, extensor indicis, extensor digiti minimi, and extensor pollicis longus.

Ulnar and Radial Deviation

Ulnar deviation and *radial deviation* are terms that are synonymous with *ulnar flexors and extensors* and *wrist adduction and abduction*. These motions occur in the frontal/coronal plane at the anteroposterior/sagittal axis, with the axis of motion through the capitate at a right angle to the palm (Figure 7-11; Nicholas & Hershman, 1990; Provident & Houglum, 2012). Motion that occurs lateral to this front-to-back axis is radial deviation (abduction), and motion medial to this axis is ulnar deviation (adduction).

There is more movement in ulnar deviation than radial because the radial styloid process encounters the scaphoid in radial deviation, which prevents further motion and causes the normal hard end feel. Ulnar and radial deviation is greatest if the wrist is in neutral regarding wrist flexion or extension. If the wrist extends, very little deviation occurs because the carpals are drawn into a locked, close-packed position. In wrist flexion, further movement is not possible because the bones are already splayed and the joint is in its loose-packed position (Levangie & Norkin, 2011). Normative ROM values for ulnar deviation are between 30 to 35 degrees and 15 to 25 degrees for radial deviation.

In radial deviation, the proximal carpal row moves ulnarly on the radius and the radioulnar disc, while the distal row of carpal bones is displaced radially. Most of the motion occurring in radial deviation occurs at the midcarpal joints (Figure 7-12). If movement occurred in a single plane (frontal), the distal row would swing radially during radial deviation to push the scaphoid into the radial styloid. Instead, what happens is that there is a shift in the position of the scaphoid. The scaphoid flexes approximately 15 degrees (palmward rotation) as the trapezium approaches the radius via the scaphoid lunate ligament (Flinn & DeMott, 2010). As the distal portion of scaphoid rotates toward the palm, the proximal row exhibits some flexion due to the scapholunate ligament. The capitate glides ulnarly toward the proximal row, causing close-packed congruity between surfaces. The lunate moves in an ulnar direction and rests on the TFCC. Radial deviation produces tension in the medial palmar intercarpal ligament and the palmar radiocarpal ligaments. Primary radial deviators are the ECRL, ECRB, and FCR.

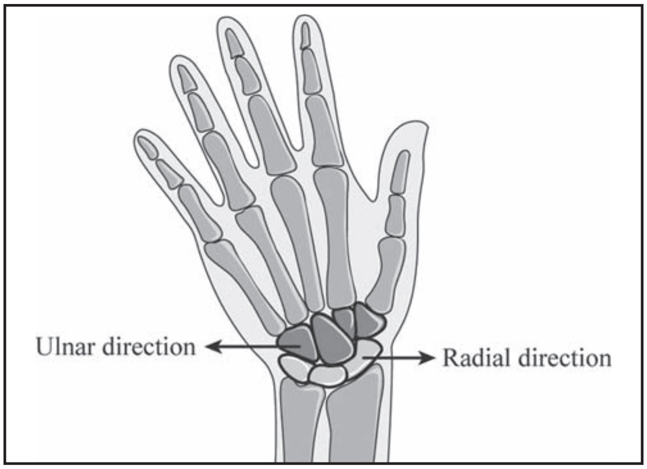

Figure 7-13. Ulnar deviation.

Ulnar deviation occurs similarly to radial deviation, with the triquetrum moving much like the scaphoid in radial deviation. Most of the motion of ulnar deviation occurs at the radiocarpal joint. The proximal carpal row flexes from the neutral position about 20 degrees and extends about 20 degrees in ulnar deviation (Wheeless, 2010). The triquetrum glides distally by the proximal migration of the hamate, which brings the lunate into an extended position and rotates toward the palm (Linscheid, 1986). The capitate rotates a small amount by rotating around the vertical axis while slightly gliding around the medial and lateral portions of the joint. This produces movement toward the radial side and functionally disengages the capitate from the proximal row. The scaphoid also moves into some extension, and the distal carpal bones move ulnarly. Most of the motion of ulnar deviation occurs at the radiocarpal joint, with very little contribution of the movements of the bones of the midcarpal articulations.

Compression of the hamate against the triquetrum pushes the proximal carpal row radially against the radial styloid process, which helps to stabilize the wrist in activities requiring large gripping forces (e.g., cutting meat or hammering; Neumann, 2002).

During ulnar deviation, tension develops in the lateral part of the palmar intercarpal ligament and palmar ulnocarpal ligament. Ulnar deviation or adduction is produced primarily by the FCU and ECU working together synergistically to produce a movement neither could produce alone. Ulnar abduction has a firm end feel due to tension on the radial collateral ligament and the radial portion of joint capsule. In ulnar deviation, radiocarpal movement predominates (Figure 7-13).

Internal Kinetics: Muscles

No wrist muscle crosses the wrist directly anterior-posterior or medial-lateral to the joint axis at the base of the capitate. Because of this, all muscles have moment arms of varying lengths and can produce force in both the sagittal and frontal planes. The wrist muscles work together to cancel one action of one muscle to produce a unique motion with another. This can be seen with the radial and ulnar wrist extensors, which work together to produce deviation. The FCR and ECRL work together to cancel the flexion and extension actions of each other and to produce radial deviation. Similarly, the FCU and ECU function antagonistically in flexion and extension but synergistically in ulnar deviation. Other synergistic actions occur when the FCR and FCU work together to hold the wrist in neutral or flexion that is needed when one performs delicate work, or when the ECRL and brevis and ECU work together to produce a powerful grip and maintain wrist extension even when the fingers tightly grasp an object. These are but a few of the muscular combinations that occur to provide sufficient wrist positioning for optimal and diverse hand function and the transmission of forces from the hand to the forearm.

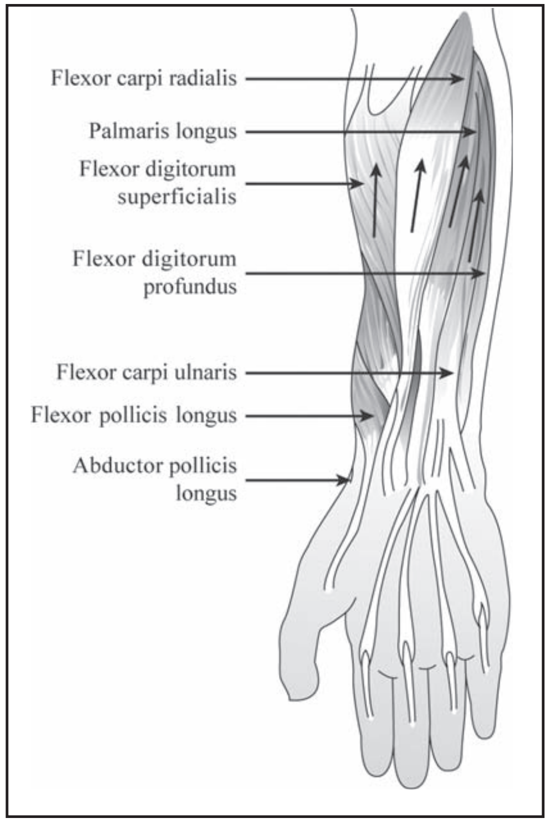

Figure 7-14. Muscles that flex the wrist.

Flexors at the Wrist

The following muscles flex the wrist because they lie anterior to the side-to-side axis: the FCR, FCU, and palmaris longus are the primary flexors, with the FCU considered the strongest of the three (Neumann, 2002). All three of these muscles are fusiform and are most powerful with the wrist in flexion or in stabilization of the wrist against resistance (Thompson & Floyd, 1994). Secondary wrist flexors include the flexor digitorum profundus, flexor digitorum superficialis, and flexor pollicis longus (Figure 7-14). The role of the wrist flexors is to maintain appropriate length-tension in finger extensors so they can forcefully open the hand.

The flexor digitorum profundus, flexor digitorum superficialis, and palmaris longus are multijoint muscles, and their capacity to produce effective forces at the wrist is dependent on a synergistic stabilizer to prevent full excursion of more distal joints. If these muscles attempt to act over both the wrist and more distal joints, they will become actively insufficient

(Gench et al., 1995; Hinkle, 1997; Jenkins, 1998; Levangie & Norkin, 2011; Provident & Houglum, 2012).

The flexor group of muscles is located on the forearm's anteromedial surface between the brachioradialis muscle and ulnar shaft (Biel, 2001). The flexor tendons are generally thicker and more pliable than the extensor tendons, but isolating specific flexor muscle bellies can be difficult. The most superficial layer of the flexor muscles includes the FCR, palmaris longus, and FCU. The FCR is medial to the pronator teres and brachioradialis, the FCU lies close to the ulnar shaft, and the palmaris longus (absent in about 10% of people) runs between the FCR and FCU. The middle and deep layers include the flexor digitorum superficialis and flexor digitorum profundus, and these are difficult to access directly.

Flexor Carpi Ulnaris

The FCU is a superficial muscle on the palmar aspect of the ulna. It crosses the wrist anterior to the flexion-extension axis and to the ulnar side of the deviation axis, so this muscle flexes and ulnarly deviates. This muscle is active in activities requiring a stronger, sustained power grip, such as using a hammer or in the stroke of an axe (Gench et al., 1995). This muscle is considered the strongest wrist flexor, especially due to the tendon encasing the pisiform bone, which adds mechanical advantage and decreases tendon tension (Gench et al., 1995; Hinkle, 1997; Jenkins, 1998; Levangie & Norkin, 2011; Smith et al., 1996).

If the FCU is impaired, there will be weakness in wrist flexion with ulnar deviation. For clients with central nervous system disorders who have spasticity and in clients with wrist instability (e.g., rheumatoid arthritis), tightness in the FCU muscle will result in the wrist being pulled into and held in a position of flexion and ulnar deviation, resulting in significant functional impairment (Oatis, 2004).

This muscle lies close to the ulnar border of the forearm, and the tendon may be palpated between the ulnar styloid process and proximal to the pisiform bone with wrist flexion and adduction resisted (Gench et al., 1995; Provident & Houglum, 2012). Pinch fingertips together or flex the wrist, and palpate proximal to the pisiform (Gench et al., 1995). When you unscrew a tight lid on a jar, you are using the FCU.

Flexor Carpi Radialis

While a primary flexor of the wrist, the FCR is only 60% as strong as the FCU. This muscle crosses the wrist anterior to the flexion-extension axis and to the radial side, and assists with radial deviation as well as flexing the wrist (Gench et al., 1995; Hinkle, 1997; Jenkins, 1998; Levangie & Norkin, 2011; Provident & Houglum, 2012).

Weakness only in the FCR muscle is uncommon but would result in weakness in wrist flexion and ulnar deviation. Tendonitis of the FCR can occur and results in pain with muscle contraction (Oatis, 2004).

When resistance is applied with the wrist in flexion and radial deviation, the FCR muscle is located on the radial side, in a superficial position in the lower part of the forearm. The palmaris longus is in the central location, while the FCR is located radially to the palmaris longus. The muscle cannot be followed to its distal attachment (Biel, 2016; Gench et al., 1995; Provident & Houglum, 2012). Figure 7-15 illustrates the location of the flexor muscles on the distal forearm. The FCR muscle is used when you turn a water valve or when you hold a cell phone (Biel, 2016).

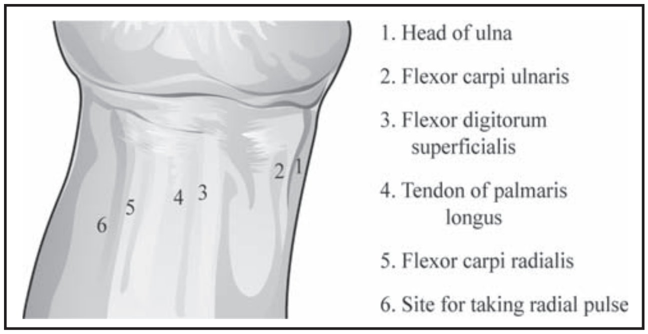

Figure 7-15. Surface anatomy of the flexor tendons.

Palmaris Longus

The palmaris longus is a small fusiform muscle that varies widely in structure and is actually absent in 10% to 15% of people (Gench et al., 1995; Thompson & Floyd, 1994). This muscle is generally seen as a contributor to wrist flexion, but because the palmaris longus crosses the wrist farther from the flexion-extension axis than the FCU or FCR and is small, it produces weak flexion even with its long force arm. Due to its insertion in the flexor retinaculum, the palmaris longus contributes to the cupping motion of the hand.

While applying resistance in wrist flexion, the centrally located tendon is the palmaris longus (Smith et al., 1996). It can also be seen and palpated when the thumb is opposed to the small finger with the wrist flexed. The palmaris longus, if present, will be between the FCR and FCU (Biel, 2016; Gench et al., 1995).

Flexor Digitorum Superficialis (Flexor Digitorum Sublimis)

This muscle has four tendons on the palmar aspect of the hand that insert into each of the four fingers. The flexor digitorum superficialis crosses the wrist, metacarpophalangeal (MCP) joint, and proximal interphalangeal (PIP) joint anterior to the flexion-extension axis. The action of the flexor digitorum superficialis is vital in gripping activities because it acts with the flexor digitorum profundus to flex the digits (Biel, 2016; Gench et al., 1995; Hinkle, 1997; Jenkins, 1998; Levangie & Norkin, 2011; Provident & Houglum, 2012).

Weakness in the flexor digitorum superficialis muscle would result in weak PIP joint flexion with the distal interphalangeal (DIP) joint relaxed, which would have an impact on the wrist and metacarpal joint movements and reduce grasping ability. If there is tightness in the flexor digitorum superficialis and flexor digitorum profundus or a loss of balance between the intrinsic and extrinsic muscles of the hand, claw hand deformity may result (Oatis, 2004).

With the fist closed tightly and wrist flexion simultaneously resisted, one or more of these tendons may become apparent between the palmaris longus and FCU. The tendons may be seen to move within their sheaths as the fingers are flexed to make a fist (Biel, 2016; Gench et al., 1995). The flexor digitorum superficialis is located underneath the FCR and palmaris

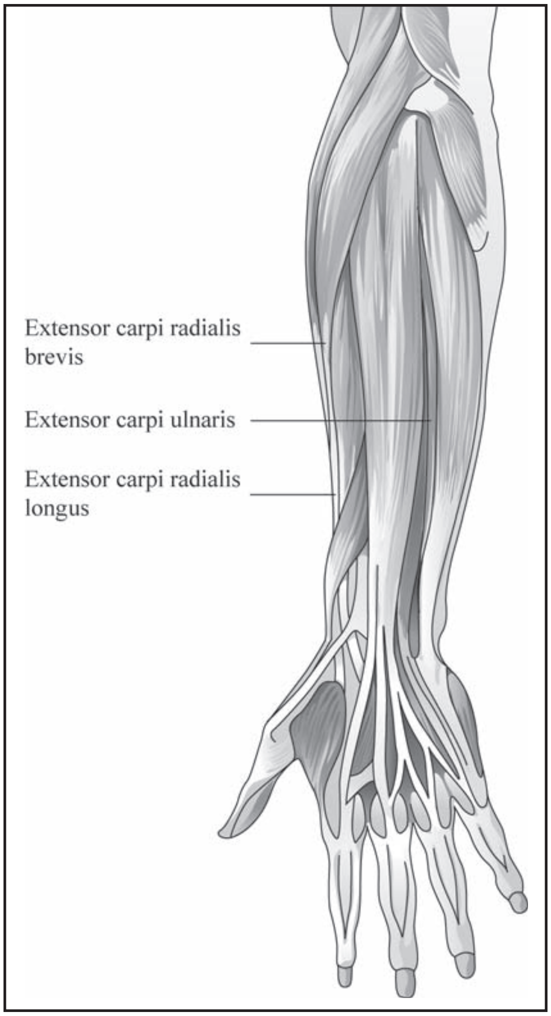

Figure 7-16. Muscles that extend the wrist.

longus and runs from the medial epicondyle to the center of the palmar side of the wrist. It is not possible to palpate the proximal attachment because the muscle is widespread, but one can observe it in the distal forearm and wrist (Provident & Houglum, 2012).

Flexor Digitorum Profundus

This deep muscle, covered by the flexor digitorum superficialis, FCU, palmaris longus, FCR, and pronator teres, assists with wrist flexion when the digits are kept extended. The flexor digitorum profundus flexes the MCP, PIP, and DIP joints but is dependent on wrist position for length-tension relationships in these actions. It is the only muscle that flexes the DIP joints. The length-tension relationship is favorable for the flexor digitorum profundus when the wrist is extended and the fist can be closed. As the wrist moves toward greater flexion, the flexor digitorum superficialis is recruited to aid in closure of the fist. Forceful fist closure elicits high activity levels of the flexor digitorum superficialis, flexor digitorum profundus, and interossei (Smith et al., 1996). The line of pull is to the palmar side of the flexion-extension axis of each joint, and the only action is flexion, which progresses sequentially from the most distal joint (DIP joint) to the most proximal (wrist joint). The strength of the contraction lessens progressively so that the flexor digitorum superficialis contributes only weakly to wrist flexion (Gench et al., 1995).

The contracting muscle belly may be palpated, provided tension is minimal in the more superficial muscles. To achieve relaxation of the overlying muscles, the subject is seated with the forearm supinated or resting in the lap while the wrist is extended by the weight of the hand. Then, ask the subject to close the fist fully with moderate effort, and the profundus may be felt under the fingers in the region between the pronator teres and FCU, about 2 inches below the medial epicondyle of the humerus (Provident & Houglum, 2012). Stabilize the PIP joint in extension, and flex the DIP joint (Biel, 2016; Gench et al., 1995).

Flexor Pollicis Longus

This penniform muscle lies deep on the radial side of the forearm, where it assists with wrist flexion due to the palmar location in the wrist and plays an important role in grip activities (Thompson & Floyd, 1994). Some authors disagree with the role of this muscle in wrist flexion because it lies too close to both wrist axes and the power of the muscle is already spent as it flexes the thumb (Gench et al., 1995; Goss, 1976).

If there is damage to the flexor pollicis longus muscle, there will be weakness in flexion of the thumb interphalangeal joint, which may occur due to anterior interosseous nerve impingement. Loss of balance of forces between the extensor pollicis longus and flexor pollicis longus may result in the ape thumb deformity (Oatis, 2004). The tendon can be palpated on the palmar surface of the thumb between the metacarpal and interphalangeal joints as the interphalangeal joint is flexed (Gench et al., 1995).

Abductor Pollicis Longus

This muscle crosses the wrist directly above the axis of flexion/extension, but bowstrings during wrist flexion, allowing it to contribute to wrist flexion. The superficial tendon can be palpated as it crosses the wrist on the palmar side of the extensor pollicis brevis when the thumb is forcefully abducted (Gench et al., 1995).

Extensors at the Wrist

The ECRL, ECRB, and ECU are the most powerful wrist extensors and are active in activities requiring wrist extension or stabilization against resistance, especially if pronated (as occurs in the backhand stroke in racquet sports; Figure 7-16). These three muscles act on the elbow, so joint position is important. The ECRL and ECRB cause flexion at the elbow and can be enhanced as wrist extensors with extension of the elbow, whereas the ECU is an elbow extensor and is enhanced as a wrist extensor with the elbow in flexion (Hamill et al., 2015). The primary wrist extensor muscles cross the dorsal and dorsal-radial side of the wrist and are covered by the extensor retinaculum, which prevents bowstringing of the tendons during extension. The primary role of the wrist extensors is to maintain appropriate length-tension forces in the finger flexors to produce a strong grip.

The primary wrist extensors are located between the brachioradialis muscle and the shaft of the ulna on the posterolateral surface of the forearm. The ECRL and ECRB are lateral and posterior to the brachioradialis muscle, while the ECU lies beside the ulnar shaft. The extensor digitorum lies between these two muscles with the long, superficial tendons stretching along the dorsal surface of the hand (Biel, 2016). The brachioradialis, ECRL, and ECRB are sometimes referred to as the *wad of three*. They can be palpated lateral to the inner elbow, and form a long mass of muscle distal to the supracondylar ridge of the humerus (Biel, 2016).

Secondary wrist extensors include the extensor digitorum communis, extensor indicis, extensor digiti minimi, and extensor pollicis longus. The extensor digitorum communis can generate significant wrist extension torque but is primarily involved in metacarpal extension (Neumann, 2002).

Extensor Carpi Ulnaris

The ECU is active in wrist extension and frequently in wrist flexion as well, and it adds stability to the less stable position of wrist flexion (Gench et al., 1995; Hinkle, 1997; Jenkins, 1998; Levangie & Norkin, 2011; Provident & Houglum, 2012). When the forearm pronates, the crossing of the radius over the ulna leads to a smaller moment arm of the ECU, so this muscle is less effective as a wrist extensor and is more effective as an extensor when the forearm is supinated.

The tendon can be palpated between the head of the ulna and the prominent tubercle on the base of the fifth metacarpal. The tendon becomes prominent if the wrist is extended with the fist closed and is even more prominent if the wrist is simultaneously abducted ulnarward. The tendon is also easily palpable when the thumb is extended and abducted.

The muscle can be palpated 2 inches (5 cm) below the lateral epicondyle of the humerus as the wrist is forcefully extended where it lies between the anconeus and extensor digitorum, and it can be followed distally along the dorsoulnar aspect in the direction toward the head of the ulna (Gench et al., 1995; Provident & Houglum, 2012). You use this muscle when you pull a book off of a high shelf or reaching into the backseat of your car (Biel, 2016).

Extensor Carpi Radialis Longus

The ECRL lies posterior to the side/side axis, so it extends the wrist and is most effective as a wrist extensor when the elbow is also extended. The ECRL has increased activation when in either radial deviation or in a position supported against ulnar deviation or when forceful finger flexion is performed (Levangie & Norkin, 2011). If there is weakness in the ECRL and ECRB, there will be a loss of wrist extension and radial deviation, resulting in loss of forceful grasp and pinch (Oatis, 2004).

This muscle may be palpated just superior to the elbow as the wrist is forcefully extended with the fist closed. The tendon is prominent during wrist extension on the dorsoradial aspect of the wrist, located on the radial side of the capitate bone but on the ulnar side of the tubercle of radius. If the subject places a lightly closed fist on a table or in the lap with the forearm pronated and the subject alternately closes and relaxes the fist, the rise and fall of the tendon may be felt, and the muscle belly may be identified in the forearm close to brachioradialis. It may improve the accuracy of identification of the ECRL muscle by identifying the extensor pollicis longus muscle first, which is seen when the thumb is in extension (Biel, 2016; Gench et al., 1995; Provident & Houglum, 2012).

Extensor Carpi Radialis Brevis

This muscle crosses well posterior to the flexion-extension axis, so it extends the wrist. While ECRB is in a central location on the forearm, it is covered by the ECRL muscle. Its tendon is crossed by the tendons of the abductor pollicis longus and extensor pollicis longus, which makes identification of the ECRB tendon difficult. While the tendon protrudes less than the ECRL, it can be felt on the dorsum of the wrist in line with the third metacarpal during fisted wrist extension (Gench et al., 1995; Provident & Houglum, 2012).

Extensor Digitorum (Extensor Digitorum Communis)

The extensor digitorum, a fusiform muscle, crosses the wrist, MCP, PIP, and DIP joints. If all of these joints are extended simultaneously, then the extensor digitorum will be contracted to its shortest length and can be only weakly responsive at the wrist as an extensor (Gench et al., 1995). The role of the extensor digitorum muscle is to open the fingers and extend the wrist.

With the wrist extended and the fist closed, the prominent tendon of the ECRL can be palpated at the base of the second metacarpal. If you maintain the wrist in this position and extend the fingers, the four tendons of the extensor digitorum can be seen and palpated on the dorsum of the hand (Provident & Houglum, 2012).

Extensor Digiti Minimi and Extensor Indicis (Extensor Indicis Proprius)

The extensor digiti minimi and extensor indicis are capable of wrist extension after continued contraction, but wrist extension action is credited more to the extensor digitorum muscle. If the MCP and interphalangeal joints are held in flexion, then the extensor indicis is an effective wrist extensor.

The extensor digiti minimi is located on the ulnar side of the extensor digitorum; the tendon can be palpated and observed on the dorsum of the hand when the small finger is extended against resistance, especially at the fifth MCP joint (Gench et al., 1995). The tendon of the extensor indicis is superficial and can be observed on the ulnar side of and parallel to the tendon of the extensor digitorum as it approaches the base of the index finger (Gench et al., 1995).

Extensor Pollicis Brevis and Extensor Pollicis Longus

While specified as contributors to wrist extension due to the location dorsal to the joint axis by some sources (Hamill et al., 2015), these muscles do not contribute much to wrist function (Thompson & Floyd, 1994).

Radial Deviation/Abductors at the Wrist

The primary radial deviators of the wrist are the FCR, ECRL, and ECRB. Additional muscles that work to abduct

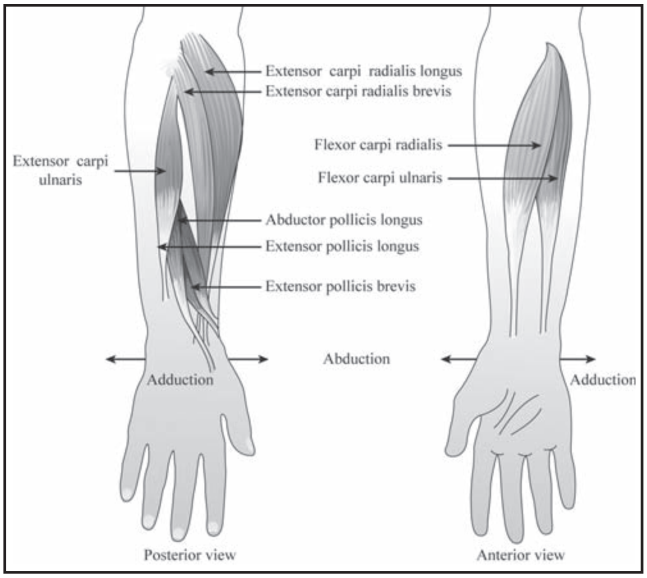

Figure 7-17. Muscles that ulnarly and radially deviate the wrist.

the wrist include the extensor pollicis longus, extensor pollicis brevis, abductor pollicis longus, and flexor pollicis longus. In neutral position, the ECRL has the largest cross-sectional area and moment arm for radial deviation followed by the ECRB and abductor pollicis longus. Of all the muscles that abduct the wrist, the abductor pollicis longus has the greatest moment arm but is not a strong radial deviator due to the small cross-sectional area. The abductor pollicis longus and extensor pollicis brevis are important in stabilization of the radial side of the wrist together with the radial collateral ligament (Neumann, 2002). The radial deviation muscles are stronger than the ulnar (Figure 7-17; Delp, Grierson, & Buchanan, 1996).

Flexor Carpi Radialis

Even though this muscle is located to the radial side of the deviation axis, it is not significantly effective as a radial deviator in isolated contractions due to the longer moment arm for flexion than for deviation. However, with the palmaris longus, the FCR does contribute to radial deviation.

Extensor Carpi Radialis Longus

Because this muscle is located on the radial side of the deviation axis, it serves to abduct the wrist. It has a longer moment arm for deviation than for extension and is more effective as a deviator than as an extensor.

Extensor Carpi Radialis Brevis

The ECRB muscle is located close to the deviation axis, so it provides scant contribution to deviation (Gench et al., 1995).

Abductor Pollicis Longus

This muscle lies on the radial side of the deviation axis and assists with wrist abduction.

Extensor Pollicis Brevis

This muscle is located so that there is a favorable line of muscle action for radial deviation regardless of the position of the thumb (Gench et al., 1995). Other sources feel that, because the muscle crosses directly over the axis, this muscle is not involved in adduction or abduction (Burstein & Wright, 1994).

Extensor Pollicis Longus

This muscle lies to the radial side of the deviation axis and serves to abduct the wrist, in addition to its contribution to wrist extension.

Ulnar Deviation/Adductors at the Wrist

The two muscles that adduct the wrist are the FCU and ECU. The extensor indicis is also considered a weak wrist adductor due to its location in relation to the joint axis.

Flexor Carpi Ulnaris

The FCU crosses farther away from the axis than the FCR, so it is more effective in ulnar deviation than the FCR is in radial deviation.

Extensor Carpi Ulnaris

Because this muscle crosses the axis posteriorly and ulnarly, it extends and ulnarly deviates the wrist. Due to the muscle's flare at the base of the fifth metacarpal, it increases the angle of the muscle's attachment and helps to stabilize the head of the ulna during wrist movements. It is a stronger ulnar deviator when the forearm is pronated (Gench et al., 1995).

Extensor Indicis

This is considered a weak adductor because the muscle crosses on the ulnar side of the adduction-abduction axis.

Assessment of the Wrist

Assessment of the wrist involves consideration of many bones, ligaments, muscles, and joints that are influenced by action at the elbow and shoulder and that control the actions of the fingers in functional, prehensile patterns. Figure 7-18 illustrates components of the wrist assessment.

Occupational Profile

As with any occupational therapy assessment, it is not only the impairment of the body part that is considered, but the use of the part in occupation. It is particularly important to understand how the client uses the hands in daily activities. Ask the client about specific tasks involved in his or her work activities and occupation. Those using a keyboard are more prone to repetitive strain injuries and postural changes, while those clients involved in construction work may have more trauma-related injuries.

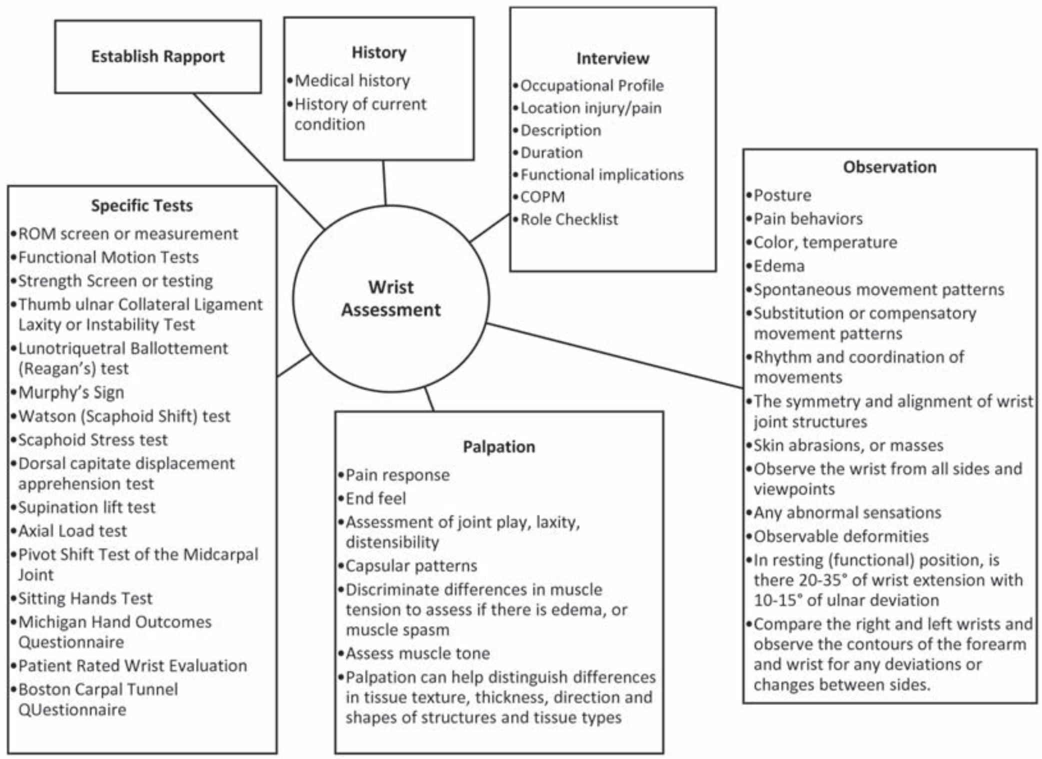

Figure 7-18. Evaluation of the wrist. (Adapted from Cooper, C. [Ed.]. [2007]. *Fundamentals of hand therapy: Clinical reasoning and treatment guidelines for common diagnoses of the upper extremity.* [p. 74]. St. Louis, MO: Mosby Elsevier.)

Awkward wrist postures can lead to deformity and loss of hand function. Computers are an integral part of daily life. Keyboard users were found to exhibit 60 degrees of pronation and 20 degrees of extension, and some had 20 degrees of ulnar deviation (Baker & Cidboy, 2006). Awkward postures can lead to elevated pressure inside the carpal tunnel, creating strain on muscle structures. Increased pressure can occur when wrist extension or pronation is past 45 degrees and when ulnar deviation is 10 degrees or more. The force exerted by the carpal bones and carpal ligament against the flexor tendons increases, which can lead to inflammation and increased pressure on nerves, blood vessels, and tendons. The result may be ischemia and tendon synovial edema, pressure on the median nerve, and, ultimately, carpal tunnel syndrome (Marklin, Simoneau, & Monroe, 1999).

Understand the client's occupational history, experiences, patterns of living, interests, values, and needs (American Occupational Therapy Association, 2014), and use this information in collaboration with the client in developing treatment goals.

Observation and Palpation

Assessment of the wrist includes looking at the skin for blisters or lacerations and observing for any abnormal formations or nodules. Edema may be seen in local swollen ganglions (synovial hernia in tendinous sheath or joint capsule), usually on the dorsum and radial side of the hand, or there could be inflammation of the tendon or its synovial sheath. Edema may occur due to fractures, tenosynovitis, or direct trauma. Immediate swelling after injury may indicate more severe injury, while swelling that is more gradual suggests ligamental or capsular sprains or subluxation. Diffuse swelling usually is seen on the dorsal surface of the hand because there is more room for expansion (Hartley, 1995). While swelling is difficult to observe in the wrist, edema will limit joint movement. Edema of the wrist is dangerous because it can congest the carpal tunnels and restrict extensor tendon compartments (Hartley, 1995).

Compare the right and left wrists and observe the contours of the forearm and wrist for any deviations or changes between sides. Look for the flexor creases that distinguish the radiocarpal from the midcarpal joints. Observe the client's ability and willingness to use his or her wrist and hand. In the resting (functional) position, there is 20 to 35 degrees of wrist extension with 10 to 15 degrees of ulnar deviation. Dense fibrous bands across the palm of the hand may indicate Dupuytren's contracture of the palmar fascia and may result in loss of extension mobility of the fourth and fifth fingers and observable deformities of the MCP and interphalangeal joints (Palmer & Epler, 1998).

With the client's hand in a static, resting position, you can observe postural resting imbalances. Resting imbalances are due to intrinsic and extrinsic forces acting on the joint. These may include factors related to articular, neurologic, and vascular structures; muscles; and tendons. Intrinsic imbalances could be due to forces acting on the joint capsule, while unopposed antagonistic muscle action may be an example of an extrinsic imbalance (Flinn & DeMott, 2010).

Table 7-6

WRIST PALPATION AND OBSERVATION

Sensations	Possible Causes
Warmth	• Inflammation • Infection
Numbness	• Carpal tunnel syndrome at the elbow or wrist • Radial nerve palsy or injury • Cervical nerve root problems • Thoracic outlet syndrome • Local cutaneous nerve injury • Cubital tunnel syndrome at the elbow
Clicking	• Lesion on the disc between the lunate and radius and triquetrum • Carpal bone subluxation (lunate or capitate)
Popping	• Ligament or muscle tears • Carpal subluxation • Joint dislocation
Grating	• Osteoarthritic changes • Cartilage deterioration
Crepitus	• Tenosynovitis of tendons in tendon sheaths as the fingers move

Be attentive to the color and temperature of the skin. Is one wrist or hand warmer than the other? Is there a difference in temperature at different parts of the wrist? Does the client respond to palpation and gentle movement with a pain response? Table 7-6 summarizes sensations that can be felt when palpating wrist structures. These are important indicators for sensory and neurological deficits that would suggest further, in-depth assessment.

Range of Motion

While the wrist is important in positioning the hand in space and for prehension, very little pure wrist motion is necessary for everyday activities. Even with a significant loss of motion in the wrist, adjacent joints can be used to compensate for diminished movement of the wrist.

Most activities of daily living require 10 to 54 degrees of flexion, 15 to 40 degrees of extension, 40 degrees of ulnar deviation, and 17 to 28 degrees of radial deviation as minimal requirements for ROM. Most activities can be accomplished with 40 degrees of flexion and extension and 40 degrees of combined ulnar-radial deviation (Aizawa et al., 2013; Barr & Bear-Lehman, 2012; Gates, Walters, Cowley, Wilken, & Resnik, 2016; Levangie & Norkin, 2011; Li, Kuxhaus, Fisk, & Christophel, 2005; Neumann, 2002; Nicholas, Sapega, Kraus, & Webb, 1978; Ryu, Cooney, Askey, An, & Chao, 1991; Wigderowitz, Scott, Jariwala, Arnold, & Abboud, 2007).

Table 7-7

ACTIVE RANGE OF MOTION SCREEN FOR THE WRIST

Motion Tested	Instructions to the Client/ Ask the Client to ...
Wrist extension	Bend the wrist up with fingers pointing toward ceiling or make the "stop" gesture with the hand.
Wrist flexion	Bend the wrist down with fingers pointing to the floor.
Radial deviation	Move their hand so that the fingers move in and the palm is pointed toward the floor.
Ulnar deviation	Move their hand so that the fingers move out and the palm is pointed toward the floor.

Active Range of Motion

Watching the client use the wrist and hand can help to identify any dynamic postural imbalances related to the movement. Consideration of the entire kinematic chain is necessary to identify the primary mechanisms interfering with normal movement patterns. Continued postural imbalances can result in permanent soft tissue changes, degeneration of joint structures, pain, and loss of function (Flinn & DeMott, 2010).

Have the client actively make a fist and open the hand wide. If there is radial nerve palsy, the extensor muscles of the wrist are paralyzed, resulting in wrist drop, and this will be apparent in the inability to actively extend the wrist. Observe the movement, and note restrictions, deviations, or pain (Magee, 2014). Observe the client pronate and supinate. Approximately 75 degrees of supination or pronation is due to forearm rotation, but the remaining 15 degrees is due to wrist movement. If the client experiences pain on supination, you can differentiate between the distal radioulnar joint and radiocarpal deficits by passively supinating the ulna on the radius with no stress to the radiocarpal joint. If this provokes the pain response, the problem is at the distal radioulnar joint, not the radiocarpal joint (Magee, 2014).

Screening tests for active ROM are shown in Table 7-7, which is a quick way to observe wrist dysfunction.

Passive Range of Motion

Moving the client passively can give the therapist information about capsular patterns, end feel, and tendon extensibility. When there are differences in values for active and passive ROM, this may indicate muscle weakness, poor tendon excursion, swelling, nerve palsy, pain, or fear of movement (Flinn & DeMott, 2010).

End feel is assessed by moving the client's wrist in all motions and applying overpressure at the end of the range. Joint play at the radiocarpal joint is assessed by distraction forces applied to the proximal row or carpal bones via ventral,

Table 7-8

STRENGTH SCREEN FOR THE WRIST

Muscle Action Tested	**Instructions to the Client/Ask the Client to …**	**Therapist's Action**
Wrist extension	Bring their hand up and hold that position. Tell the client, "Do not let me push your hand down."	Push in the direction of wrist flexion
Wrist flexion	Bring their hand down and hold that position. Tell the client, "Do not let me push your hand up."	Push in the direction of wrist extension

Table 7-9

INSTABILITY TESTS FOR THE WRIST

Test	**Structure**
Thumb ulnar collateral ligament laxity or instability test	Ulnar collateral ligament and accessory collateral ligament
Lunotriquetral ballottement (Reagan's) test	Lunotriquetral ligament
Murphy's sign	Lunate dislocation
Watson (scaphoid shift) test	Scaphoid subluxation
Scaphoid stress test	Scaphoid subluxation
Dorsal capitate displacement apprehension test	Capitate stability test
Supination lift test	TFCC pathology
Axial load test	Fracture of metacarpals or adjacent carpal bones
Pivot shift test of the midcarpal joint	Anterior capsule and interosseous ligaments
Sitting hands test	Wrist synovitis or wrist pathology

dorsal, radial, and ulnar glide procedures. If the client experiences pain or is unable to flex the wrist, the lesion is more likely to be at the midcarpal joint. If there is more restriction and pain on wrist extension, the problem is more likely in the radiocarpal joint because, with extension, more movement occurs at the radiocarpal than the midcarpal joint. If there is pain during pronation or supination, there may be lesions at the ulnomeniscocarpal or inferior radioulnar joints (Magee, 2014).

Strength Assessment

Resisted isometric movements of the wrist are influenced by muscles acting on the forearm, wrist, and hand, so injuries to any of these structures will influence the strength of the wrist. Table 7-8 provides examples of strength screening tests for the wrist.

Assessment of strength can occur by observing the client perform daily tasks. Watching a client clean a countertop (which requires at least a fair muscle grade), pulling up on a car door handle to open it (requiring 30 degrees flexion), or pushing up from a chair to stand (requiring 25 degrees wrist extension) can provide valuable information directly related to functional tasks (Gutman & Schonfeld, 2003).

Stability Assessment

If there are alterations in joint surface contact, orientation, or ligamental support, an abnormal path of articular contact during or at the end of the ROM may occur. This is instability (Ozer & Scheker, 2006). All of the ligaments providing support at the wrist except for the dorsal radioulnar ligament have equivalent tensions during joint movements indicative of their role in stabilization of the joint (DiTano, Trumble, & Tencer, 2003). Instability may result in subluxations or dislocations of the many bony articulations in the wrist complex.

Acute dislocations may be due to an isolated injury or may be the result of fractures of the radial head, distal radius, and both bones of the forearm. In isolated injuries, ulna dorsal dislocations occur because of hyperpronation injury, whereas ulna volar dislocations occur due to hypersupination (Andersson, Nordin, & Pope, 2006; Ozer & Scheker, 2006). Chronic instability can progress to osteoarthritis in the joint, further limiting ROM and limiting functional use of the elbow and wrist.

Tests for ligament, capsule, and joint instability are listed in Table 7-9.

Table 7-10

Pain Sensations at the Wrist

Localized	• Indicative of more superficial structures such as muscles, ligaments (radial and ulnar collateral ligaments), or periosteum (pisiform, styloid process, or metacarpal heads)
Deep	• Referred pain • Deeply located muscles, ligaments, bursae, or bones (scaphoid or radius)
Sharp	• Skin • Fascia • Tendon (de Quervain's disease) • Ligaments • Muscles • Bursitis
Dull	• Neurological problem • Bony injury • Chronic capsular problem • Deep muscle injury • Tendon sheath problem
Ache	• Tendon sheath • Deep ligament • Fibrous capsules • Deep muscles • Rheumatoid arthritis • Complex regional pain syndrome
Pins and Needles	• Peripheral or dorsal nerve root damage • Systemic condition • Vascular occlusion (Raynaud's disease)
Tingling	• Neural involvement (C7-C8 dermatome or peripheral nerve involvement) • Circulatory involvement

Pain Assessment

A complete understanding of the pain symptoms from the client's perspective is an important part of the assessment process. Pain can invalidate strength tests and limit functional movement of the wrist joint. Understanding and describing the exact location of the pain may help to identify structures involved. Having the client describe the type of pain that is being experienced (e.g., burning, tingling), the frequency and duration of the pain, and what movements or activities aggravate or bring relief from the pain is essential information to gather from the client. Immediate onset of pain usually indicates a more severe injury than pain occurring within 6 to 12 hours after the activity. Gradual onset of pain may also indicate overuse syndromes, neural lesions, or arthritic changes. Table 7-10 summarizes pain and sensory indications for the wrist.

If the client can localize the pain in the anatomic snuffbox and reports a fall on an outstretched hand (FOOSH) injury, a scaphoid fracture or Preiser's disease (osteonecrosis or avascular necrosis of the scaphoid) might be suspected. There would be a loss of wrist motion, decreased grasp, and pain with movement. If the client locates the site of pain over the lunate with localized pain and history of a FOOSH injury, this may be due to Keinböck's disease (osteonecrosis or avascular necrosis of the lunate).

There may be referred pain in the deeper structures, such as in the more deeply located muscles and ligaments; in the bursae; in the bones (especially the scaphoid or radius; Hartley, 1995); or in the cervical spine or upper thoracic spine, shoulder, and elbow. The muscles acting on the wrist have specific pain referral patterns when injured, such as pain referring to the medial side of the dorsum of the wrist when the ECU is injured or a pain referral pattern to the anteromedial wrist and lateral palm for the FCU (Magee, 2014).

Pain may be due to compression of the median nerve in the carpal tunnel leading to carpal tunnel syndrome. Compression may be due to trauma (Colles fracture or lunate dislocation), flexor tendon paratendonitis, a ganglion, arthritis, or collagen disease (Magee, 2014). Symptoms are usually worse at night and include burning, tingling, pins and needles, and numbness, which may be referred to the forearm. Specific tests for carpal tunnel syndrome include Phalen's test and the Tinel's sign at the wrist. The ulnar nerve can become compressed as it passes through the pisohamate or Guyon's canal (Guyon's canal syndrome), but only the fingers show altered sensation. There may be motor loss in the hypothenar, adductor pollicis, interossei, medial two lumbricals, and palmaris brevis (Magee, 2014). Special tests for the ulnar nerve would be the Froment sign and Wartenberg sign.

Pathology of the Wrist

Common injuries to the wrist include FOOSH, which can result in fracture or dislocation of the scaphoid or lunate bones, and anterior ligamental strain, which can produce synovial effusion, joint pain, and limited movement. FOOSH injuries affect not only the wrist, but, due to the interrelatedness of the structures in the upper extremity kinematic chain, forces are transmitted from the scaphoid to the distal radius, across the interosseous membrane to the ulna, from the ulnar to the humerus. From the glenoid, the force then moves to the coracoclavicular ligament and clavicle to the sternum. Because of these links, evaluation of more than just the wrist is important. FOOSH injuries can result in radial head fracture if the arm is supinated with anterolateral pain and tenderness at the elbow. Distal radius fracture (Colles fracture) can occur in FOOSH injuries with forceful wrist extension. Distal radius fractures are accompanied by wrist swelling and pain upon wrist extension.

Carpal tunnel syndrome is a compression of the median nerve at the carpal tunnel of the wrist. The carpal tunnel contains (from radial to ulnar side) the FCR tendon, flexor pollicis longus tendon, median nerve, tendons of the flexor digitorum superficialis and profundus, and vascular structures. Overuse of the wrist via repetitive motion can produce tenosynovitis in the tendon sheaths of the long flexor muscles. This can increase hydrostatic pressure in the tunnel, causing compression damage to the median nerve. Another overuse syndrome of the wrist and thumb is the extensor intersection syndrome, where there is pain and inflammation in the upper forearm.

The TFCC can acquire an isolated lesion but may also incur injury in association with a distal radius fracture, distal radioulnar fracture, ulnar styloid fracture, or radial shaft fracture. Injury to the TFCC is controversial and can result in prolonged disability (Tang et al., 1998). The central portion of the articular disc is avascular, and this hinders healing. Classification of TFCC lesions is based on traumatic injuries (specifying location of injury such as central, ulnar, radial) or degenerative injury, which specifies which structures are worn or perforated (Palmer & Werner, 1981). Initial treatment options are activity modification, splinting, and anti-inflammatory medications. If surgery is required, the goal is to decrease the force loading on the ulnar side of the wrist. Additional wrist pathology is summarized in Table 7-11.

Outcome Measures for the Wrist and Hand

The use of outcome measures in occupational therapy is necessary to improve decisions about specific treatment procedures with specific clients in order to provide the most cost-effective and evidence-based interventions (Law & McColl, 2010). Outcomes in occupational therapy include changes in occupational performance, enhanced adaptation, improved health and wellness, increased participation, prevention of disability, improved quality of life, development of role competence, self-advocacy, and enriched occupational justice (American Occupational Therapy Association, 2014).

Wrist and hand outcome measures include the Boston Carpal Tunnel Questionnaire (Levine and Katz Questionnaire), Jebsen Hand Function Test, Michigan Hand Outcomes Questionnaire, and the Patient-Rated Wrist Evaluation (Angst, Schwyzer, Aeschlimann, Simmen, & Goldhahn, 2011). The Boston Carpal Tunnel Questionnaire is a patient-reported assessment that evaluates the symptoms and functional status associated with carpal tunnel syndrome (Levine et al., 1993). The first, introduced in 1969, assesses hand function in seven unilateral tasks (Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969). The Michigan Hand Outcomes Questionnaire includes 25 items and is designed for self-administration (Chung, Hamill, Walters, & Hayward, 1999; Chung, Pillsbury, Walters, & Hayward, 1998). The Patient-Rated Wrist Evaluation is composed of 5 questions about wrist pain and 10 questions about function in daily activities for clients with distal radius fractures (MacDermid, Turgeon, Richards, Beadle, & Roth, 1998). The Levine Symptom Severity Scale (Levine et al., 1993) and related Brigham and Women's Hospital Carpal Tunnel Questionnaire, and the Disabilities of the Arm, Shoulder, and Hand (Hudak, Amadio, & Bombardier, 1996) measure limitations in activities of daily living and instrumental activities of daily living. The Gartland and Werley score (Gartland & Werley, 1951) involves an objective evaluation of wrist function, and while this tool is used extensively by orthopedic surgeons as an objective assessment of outcome, there have been no validity and reliability studies completed on this tool (Changulani, Okonkwo, Keswani, & Kalairajah, 2008).

Table 7-11

Wrist Pathology

Fracture	• Scaphoid may be impinged between capitate and radius
	  ◦ Particularly high incidence in young athletes in contact sports
	  ◦ Point tenderness in the anatomical snuffbox and history of hyperextension
	  ◦ Fracture often misdiagnosed
	  ◦ Bone heals poorly due to poor blood supply
	• Lunate fracture

Rheumatoid Arthritis	• Commonly affects the wrists bilaterally
	• In advanced stages, there may be subluxation or deformities that may include the following:
	  ◦ Volar subluxation of the triquetrum with relation to the ulna
	  ◦ Extensor carpi ulnaris tendon displacing volarly
	  ◦ Subluxation of the carpals, which would result in radial deviation

Strains	• FCR and FCU most commonly strained
Dislocation	• Distal ulna dislocation can occur with ulnar styloid fracture • Radiocarpal or midcarpal dislocations are rare • With hyperextension, lunate dislocates anteriorly then remains stationary while the rest of the carpals dislocate anteriorly

Sprains or Tears	• Forced radial deviation
	  ◦ Can sprain or tear the medial ligament of the radiocarpal joint at the ulnar styloid process, the anterior band into the pisiform, or the posterior band into the triquetrum
	  ◦ May fracture the scaphoid or distal end of the radius or avulse the ulnar styloid process
	• Forced wrist ulnar deviation
	  ◦ Can sprain or tear the lateral ligament of the radiocarpal joint at the radial styloid process, the anterior band into the scaphoid, or the posterior band into the scaphoid tubercle
	  ◦ Can strain the ECRL or APL tendons or avulse the radial styloid process

Hyperpronation and Hypersupination	• Hyperpronation can cause dorsal subluxations or dislocations of the distal radioulnar joint • Hypersupination is less common but can result in volar radioulnar subluxations or dislocations

Overuse	• Carpal tunnel syndrome
	  ◦ Can occur in baseball, rowing, weight lifting, wheelchair athletes
	  ◦ Carpal tunnel can become constricted due to many conditions
	  ◦ Numbness or tingling in the hand and fingers that are supplied by the median nerve
	  ◦ Motor weakness can develop from prolonged or severe constriction
	• Extensor intersection syndrome
	  ◦ Overuse of thumb or wrist causing inflammation of APL and EPL in upper forearm where they cross each other
	  ◦ Common in weight lifters and paddlers
	• Ulnar nerve entrapment as it passes around the hook of hamate or can be damaged with scaphoid or pisiform fractures
	  ◦ Tingling and paresthesia of the hand and fingers in ulnar distribution
	  ◦ Can be seen from trauma from the handle of a baseball bat or hockey stick, karate blows, or prolonged wrist extension that occurs with long distance cycling.

APL=abductor pollicis longus, EPL=extensor pollicis longus.

Summary

- The radiocarpal joint is made up of the radius and carpal bones.
- The wrist includes three joints: the radiocarpal, midcarpal, and intercarpal joints.
- Movements at the radiocarpal and midcarpal joints occur at the same time and are involved in the motions of flexion and extension.
- Adduction/abduction of the wrist (also known as *ulnar* and *radial deviation*) is accomplished when the capitate and scaphoid carpal bones move in radial deviation; triquetrum/triangular in ulnar deviation.
- Circumduction is a combined sequence of movement of adduction, extension, abduction, and flexion.
- Many muscles work together at the wrist to produce movement that a single muscle alone would not be able to produce.
- Assessment of the wrist includes consideration of the movement produced, pain, edema, and functional use of the wrist in activities.

Figure 7-1 is adapted from Biel, A. (2001). *Trail guide to the body*. Boulder, CO: Books of Discovery.
Figures 7-6, 7-7, 7-8, and 7-9 are adapted from Neumann, D. A. (2002). *Kinesiology of the musculoskeletal system: Foundations for physical rehabilitation*. St. Louis, MO: Mosby.

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8

The Hand

Melinda F. Rybski, PhD, MS, OTR/L

The hand is amazingly complex, intricately constructed, and vital to daily life activities. Capable of complex movements, the hand is a vital connection and mechanism for interaction with the environment. Since the hand is positioned opposite to that of the wrist, maximal finger movement can occur (Nordin & Frankel, 2012). Not only does the hand provide mobility for the proximal joints to move the hand in large areas of space and to reach nearly all parts of the body, but the hand also participates in fine motor grasp and pinch, tactile exploration of the environment, and nonverbal communication with others.

The hand has three functional components. The first component is the thumb, which is positioned at right angles to the fingers to produce effective grip forces. The second functional component includes the index and middle fingers. These two fingers work with the thumb for precision grip. These fingers have thick, long, and strong bones with strong ligaments to add rigidity to the hand. The final component is made up of the ring and little fingers with smaller, shorter bones. This component provides flexible grip to mold around objects of different shapes. The differences in bone length of the metacarpals result in flexed fingers moving diagonally toward the thenar eminence to facilitate the grasping of objects of a variety of shapes (Trew & Everett, 2005).

Mobility within the hand is variable. The distal row of the carpals and their articulation with the metacarpals of the index and long fingers are relatively fixed due to the intercarpal ligaments and distal carpal bones. The thumb is the most mobile digit, followed by (in order from most to least) the phalanges of the index, long, ring, and small fingers, and then the fourth and fifth metacarpals.

Bones of the Hand and Palpable Structures

The hand consists of five digits, or four fingers and one thumb. Each of the digits has a carpometacarpal (CMC) articulation and a metacarpophalangeal (MCP) joint. The fingers have two interphalangeal (IP) joints while the thumb has only one. There are 19 bones distal to the carpal bones of the wrist that make up the hand: five metacarpal bones, five proximal phalanges, five middle phalanges, and four distal phalanges.

Appearance

The hand has a concave appearance even when the palm is fully opened. This is due to the arches in the hand produced by the carpal bones and ligaments. There are two transverse arches and one longitudinal arch in the hand, as seen in Figure 8-1.

The proximal transverse arch (or carpal transverse arch) is curved due to the shape of the carpal bones, with the flexor retinaculum (transverse carpal ligament) as the "roof" of the arch (Magee, 2014). This becomes the carpal tunnel. There is much variability in the shape of this arch due to the mobility of the bones that make up the arch. It is situated across the hand at the level of the CMC joint with the capitate centrally located and is a rigid arch (Muscolino, 2006), producing the concave appearance of the palm.

The distal transverse arch is found at the level of the MCP joint. The first, fourth, and fifth metacarpals rotate around the

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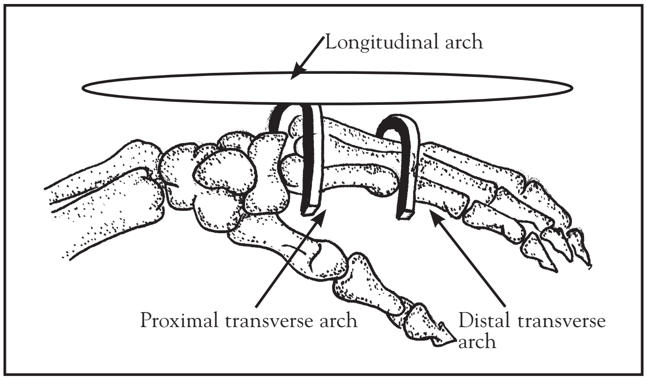


Figure 8-1. Arches of the hand.

stable second and third metacarpals to cup or flatten the palm by changing the distal transverse arch (Bugbee & Botte, 1993).

The longitudinal arch runs from the wrist to the fingertips, with the apex of the arch along the row of metacarpal heads. The carpal bones, metacarpal bones, and phalanges make up this arch, with the metacarpal bones providing the stability. The length of the arch is greatest at the second metacarpal and shortest at the fifth metacarpal. Consideration of the arch length is important when making splints so that the splint does not extend too far distally, which may block flexion of the fourth and fifth MCP joints (Greene & Roberts, 1999).

Weakness or atrophy of intrinsic hand muscles will lead to loss of arches, which are most noticeable with medial and ulnar nerve damage, resulting in the development of the ape hand deformity. The palmar arches provide the function of palmar cupping, which enables the hand to conform to the object being held. Maximum surface contact is made, increased stability is produced, and additional sensory input is provided in this cupped hand position.

The two transverse arches are connected by the longitudinal arch. In finger flexion, the longitudinal arch curls in a pattern called an equiangular spiral or logarithmic spiral. This spiral pattern comprises a series of isosceles triangles with angles of 36 degrees and is a biologically natural pattern, as seen in flowers and in the shell of the nautilus. Again, it is important to recognize the importance of maintaining these arches when splinting to enable normal hand function.

Visually, the hand and wrist have many creases that are easily seen in Figure 8-2. In the palmar view, the proximal transverse skin crease (linea carpi palmaris proximalis), located at the wrist, is the upper limit of the synovial sheaths of the flexor tendons and indicates the radiocarpal joint. The middle skin crease is an indication of the location of the radiocarpal joint, and the distal skin crease (linea carpi palmaris distalis) is the location of the upper margin of the flexor retinaculum and midcarpal joint motion. The radial longitudinal skin crease (thenar crease) encircles the thenar eminence and is sometimes referred to as the *life line*. The proximal transverse line of the palm runs across shafts of metacarpal bones (sometimes called the *head line*), and the distal transverse line of the palm lies over the head of the second to fourth metacarpals (commonly called the *love line*). The proximal skin crease of fingers is 2 cm distal to the MCP joints, the middle skin crease of fingers indicates the location of the proximal IP joints, and the distal skin crease of fingers lies over the distal interphalangeal (DIP) joints (Greene & Roberts, 1999; Magee, 2014).

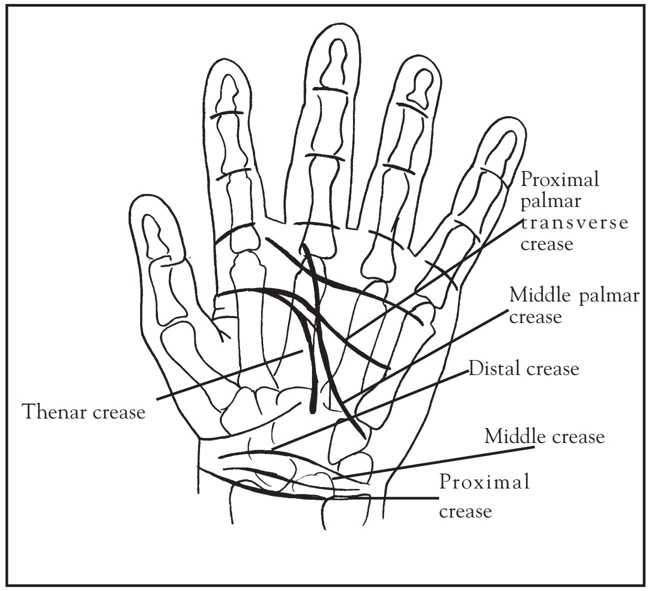


Figure 8-2. Palmar creases of the hand.

Metacarpals

On the dorsum of the hand, palpate the superficial metacarpal shafts and the space between the metacarpals for the interosseous muscles. If your subject flexes the wrist, on the dorsum of the hand is a ridge of bony protuberances that are the bases of the metacarpals as they articulate with the carpals to form the CMC joints (Biel, 2016).

Phalanges

Distal to the metacarpals are the DIP and proximal interphalangeal (PIP) joints. Follow the metacarpals up to the MCP joint. Gently distract the joint surfaces at the MCP joint to differentiate the heads of the metacarpals from the phalanges.

Articulations of the Hand

The articulations in the hand include the CMC, MCP, PIP, and DIP joints of the fingers and thumb.

Carpometacarpal Joints of the Fingers

The CMC joint is the articulation of digits two through five with the distal row of carpal bones, as well as the articulation of each metacarpal bone with the base of the adjacent metacarpal bone. Specifically, the second metacarpal bone articulates primarily with the trapezoid and partially with the trapezium, the capitate, and with the base of the third metacarpal. The third metacarpal articulates with the capitate and the second and fourth metacarpals. The second and third CMC joints are the primary parts of the transverse arch of the hand and are relatively rigid and primary stabilizers of the hand. The fourth metacarpal articulates with the capitate and

Table 8-1

OSTEOKINEMATICS OF THE CARPOMETACARPAL JOINTS OF THE FINGERS

FUNCTIONAL JOINT	Synarthrotic, nonaxial
STRUCTURAL JOINT	Synovial, plane
CLOSE-PACKED POSITION	Full flexion
RESTING POSITION	Midway between flexion and extension
CAPSULAR PATTERN	Equal limitations in all directions

Table 8-2

ARTHROKINEMATICS OF THE CARPOMETACARPAL JOINTS OF THE FINGERS

MOVEMENT OF CONVEX METACARPALS ON CONCAVE CARPALS	DIRECTION OF SLIDE OF METACARPALS ON CARPALS	RESULTANT MOVEMENT
Flexion	Volar (anterior) slide, volar roll	Movement in same direction
Extension	Dorsal (posterior) slide, dorsal roll	Movement in same direction

the hamate bones and with the side of the third and fifth metacarpal bone. The fifth metacarpal articulates with the hamate, and the ulnar side articulates with the fourth metacarpal bone. The fourth and fifth CMC joints are mobile to permit cupping of the hand. All of the CMC joints are united by the dorsal, palmar, and interosseous ligaments.

The CMC joint provides the most movement for the thumb and the least amount of movement for the fingers (Hamill, Knutzen, & Derrick, 2015). The most movement of the CMC joint is the metacarpal bone of the little finger, followed by the metacarpal bone of the ring finger. The metacarpal bones of the index and middle fingers are almost immovable, so the range of motion (ROM) increases from the radial side to the ulnar side, which enables the hand to curve anteriorly or to cup. The relative immobility of the second and third metacarpals enables us to hold tools more firmly and enhances the function of the radial wrist flexors and extensors (flexor carpi radialis, extensor carpi radialis longus, extensor carpi radialis brevis), serving as a fixed axis about which the first, fourth, and fifth metacarpals can move. This provides an increased lever arm without the loss of tension resulting from excessive ROM (Levangie & Norkin, 2011).

Osteokinematics

Movements at the CMC joints of the fingers are of the nonaxial gliding plane synovial type, although some authors suggest the fourth and fifth are a modified saddle biaxial joint (Gench, Hinson, & Harvey, 1995; Muscolino, 2006), and others classify the second and third digits as *complex saddle joints* (Neumann, 2002). Generally, the CMC joints of the fingers are seen to be plane joints with only gliding movements possible.

Movements produced are flexion and extension, which can be seen when the hand is cupped or flattened. There are approximately 25 to 30 degrees in the fifth CMC, 10 to 15 degrees in the fourth CMC, and minimal movements in the second and third metacarpals. A summary of the osteokinematics of the CMC joints of the fingers is presented in Table 8-1.

Arthrokinematics

When the metacarpals flex (as when cupping the hand), the metacarpals slide on the carpals in a volar (palmar or anterior) direction, creating an increased transverse arch, whereas when the hand is flattened in extension, the metacarpals slide on the carpals in a dorsal (posterior) direction, resulting in a decreased transverse arch (Table 8-2). In both flexion and extension, the rolling movement of the proximal phalange is in the same direction of the metacarpal slide on the carpals (Kisner & Colby, 2012).

Muscles contributing to the movement at the CMC joints of the fingers are the radial wrist muscles (flexor carpi radialis, extensor carpi radialis longus, extensor carpi radialis brevis, extensor carpi ulnaris), flexor digitorum superficialis, and flexor digitorum profundus.

Stability

In addition to the stabilizing effect of the relatively immobile second and third CMC bony surfaces, the CMC joints are surrounded by fibrous articular capsules and dorsal, palmar, and interosseous CMC ligaments, as seen in Figure 8-3.

The ligaments are the primary control of the amount of ROM of the CMC joints. The dorsal CMC ligaments are particularly well-developed around the middle CMC joints. They connect the carpals and metacarpal bones on the dorsal surface.

The palmar ligaments perform a similar function on the palmar surface of the hand. The interosseous ligament is short and thick in appearance and is limited to one part of the CMC articulation—that of connecting the inferior angles of the capitate and hamate with the third and fourth metacarpal bones (Goss, 1976). The transverse metacarpal (intermetacarpal) ligament is a narrow, fibrous band connecting the palmar surfaces of the heads of the second through fifth metacarpal bones. This ligament functions to prevent abduction and adduction at the CMC joint (Nordin & Frankel, 2012).

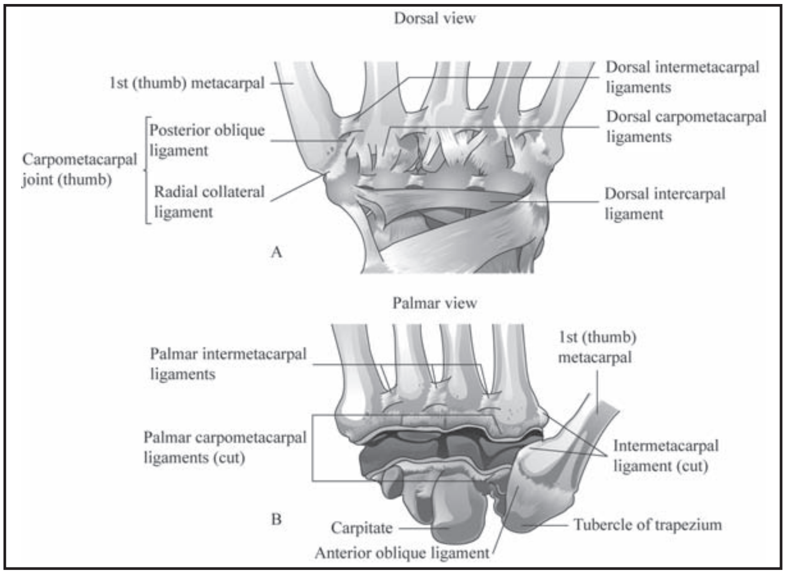


Figure 8-3. Ligamental support for the CMC joints.

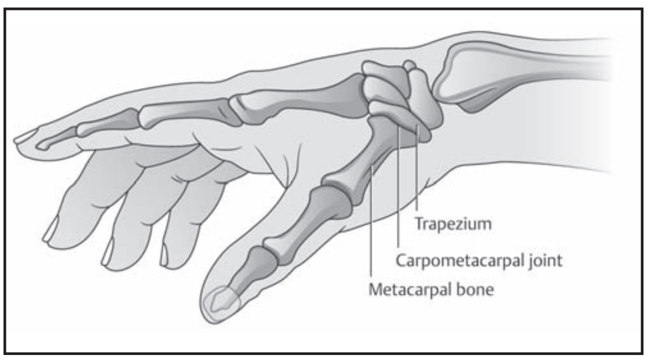


Figure 8-4. CMC joint of the thumb.

Carpometacarpal Joint of the Thumb (Trapeziometacarpal)

This articulation is formed at the juncture of the trapezium and base of the first metacarpal (Figure 8-4). The CMC joint of the thumb is capable of many movements. Because this joint is at the base of the thumb, there are large functional demands placed on the joint, often resulting in the painful condition of basilar (referring to the base) arthritis, often in women in the fifth to sixth decade of life. Without movement of the CMC joint of the thumb, firm grasp is limited.

Terminology used to describe motions of the thumb is specialized due to the rotation of the thumb in relation to the fingers. The planes of motion are in relation to the palm so that flexion-extension movements are parallel to the palm and abduction-adduction movements are perpendicular. Flexion, also known as *ulnar adduction* or *palmar flexion*, is the movement of the palmar surface of the thumb in the frontal plane across the palm. Extension (radial abduction or radial extension) returns the thumb to the anatomic position. This is also referred to as the *hitchhiking position*. Abduction of the CMC joint (palmar abduction) is the forward movement of the thumb away from the palm in the sagittal plane, and adduction returns the thumb to the palm (Neumann, 2002).

Circumduction (axial rotation or opposition in the CMC joint, thumb rotation, thumb pronation) is a combined movement of abduction, flexion, adduction, and extension that involves medial rotation of the thumb's metacarpal. The first metacarpal rotates on the trapezium to permit placement of the pad of the thumb on the pads of one or more fingers in a cone-shaped path. Reposition (supination of the thumb) is the combination of adduction, extension, lateral rotation of the thumb's metacarpal, abduction, and flexion. Movements of the thumb are shown in Figure 8-5.

Osteokinematics

The CMC joint of the thumb is a saddle-shaped joint that is classified as a biaxial joint but is capable of movement in three planes and three axes. Flexion and extension occur in a frontal plane around the anteroposterior axis; abduction and adduction occur in a sagittal plane around a mediolateral axis; and medial and lateral rotation occurs in a transverse plane around the vertical axis. However, the rotational movements in the transverse plane cannot be actively isolated, which explains why the joint is considered a biaxial joint. Medial rotation of the first metacarpal must accompany flexion of the first metacarpal, and lateral rotation accompanies extension (Muscolino, 2006). The CMC joint of the thumb is capable of 60 degrees of abduction, 10 degrees of adduction, 15 degrees of flexion, 10 degrees of extension, and 10 to 15 degrees of rotation.

The orientation of the axis of motion in the thumb differs from the axes at other joints. The two axes of motion are offset from the cardinal planes of motion and are not perpendicular to the bones or to each other (Gench et al., 1995; Provident & Houglum, 2012). Flexion and extension occur in the plane of the palm, with the axis oriented to the front and back in relation to the palmar and dorsal hand surfaces (i.e., the motion is parallel to the palm; Goss, 1976; Greene & Roberts, 1999). This axis goes through the trapezium but at a right angle to the palm (Gench et al., 1995; Provident & Houglum, 2012). Adduction and abduction occur in the plane at right angles to the palm, with the axis in a side-to-side orientation rather than

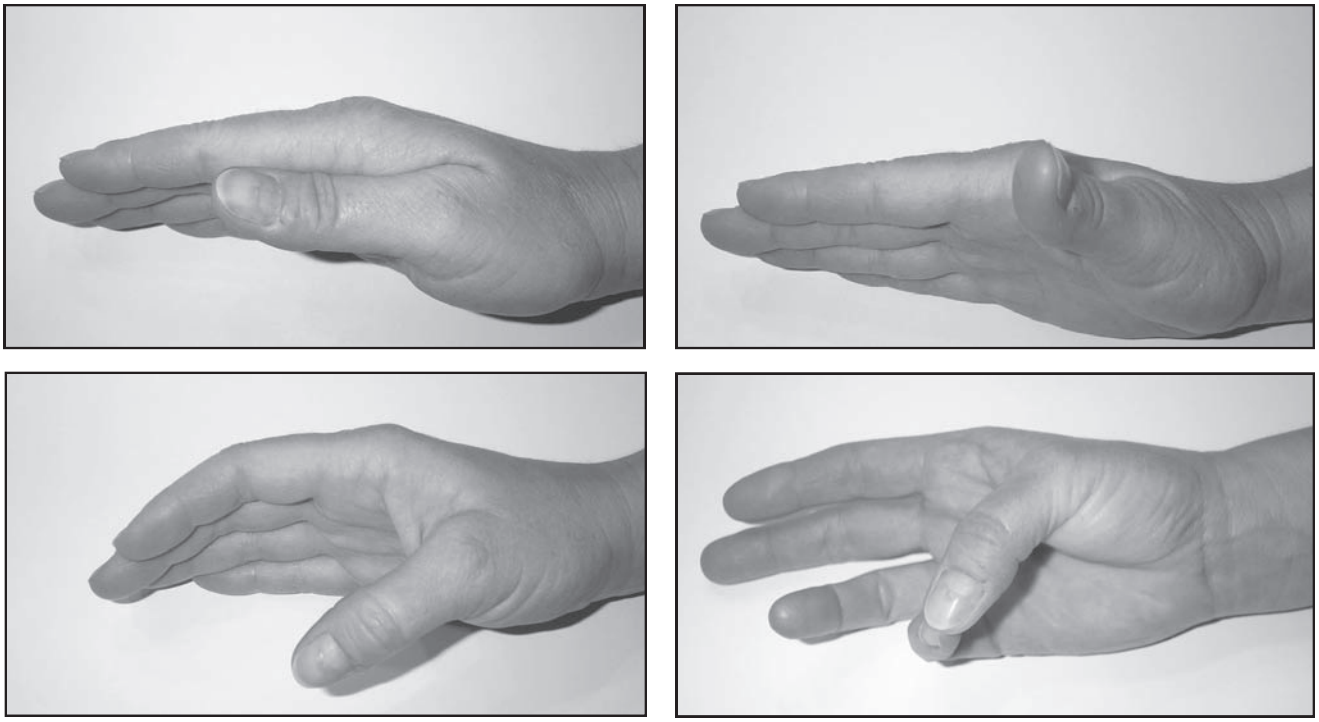


Figure 8-5. Movements of the thumb.

front to back (Goss, 1976; Greene & Roberts, 1999). This axis is at the base of the first metacarpal and slants toward the base of the ring finger (Gench et al., 1995; Provident & Houglum, 2012). A summary of the osteokinematics of the CMC joint of the thumb is provided in Table 8-3.

Arthrokinematics

Because there are both convex and concave bone surfaces, this is a biaxial sellar (saddle-shaped) joint. In flexion and extension, the convex trapezium articulates on the concave metacarpal base so the surface slides in the same direction as the angulating bone. In flexion, the concave metacarpal rolls and slides in an ulnar (medial) direction. There is slight medial rotation of the metacarpal as it moves toward the third digit with elongation of the radial collateral ligament.

In extension, the concave metacarpal rolls and slides in a lateral (radial) direction (i.e., away from the third digit) with slight lateral rotation of the metacarpal of the thumb, which requires elongation of the anterior oblique ligament. Flexion and extension of the CMC joint of the thumb can be observed by watching the change of orientation of the thumbnail during flexion and extension (Neumann, 2002).

Adduction and abduction movements occur in the sagittal and frontal axis and, because the trapezium is concave and the metacarpal convex, the surface slides in an opposite direction of the articulating bone (Kisner & Colby, 2012), as summarized in Table 8-4. In abduction, the convex metacarpal rolls in a palmar direction with a dorsal slide on the concave surface of the trapezium. Full abduction stretches the anterior oblique ligament, intermetacarpal ligament, and adductor pollicis muscle, with the abductor pollicis longus muscle responsible for the roll. Adduction results in a dorsal roll and palmar slide of the convex surface of the metacarpal on the concave trapezium.

Table 8-3

Osteokinematics of the Carpometacarpal Joint of the Thumb

Functional Joint	Diarthrotic, biaxial
Structural Joint	Synovial, saddle
Close-Packed Position	Full opposition
Resting Position	Midway between flexion and extension and midway between abduction and adduction
Capsular Pattern	Abduction, then extension

Stability

The CMC joint of the thumb is surrounded by a thick but loose fibrous joint capsule that is reinforced by radial, ulnar, volar, and dorsal ligaments, as well as an intermetacarpal ligament that holds the bases of the first and second metacarpals together. This prevents extreme radial and dorsal displacements of the base of the first metacarpal (Nordin & Frankel, 2012). The laxity of the joint capsule allows 10 to 15 degrees of rotation, and the metacarpal can be distracted up to 3 mm from the trapezium.

Five major ligaments provide stability to the CMC joint of the thumb, as shown in Figure 8-6. Three oblique capsular ligaments (anterior oblique, posterior oblique, and radial collateral ligament) attach the first metacarpal to the trapezium. Located from the tubercle of the trapezium to the base of the

Table 8-4

Arthrokinematics of the Carpometacarpal Joint of the Thumb

Movement of Metacarpals on Carpals	Direction of Slide of Metacarpals on Carpals	Resultant Movement
Flexion	Ulnar (medial) slide, ulnar roll	Movement in same direction
Extension	Radial (lateral) slide, radial roll	Movement in same direction
Abduction	Dorsal slide, volar roll	Movement in opposite direction
Adduction	Volar slide, dorsal roll	Movement in opposite direction

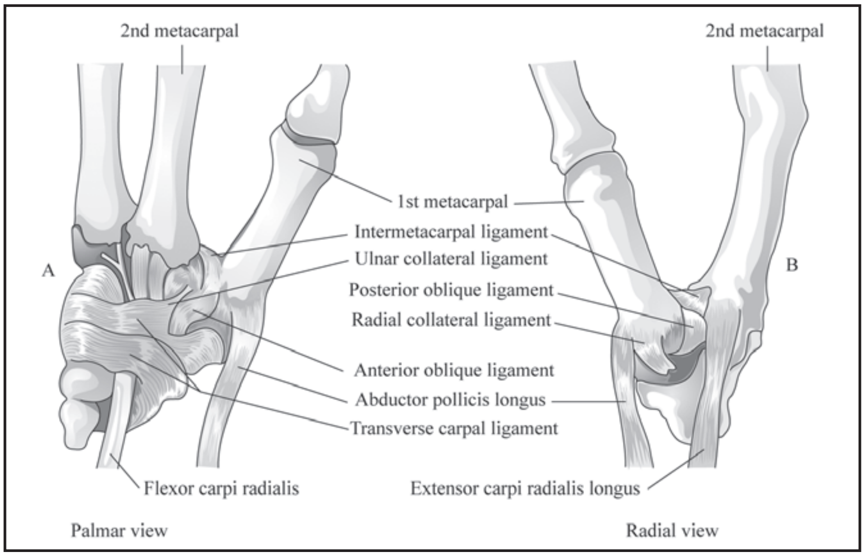


Figure 8-6. Ligaments of the CMC joint of the thumb.

metacarpal of the thumb is the anterior oblique ligament, which is taut in abduction, extension, and opposition and is considered the strongest of the three. Laxity in these three ligaments allows for circumduction and rotation of the CMC joint. The radial collateral ligament (also called the *dorsal-radial ligament*), located from the radial surface of the trapezium to the base of the thumb metacarpal, is taut in all thumb movements except extension. The posterior oblique ligament and the first intermetacarpal ligaments are taut in abduction and opposition. The ulnar collateral ligament (palmar oblique ligament), located from the transverse carpal ligament to the base of the thumb metacarpal, is taut in abduction, extension, and opposition. In addition, the interosseous ligaments also provide support.

Metacarpophalangeal Joints of the Fingers

The metacarpal bones articulate into shallow cavities of the proximal ends of the first phalanges (with the exception of the thumb) at the MCP joints (Goss, 1976). The first MCP joint is located between the first metacarpal and the proximal phalanx of the thumb, and subsequent MCP joints are located between the metacarpal and the proximal phalanx of the adjacent finger.

When the MCP joints are flexed, it is not possible to abduct and adduct the fingers due to the shapes of the bones and tension in ligaments. There is, however, substantial accessory movement possible when the fingers are extended and relaxed. There is a great deal of anteroposterior, side-to-side, and distraction gliding motions. Axial rotation of the metacarpals occurs with as much as 30 to 40 degrees possible in the ring and little fingers. These accessory motions enable the hand to conform to the shape of objects held in the hand with greater control.

Osteokinematics

The MCP joints of the fingers are unicondylar diarthrodial biaxial joints with three planes of movement (Nordin & Frankel, 2012), with flexion, extension, abduction, adduction, and slight rotational movements possible. The flexion-extension axis is in the sagittal plane around a mediolateral axis. The location of the axis permits as much as 95 to 110 degrees of flexion in the little finger, approximately 70 to 90 degrees in the index finger, and 90 to 115 degrees at the fifth finger. The mobility of the second and fifth digits is the greatest because adjacent fingers do not limit the motion (Neumann,

Table 8-5

OSTEOKINEMATICS OF THE METACARPOPHALANGEAL FINGER JOINTS

FUNCTIONAL JOINT	Diarthrotic, biaxial
STRUCTURAL JOINT	Synovial, condyloid
CLOSE-PACKED POSITION	Full flexion
RESTING POSITION	Slight flexion
CAPSULAR PATTERN	Flexion, then extension

Table 8-6

ARTHROKINEMATICS OF THE METACARPOPHALANGEAL FINGER JOINTS

MOVEMENT OF METACARPALS ON CARPALS	DIRECTION OF SLIDE OF METACARPALS ON CARPALS	RESULTANT MOVEMENT
Flexion	Volar slide, volar roll	Movement in same direction
Extension	Dorsal slide, dorsal roll	Movement in same direction
Abduction	Radial roll, radial slide	Movement in same direction
Adduction	Ulnar roll, ulnar slide	Movement in same direction

2002). Passive hyperextension of the MCP finger joints of 30 to 45 degrees is possible and is often used as a measure of generalized body flexibility. Being considered "double-jointed" is due to laxity of the ligaments of the joint, and hyperextension is normally limited by the palmar plate.

The point of reference for abduction and adduction is the middle finger. Lateral movement of the middle finger is called *radial abduction*, and medial movement is called *ulnar abduction*. Brand and Hollister (1999) describe the adduction-abduction axis as a cone that runs forward from the metacarpal head with an inclination distally of approximately 30 degrees above a right angle. Abduction and adduction can occur in this anteroposterior axis that passes from the palmar to dorsal surfaces when the fingers are extended because the tip of the finger is a long distance from the joint axis, thereby permitting this motion. When the fingers are flexed, the tips of the fingers are on the axis of rotation, so no further lateral movement can occur. For example, when the hand holds a hammer in a power grip, the thumb aligns with the longitudinal axis, providing maximal strength and stabilization against lateral forces. In full flexion, the phalange is parallel to the longitudinal axis, putting the joint into the most stable, close-packed position. The close-packed position of the MCP joints is in full flexion as this is when the cord portion of the collateral ligaments are taut, providing substantial stability to the base of the fingers (Table 8-5; Neumann, 2002).

Arthrokinematics

Although each metacarpal has a slightly different shape, generally, the concave articulating surface of the phalanges moves on a convex metacarpal head in the MCP joints of the fingers. In extension, the proximal phalanx rolls and slides dorsally via the extensor digitorum communis muscle. At 0 degrees of extension, the collateral ligaments slacken, and the palmar plate unfolds, which enables total contact with the head of the metacarpal. Flexion motion of rolling and sliding occurs in the palmar direction and extension rolling and sliding in a dorsal direction. At 0 degrees of extension, the collateral ligaments slacken, and the palmar plate unfolds, which enables total contact with the head of the metacarpal. Flexion motion of rolling and sliding occurs in the palmar direction and extension rolling and sliding in a dorsal direction. Table 8-6 summarizes arthrokinematics of the metacarpophalangeal joints.

Figure 8-7 illustrates flexion at the MCP, PIP, and DIP joints. Abduction produces movement as the proximal phalanx rolls and slides in a radial direction with the first dorsal interosseous muscle directing both the roll and slide. Figure 8-8 summarizes the arthrokinematics of the MCP joints of the fingers.

Stability

Mechanical stability of the MCP joints is crucial to the hand as the metacarpals are the support of the arches of the hand (Neumann, 2002). Each joint has a fibrous joint capsule that is lax in extension and taut in flexion. The MCP joints are often affected by rheumatoid arthritis because the joint capsules are not stable enough to resist ulnarly directed forces, such as when things are held between the thumb and fingers (Muscolino, 2006).

Imbedded in each capsule of each MCP joint are radial and ulnar ligaments and one palmar ligament or plate. The collateral ligaments are strong and they run along the sides of the joints. The dorsal surface is covered by the extensor tendons with tissue that connects the deep surfaces of the tendons to bones. The collateral ligaments are slack in extension, although some authors disagree and say that parts often provide stability throughout the range (Levangie & Norkin, 2011). The laxity in extension allows some passive axial rotation of the proximal phalanx. Because the ligament is taut with flexion, this prevents abduction and adduction because there is a longer distance between the points of attachment when these joints are flexed than extended. Abduction and adduction can occur only when the joints are extended. This enables mechanical stabilization of the MCP joint (Provident & Houglum, 2012).

Each collateral ligament has two parts: the cord part, which is thick and strong and attaches to the palmar aspect of the distal end of the phalanx, and the accessory part, which is fan-shaped and attaches distally to the palmar plate.

The palmar ligaments (or volar plate) are thick, dense, multilayered, and fibrocartilaginous. These are located between

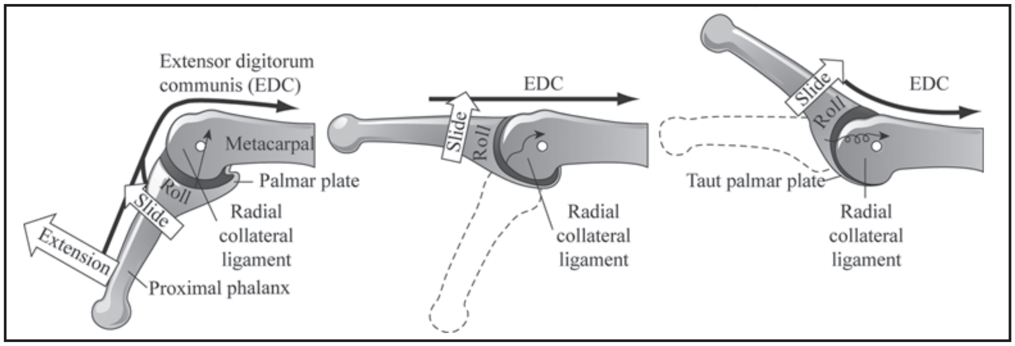


Figure 8-7. Arthrokinematics of flexion at the MCP, PIP, and DIP joints.

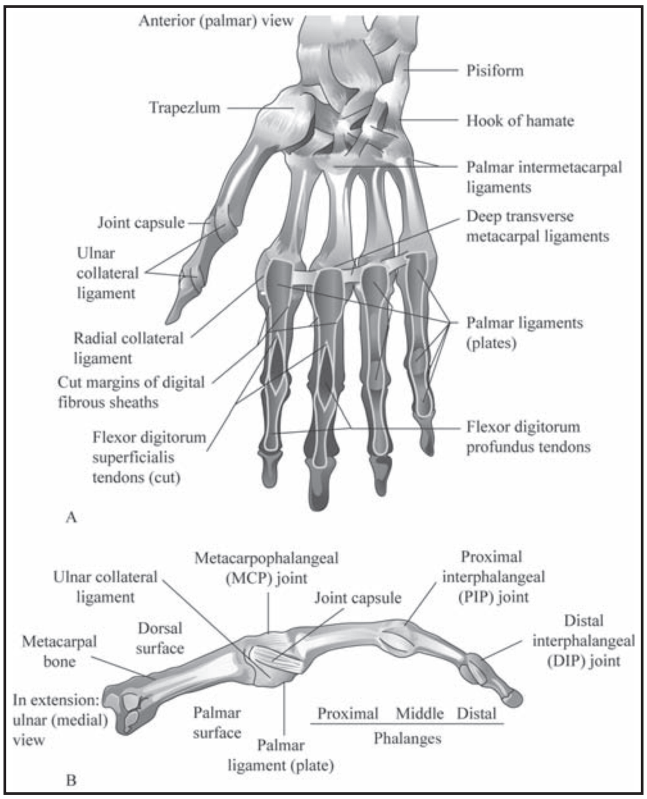


Figure 8-8. Ligaments of the MCP and intermetacarpal joints.

the collateral ligaments to which they are connected. These ligaments are loosely connected to the metacarpal bones but are firmly attached to the base of the first phalanges, helping to reinforce the joint capsule as well as provide a surface for contact in extension and in prevention of excessive hyperextension (Levangie & Norkin, 2011). Fibrous digital sheaths form tunnels or pulleys for the extrinsic finger flexors, which are anterior to the palmar plates. The purpose of the palmar plates is to strengthen the MCP joints and resist hyperextension. Between the palmar plates are three deep transverse metacarpal ligaments that interconnect the second through fifth metacarpals, as seen in Figure 8-8.

Metacarpophalangeal Joint of the Thumb

The MCP joint of the thumb is located between the convex head of the first metacarpal and the concave proximal phalanx of the thumb. While the arthrokinematics are very similar to the MCP joints of the fingers, there is much less active and passive movement in the MCP joints of the thumb.

Osteokinematics

The articulation of the first metacarpal bone and the proximal phalange produces a condyloid joint that acts like a ginglymus (hinge) joint. Goss (1976) states this is a ginglymoid joint, and Hamill et al. (2015) say this is a hinge joint, while Levangie and Norkin (2011) indicate this is a condyloid joint. Movements include flexion/extension and abduction/adduction (considered an accessory motion), with an insignificant amount of passive motion possible. Close-packed position is in full opposition, and resting position is with the joint in slight flexion. The joint is more limited in flexion followed by extension in capsular restrictions (Table 8-7).

Arthrokinematics

As with the other metacarpals, the metacarpal head is convex and fits into the concave base of the first phalange, so, arthrokinematically, the MCP joint of the thumb slides and rolls, as do the phalanges, as previously discussed regarding the MCP joints of the fingers.

Stability

Motion at the MCP joint of the thumb is more restricted than at the fingers. The collateral ligaments restrict abduction and adduction. Adduction and abduction forces are transferred to the CMC joint (Neumann, 2002). The joint capsule and ligaments of the thumb at this joint are similar to the other MCP joints with the addition of two sesamoid bones that act as additional reinforcement for thumb stability.

Table 8-7

OSTEOKINEMATICS OF THE METACARPOPHALANGEAL JOINT OF THE THUMB

FUNCTIONAL JOINT	Diarthrotic, biaxial
STRUCTURAL JOINT	Synovial, condyloid
CLOSE-PACKED POSITION	Full opposition
RESTING POSITION	Slight flexion
CAPSULAR PATTERN	Flexion, then extension

Table 8-8

OSTEOKINEMATICS OF THE INTERPHALANGEAL JOINTS

FUNCTIONAL JOINT	Diarthrotic, uniaxial
STRUCTURAL JOINT	Synovial, hinge
CLOSE-PACKED POSITION	Full extension
RESTING POSITION	Slight flexion
CAPSULAR PATTERN	Flexion, extension

Interphalangeal Joints

The articulation of the IP joints with each other and proximally with the phalanges produces two IP joints for digits two through five and one IP joint for the thumb. There are nine IP joints in the hand (one IP joint, four PIP joints, and four DIP joints). The thumb IP joint is structurally and functionally identical to the DIP joints of the fingers (Levangie & Norkin, 2011; Muscolino, 2006; Neumann, 2002).

Osteokinematics

Flexion and extension movements in the sagittal plane around a coronal axis are more extensive between the proximal and middle phalanges than between the middle and distal joints. In addition, flexion is considerable, while extension is limited by the ligamental tautness. Because there is a larger proximal articular surface than distal, there is very little hyperextension and practically no passive hyperextension at the PIP joint. The joints are closely congruent during movement, which adds stability to these joints. Full extension results in the close-packed position, and slight flexion is the resting position of these joints (Table 8-8).

There is greater ROM going from the radial to ulnar joint, permitting more opposition in the ulnar fingers by angling these fingers toward the thumb so one can get a tighter grip on objects from the ulnar side. Average ROM are 0 to 100 to 120 degrees for PIP flexion, 0 to 70 to 90 degrees for DIP flexion, and 0 degrees to 80 degrees for thumb flexion. Flexion and extension of the IP joints of the ring and little fingers are accompanied by slight axial rotation of the phalanx, which allows greater contact with the thumb during opposition (Neumann, 2002). The rotation of the joints during flexion is called the *cascade sign*, and failure of the joints to converge toward the scaphoid tubercle may indicate trauma or possibly a fracture.

Because of the greater movement in the ulnar fingers, this reinforces the idea that digits one and two are primarily functional in prehension and precision movements, while digits three through five are used for power. Notice how many tools have handles that are narrower at the ring and little fingers and wider at the radial side along the base of the long and index fingers. These also are concepts to be remembered in making adaptations to tools and utensils.

Arthrokinematics

With flexion of the phalanx, the base of the phalanx slides and rolls in a volar direction, while, during extension, the base of the phalanx slides and rolls dorsally because the distal end of each phalanx is convex and the articulating surface at the proximal end of each phalanx is concave. Rolling and sliding are in the same direction.

Stability

There are two collateral ligaments and a palmar (volar plate) ligament for each IP joint, with a similar arrangement as those of the MCP joint. The PIP joints have an additional structure, the check-rein ligament, to restrict hyperextension at those joints. In athletic injuries, there is often an injury to both the palmar plate and check-rein ligament.

The radial collateral ligaments of the IP joints are essentially identical to the radial collateral ligaments of the MCP joints. There is a cord part that limits abduction and adduction and an accessory portion that blends with and reinforces the palmar plate. The radial collateral ligament limits the motion of the phalanx to the ulnar side, and the ulnar collateral ligament limits motion of the phalanx to the radial side. The palmar plate stabilizes the IP joints and resists hyperextension.

Intermetacarpal Joints

Additional synovial plane joints are formed between the metacarpal bones and the hand. There are four proximal intermetacarpal joints, as the metacarpals articulate with each other at their bases, and three distal intermetacarpal joints, as metacarpals two through five articulate with each other at the metacarpal heads. The intermetacarpal joints produce slight nonaxial gliding motions. The metacarpals at the intermetacarpal joints on either side of the hand (first and fifth) are the most mobile (Muscolino, 2006).

These joints are bound together by palmar and dorsal intermetacarpal ligaments, interosseous ligaments, and dense fibrous joint capsules. The dorsal and palmar intermetacarpal ligaments and interosseous ligaments connect the base of each of the five metacarpals to the base of the adjacent metacarpal. The deep transverse metacarpal ligament connects the heads of metacarpals two through five.

Movements of the Hand

The amount and type of movement of the hand depends on the specific joint and digit. The most mobility of the CMC joints occurs in the thumb followed by the little and ring fingers. This enables cupping of the hand to cup around a stable core of the index and middle CMC joints. At the MCP joints, there is much less movement possible at the thumb. The second and fifth fingers have the greatest mobility because movement is not hampered by adjacent fingers. There is much accessory motion and passive hyperextension possible at the MCP joints of the fingers, but not at the thumb. The greater movement of the IP joints from the radial to ulnar direction permits the fingers to angle their location to permit more opposition and grasp. All of these factors enable prehension. A summary of the movements of the hand is presented in Tables 8-9 and 8-10.

Prehension

The hand is capable of many movements with variations in strength and in precision. Many efforts have been made to categorize these movement patterns so that consistent use of descriptive terminology can be used. Movements can be produced where the hand as a whole pushes, pulls, or moves an object and where no actual grasp is involved. This would essentially be a nonprehensile movement pattern.

Prehension includes reaching, grasping, carrying, and releasing and not just pushing or pulling on the object. The thumb tends to be the defining factor in prehension for stabilization, control of direction, and power. When the thumb is not functional in the grasp pattern, the prehension is nonmanipulative and essentially one of power. When the thumb and one or more fingers are involved in the action, the pattern is one of manipulative prehension and precision.

Prehension requires the coordinated interaction of muscles, joints, and intact sensation. Peripheral mobility is achieved by the movement of the CMC joint of the thumb and the fourth and fifth MCP joint movement. The rigidity of the CMC joints of digits two and three provides central stability on which to base movement. The stability of the arches of the hands assists with cupping the hand to hold objects. There is a synergistic balance between the agonists and antagonists of the extrinsic and intrinsic muscles so that optimal length-tension relationships are maintained. Finally, intact proprioception and sensation are necessary to perceive the object, its characteristics, and the relationship of the object to the hand for skillful object manipulation (Konin, 1999; Nordin & Frankel, 2012).

Gripping an object occurs in four stages. Opening the hand requires simultaneous activity of the intrinsic muscles and long extensor muscles and is considered the first stage. Closing the hand around the object is stage two, requiring flexion of the fingers to grasp it. The third stage involves application of the correct amount of force upon the object based on the weight and size of the object and its surface characteristics, fragility, and use. In stage four, the hand opens to release the object (Magee, 2014). Precision pinch patterns also involves the first three stages but does not have a static phase (Levangie & Norkin, 2011).

Prehensile patterns can be nonmanipulative or manipulative patterns of movement. Often, the distinction is made between grasp (power grip) and precision grip (pinch) to differentiate those actions with the thumb and those without. In grasping, all digits and the palm are used, but pinch typically uses the digits on the radial side of the hand without contact with the palm. The area of contact within the hand is just one of the factors that distinguish pinch from grasp. Other factors include the number of fingers involved, the amount of finger flexion, the position of the thumb, and the position of the wrist (Oatis, 2004).

In prehensile nonmanipulative patterns (power grip), the digits position the object against the palm. The fingers are often flexed at all three joints, laterally rotated, and ulnarly deviated. The ulnar fingers work together for support and control. The thumb, if used, is adducted and on the palmar side of the object in a position to stabilize the object. The wrist is usually in slight extension with ulnar deviation to align the hand with the forearm (Magee, 2014). The extrinsic finger flexor muscles provide the gripping force, and the extensor digitorum provides a compressive force to the MCP joints, increasing stability and balancing the flexor forces (Kisner & Colby, 2012; Nordin & Frankel, 2012). Types of power grips include hook grasp, cylindrical grasp, or spherical grasp (Magee, 2014).

In the hook grip, digits two to five are used as a hook to carry objects, such as a purse or briefcase, where force is sustained for long periods (Provident & Houglum, 2012). The extended thumb is nonfunctional, and the heel of the hand may provide some counterpressure. The MCP joints are in neutral or are extended with the fingers flexed at the PIP and DIP joints. Primarily, the muscles involved include the flexor digitorum superficialis, flexor digitorum profundus, extensor pollicis longus and brevis, extensor digitorum, and fourth lumbrical and interossei. If a powerful grip is needed, the fingers will flex at all three joints, and the thumb will be adducted (Levangie & Norkin, 2011).

In cylindrical and spherical prehensile nonmanipulative grip patterns, the fingers are used to hold an object in the palm of the hand so that the actual position of the hand varies according to the size, shape, and weight of the object being held. The palm contours to the object, and the thumb provides an additional surface for the object by adducting against it. The thumb applies counterpressure to the partially flexed fingers but again is essentially not functional as a manipulative force.

Cylindrical grasp and spherical grasp are considered palmar prehension or power grips. In cylindrical grasp, the thumb is in opposition and the fingers are adducted and flexed; this can be visualized by the position of the hand in holding a beverage can. The flexor pollicis longus and adductor pollicis, flexor digitorum profundus, and fourth lumbrical are active in this grasp pattern. Spherical grasp is seen when one holds a round object, such as a ball, where the thumb is in opposition with fingers flexed and abducted. The flexor pollicis longus and adductor pollicis, flexor digitorum profundus, and fourth lumbrical are active in this prehension pattern. Some sources state that cylindrical and spherical grasps are merely descriptions of the objects held in the hand and are not distinct grasp patterns. An additional type of power grip is the fist grasp or digital palmar prehension pattern, when the hand grips a narrow object such as a broom handle. Fisted grasp is also seen in very young children when the object is held in a fisted hand.

Table 8-9

Hand Movements

Motion	Joint	Plane/Axis	Normal Limiting Factors (Tension In)	End Feel	Primary Muscles	Normative ROM/ Functional ROM (In Degrees)
Flexion	• MCP	• Sagittal/ frontal	• Posterior joint capsule • Collateral ligaments • Contact between the proximal phalanx and the metacarpal	• Firm	• Flexor digitorum superficialis • Flexor digitorum profundus • Lumbrical • Flexor digiti minimi brevis • Dorsal interossei • Palmar interossei • Opponens digiti minimi	• 0 to 90/0 to 61
	• PIP		• Posterior joint capsule • Collateral ligaments • Contact between the middle and proximal phalanx • Soft tissue apposition of the middle and proximal phalange	• Hard		• 0 to 100/0 to 60
	• DIP		• Posterior joint capsule • Collateral ligaments • Oblique retinacular ligament	• Firm		• 0 to 90/0 to 39

(continued)

Table 8-9 (continued)

Hand Movements

Motion	Joint	Plane/Axis	Normal Limiting Factors (Tension In)	End Feel	Primary Muscles	Normative ROM/ Functional ROM (In Degrees)
Extension	• MCP	• Sagittal/ frontal	• Anterior joint capsule • Palmar fibrocartilaginous plate (palmar ligament)	• Firm	• Extensor digitorum communis • Extensor inidicis proprius • Extensor digiti minimi • Lumbricals • Dorsal interossei • Palmar interossei	• 90 to 0/61 to 0
	• PIP		• Anterior joint capsule • Palmar ligament	• Firm		• 100 to 0/60 to 0
	• DIP		• Anterior joint capsule • Palmar ligament			• 90 to 0/39 to 0
Abduction of the fingers	• MCP	• Sagittal/ frontal	• Collateral ligaments • Fascia and skin of the web spaces • Palmar interosseous ligament	• Firm	• Abductor digiti minimi • Dorsal interossei • Extensor indicis	• No norms
Adduction of the fingers	• MCP	• Sagittal/ frontal			• Palmar interossei • Opponens digiti minimi	• No norms
Opposition of the little fingers	• CMC • MCP	• Sagittal/ frontal			• Opponens pollicis • Flexor digiti minimi • Palmaris longus • Palmaris brevis	• No norms

Table 8-10

Thumb Movements

Motion	Joint	Plane/Axis	Normal Limiting Factors (Tension in)	End Feel	Primary Muscles	Normative ROM/ Functional ROM (In Degrees)
Flexion	• CMC	• Sagittal/ frontal	• Posterior joint capsule • Extensor pollicis brevis • Abductor pollicis brevis • Soft tissue apposition between the thenar eminence and the palm	• Soft	• Adductor pollicis • Flexor pollicis longus • Flexor pollicis brevis	• 0 to 15
	• MCP		• Posterior joint capsule • Collateral ligaments • Extensor pollicis brevis • Contact between the first metacarpal and the proximal phalanx	• Hard	• Adductor pollicis • Flexor pollicis brevis • Abductor pollicis brevis • Flexor pollicis longus	• 0 to 50/0 to 21
	• IP		• Collateral ligaments • Posterior joint capsule • Contact between the distal phalanx, fibrocartilaginous plate, and the proximal phalanx	• Firm	• Flexor pollicis longus	• 0 to 80/0 to 18
Extension	• CMC	• Sagittal/ frontal	• Anterior joint capsule • Flexor pollicis brevis • First dorsal interosseous	• Firm	• Extensor pollicis brevis • Extensor pollicis longus • Abductor pollicis longus	• 0 to 20
	• MCP		• Anterior joint capsule • Palmar ligaments • Flexor pollicis brevis	• Firm	• Extensor pollicis longus • Extensor pollicis brevis	• 50 to 0/21 to 0
	• IP		• Anterior joint capsule • Palmar ligaments	• Firm	• Extensor pollicis longus • Abductor pollicis brevis	• 80 to 0/18 to 0

(continued)

Table 8-10 (continued)

Thumb Movements

Motion	Joint	Plane/Axis	Normal Limiting Factors (Tension In)	End Feel	Primary Muscles	Normative ROM/ Functional ROM (In Degrees)
Abduction	• CMC • MCP	• Sagittal/ frontal	• Fascia and skin of the first web space • First dorsal interosseous • Abductor pollicis longus	• Firm	• Abductor pollicis brevis • Abductor pollicis longus	• No norms
Adduction	• CMC • MCP	• Sagittal/ frontal	• Soft tissue apposition between the thumb and index finger	• Soft	• Adductor pollicis • Extensor pollicis longus • First dorsal interossei	• No norms
Opposition	• CMC • MCP	• Sagittal/ frontal			• Opponens pollicis • Flexor pollicis brevis • Abductor pollicis brevis • Flexor pollicis longus • Abductor pollicis longus	• No norms
Reposition	• CMC • MCP	• Sagittal/ frontal			• Extensor pollicis longus	• No norms

In prehensile manipulative pinch patterns, there is slight finger flexion and the thumb is palmarly abducted and opposed with the wrist in neutral deviation. The palm is not involved in precision patterns as it is in power grips. Movement occurs primarily at the MCP joints and the radial side of the hand, with the radial fingers providing control with the thumb (Magee, 2014). The extrinsic muscles provide compressive forces to hold the object and the interossei abduct and adduct the fingers. The lumbrical muscles help move the object from the palm of the hand (Kisner & Colby, 2012; Nordin & Frankel, 2012). Types of precision patterns, or pinches, include tip pinch, lateral pinch, pulp pinch, and palmar pinch.

Lateral pinch (also known as *key pinch*, *pad-to-side*, *subterminolateral opposition*, or *pulp pinch*) is used when a thin object is held in the hand, such as a card or a key. It is the least precise of the manipulative prehension patterns and is the finest grasp that can be accomplished without active hand musculature via tenodesis action (Levangie & Norkin, 2011). The object is grasped between the palmar surface of the thumb and the lateral side of the index finger (Provident & Houglum, 2012). The thumb is adducted with IP flexion, with the index finger flexed and abducted, which involves the flexor pollicis longus and brevis, adductor pollicis, flexor digitorum profundus and superficialis, as well as first dorsal interossei. There is more thumb adduction and less rotation than in the other types of pinches. The flexor pollicis brevis and adductor pollicis activity is greater than in the tip pinch, and there is less opponens pollicis activity.

Palmar pinch, also known as *subterminal opposition* or *pad-to-pad prehension*, occurs when the palmar surfaces of the distal phalanges contact the palmar surface of the thumb. The thumb is in opposition and slight flexion with the fingers in flexion at the MCP and PIP joints. This grip pattern can be seen in picking up and holding a coin between the thumb and fingers or even with larger objects. From a radial view, this grip pattern forms an oval. The muscles involved in this pinch pattern are the flexor pollicis longus, select interossei, and flexor digitorum superficialis of the involved fingers (flexor digitorum profundus in DIP flexion is also present). If the index and middle fingers meet the opposed thumb, this is called *three-jaw chuck*, *three-point chuck*, *three-fingered* or *digital prehension*, or the *dynamic tripod*, and can be considered a "precision grip with power" (Magee, 2014, p. 453). This type of grip pattern is seen when one holds a pencil.

Tip pinch (tip-to-tip) is described as the movement of the tip of the thumb against the tip of another finger to pick up a small object, such as a pin. From the radial side, the finger and thumb form a circle. As with palmar pinch, the thumb is in opposition with slightly greater flexion, and the fingers are flexed at the MCP, DIP, and PIP joints. The same muscles are involved in tip pinch as are in palmar pinch. Unlike palmar pinch, the IP joints of the finger and thumb need sufficient ROM and strength to nearly fully flex and the opposing finger must be ulnarly deviated. The activity of flexor digitorum profundus, flexor pollicis longus, and interosseous is required for tip pinch but not for palmar pinch (Levangie & Norkin, 2011). Tip pinch is also referred to as *terminal opposition*, and tip pinch is involved in activities requiring fine coordinated movement rather than power.

Pinch patterns develop in stages of prewriting development. A primitive pinch pattern seen in children aged 1 to 1.5 years old is the palmar supinate pattern in which an object is held with a fisted hand with the wrist slightly supinated and the arm moves as a unit. The digital-pronate grasp (2 to 3 years old) is considered a transitional grasp. The object is held with the fingers, while the wrist is neutral, and the forearm moves as a unit. At 3.5 to 4 years old, the static tripod posture develops with some approximation of thumb, index, and middle fingers. The hand moves as a unit. The dynamic tripod posture occurs in children 4.5 to 6 years old and there is precision opposition of distal phalanges of the thumb, index, and middle fingers. The wrist is slightly extended and the MCP joints are stabilized (Exner, 2005).

Table 8-11

Frequency of Use of Pinch Patterns

Pulp to pulp pinch (lateral)	20%
Three lateral pinch	20%
Five finger pinch	15%
Fist grip	15%
Cylindrical grip	14%
Three-fingered pinch	10%
Spherical grip	4%
Hook grip	2%

Adapted from McPhee, S. D. (1987). Functional hand evalutions: A review. *American Journal of Occupational Therapy, 41*(3), 158-163.

A study by Smith, Weiss, and Lehmkuhl (1996) shows the frequency of use of the three types of prehension patterns for picking up and holding objects. Palmar pinch is used 50% of the time to pick up objects and 88% of the time to hold objects for use. Lateral pinch was the second most frequently used prehension pattern for picking up and holding objects, with tip pinch used only 17% of the time to pick items up and 2% of the time to hold them for use. The dynamic tripod pinch pattern is used more commonly than tip or lateral pinch patterns for picking up and holding objects (Provident & Houglum, 2012).

The frequency of pinch patterns used in daily activities, such as buttoning, tying a shoelace, and tracing activities, found by McPhee (1987) is shown in Table 8-11. From these studies, it could be stated that different types of pinch are used to pick up and hold objects and that daily activities did not significantly indicate one pinch preference over another.

Other researchers disagree with the distinction of power and prehension, contending that hand function is far more complex than these descriptions portray and that these words limit descriptions of the hand to static positions (Bongers, Zaal, & Jeannerod, 2012). Cassanova and Gernert (1989) proposed a classification system based on the contact of the hand surfaces using anatomical terminology. The fingers would be designated by roman numerals (thumb = I, index = II, middle = III, ring = IV, and little = V), and contact areas would be noted as well (e.g., palmar, surface, or pad). Examples of the different pinch patterns are shown in Table 8-12.

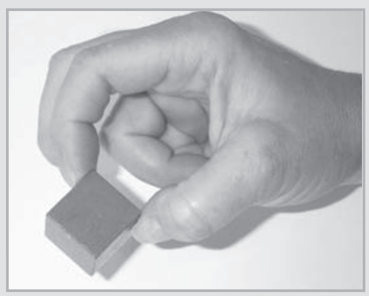
Table 8-12

EXAMPLES OF PINCH PATTERNS

LATERAL PINCH




TIP PINCH

PALMAR PINCH




A grasp taxonomy was developed by Feix, Romero, Schmiedmayer, Dollar, and Kragic (2015) that arranged grasp types identified in the literature into 33 unique prehensile grasp types based on the number of fingers in contact with the object and the position of the thumb. Grasp was further classified as *power, intermediate*, or *precision patterns*. By having a common language to describe prehension, this will be useful not only to clinicians but also to engineers designing robotic grasping systems (Feix et al., 2015). Liu, Feng, Nakamura, and Pollard (2014) identified 40 grasp types that could not be captured in existing taxonomies and developed a taxonomy that was not limited to grasps only but reincorporates nonprehensile manipulation tasks. In this taxonomy, grasp type, opposition type, thumb position, involvement of specific fingers, and shape and size of the hand were considered. Grasp type, like the Feix et al. taxonomy, can be power grip, precision grip, or intermediate (Liu et al., 2014).

Stability of the Hand

Many ligaments operate within the hand to provide stability and permit mobility. At the wrist, there is a concavity formed by the arched carpal bones that is spanned by the transverse carpal ligament (flexor retinaculum or anterior annular ligament creating the carpal tunnel). The flexor retinaculum covers the scaphoid, trapezium, pisiform, and hamate carpal bones. The tendons of the flexor digitorum profundus, flexor digitorum superficialis, flexor carpi radialis, flexor pollicis longus, and medial nerve run through this tunnel. The transverse carpal ligament restricts bowing of the long finger flexor tendons when the wrist is flexed, disallows abduction, protects the median nerve, and is the site of origin for thenar and hypothenar muscles (Gench et al., 1995; Muscolino, 2006; Provident & Houglum, 2012).

The proximal band of the transverse carpal ligament becomes taut when the flexor carpi ulnaris contracts and when the hand is held in an ulnarly flexed position. It is located at the distal skin crease of the wrist and forms the border on the palmar side of the carpal tunnel. The distal band is always taut, acts as a pulley for flexor tendons (Gench et al., 1995; Provident & Houglum, 2012), and holds down the extrinsic finger flexor muscles to prevent bowstringing of the tendons. The palmar plate supports the anterior MCP, DIP, and PIP joints. There are also five dense annular pulleys and three cruciform pulleys to allow for a smooth curve for tendon excursion.

The second connective structure in the palm is the heavy fibrous palmar aponeurosis (palmar fascia), a thick and deeply located continuation of the flexor retinaculum. It forms the ridges in the palm, which increases friction for firm grasp of objects. The palmaris longus inserts into the palmar aponeurosis. This tissue receives the insertion of the palmaris longus muscle, and it merges with the flexor retinaculum at its distal edge.

Firm collateral ligaments and a thick anterior capsule that is reinforced by the palmar fibrocartilaginous (volar) plate provide support as do the collateral ligaments at the MCP, PIP, and DIP joints. The collateral ligaments support the sides of the fingers and restrict varus and valgus forces. Additional support comes from the transverse intermetacarpal ligaments. The dorsal intercarpal ligaments keep the carpals together.

The extensor retinaculum (dorsal carpal ligament or posterior annular ligament) goes across the dorsal surface of the wrist and forms a roof for the extensor tendons. Fibers of the retinaculum insert on the pisiform and triquetrum on the ulnar side, and on the radial side, the retinaculum blends with flexor retinaculum. The extensor retinaculum holds the extensor muscle tendons in place and acts as a pulley mechanism for the extensor tendons. Each extensor tendon is surrounded by a synovial sheath, and these form into six compartments that contain the following:

1. First: Radial nerve, tunnel for abductor pollicis longus, extensor pollicis brevis
2. Second: Extensor carpi radialis longus, extensor carpi radialis brevis
3. Third: Extensor pollicis longus
4. Fourth: Extensor indicis, extensor digitorum
5. Fifth: Extensor digiti minimi
6. Sixth: Extensor carpi ulnaris

A helpful way to remember the contents in each dorsal compartment is to remember the numbers 22, 12, and 11, which correspond to the numbers of tendons in each compartment (i.e., two muscles in the first compartment and two in the second = 22; one muscle in the third compartment and two in the fourth = 12; one muscle in the fifth and one in the sixth compartment = 11; Fess, Gettle, Philips, & Janson, 2005).

Internal Kinetics: Muscles

Muscles of the hand are often divided into intrinsic (originating within the hand) and extrinsic (originating outside of the hand). Extrinsic muscles can be divided into those muscles that flex the digits (flexor digitorum superficialis, flexor digitorum profundus, and flexor pollicis longus); that extend the digits (extensor digitorum communis, extensor indicis, and extensor digiti minimi); and extensors of the thumb (extensor pollicis longus, extensor pollicis brevis, and abductor pollicis longus). The actions of the extrinsic muscles are influenced by the position of the wrist.

Intrinsic muscles can be organized into those muscles acting on the thenar eminence (abductor pollicis brevis, flexor pollicis brevis, and opponens pollicis); those influencing the hypothenar eminence (abductor digiti minimi, flexor digiti minimi, opponens digiti minimi, and palmaris longus); adductor pollicis; four lumbricals; and palmar and dorsal interossei.

An acronym for remembering the intrinsic muscles is "A of A of A," which stands for A: abductor pollicis brevis, O: opponens pollicis, F: flexor pollicis brevis, A: adductor pollicis, O: opponens digiti minimi, F: flexor digiti minimi brevis, and A: abductor digiti minimi. Another mnemonic would be All For One, And One For All (A: abductor pollicis brevis, F: flexor pollicis brevis, O: opponens pollicis, A: adductor pollicis, O: opponens digiti minimi, F: flexor digiti minimi, A: abductor digiti minimi). Intrinsic muscles are influenced by different positions of the MCP, PIP, and DIP joints rather than changes in wrist position (Flinn & DeMott, 2010), so just remember to include the interossei and lumbricals with the acronyms. For

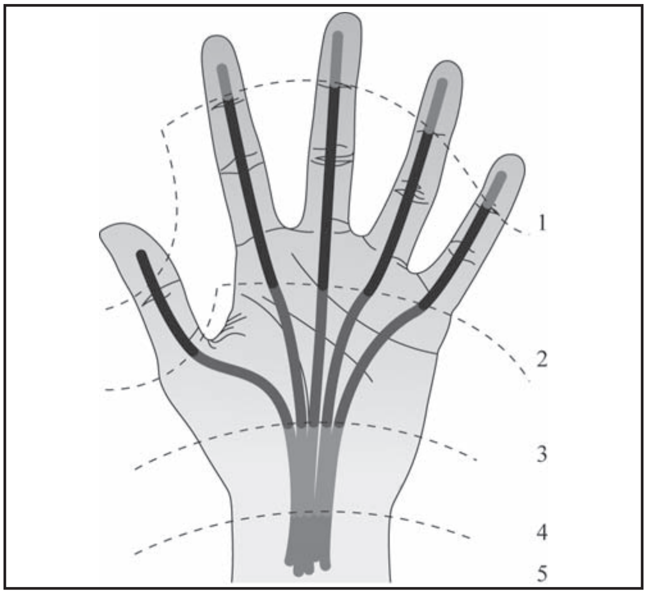


Figure 8-9. Flexor zones of the hand.

precision movements of the hand, cooperation between the intrinsic and extrinsic muscles is necessary.

Because the hand is capable of such diverse movements, there is much intricacy in the relationships of the many muscles involved. The finger muscles have effects on the wrist and moment arms as long as those of the wrist (Greene & Roberts, 1999). The finger muscles would move both the wrist and joints of the fingers if they were not stabilized. For example, the finger flexors are multijoint muscles, and without stabilization at the wrist, these flexors would flex each of the joints they cross. By doing this, the fingers would be unable to fully flex due to active insufficiency of the flexors because they cannot fully flex at each of the joints they cross. This inability to fully flex all of the joints crossed by the finger flexors is actually a combination of insufficient excursion and insufficient strength capability.

The insufficient strength production is due to poor length-tension relationships that limit the amount of force that can be produced. By flexing all of the joints, the flexors are attempting to produce strength in a shortened position at the lower end of the length-tension curve.

Excursion refers to the distance that each tendon slides as the fingers move. Excursion takes place simultaneously in flexor and extensor tendons, and this is an important concept in determining muscle forces, fabricating splints, and in rehabilitation as well as in surgical procedures. Measurement of tendon excursion is in relation to angular motion. Nordin and Frankel (2012) state that "when a lever rotates around an axis of an angle, the distance moved by every point on the lever is proportional to its own distance from the axis" and that "every point on the lever moves through a distance equal to its own distance from the axis—its moment arm" (p. 285). Given this, the moment arms and the excursion are larger in muscles that are more proximally located. For example, the flexor superficialis has a longer tendon excursion than does the flexor profundus. The excursion of the flexor tendons is larger than the extensors, and the excursion of the extrinsic muscles is generally larger than the intrinsic muscles.

When the finger flexors attempt to flex fully over all of the joints they cross, there is insufficient excursion of the flexor muscles. This insufficiency explains tenodesis grasp where passive tension yields finger extension and forces the fingers to release an object. Wrist extension stretches the flexor digitorum profundus, producing finger flexion. Passive tension, not contraction, produces the finger movement. The same is true for the passive insufficiency that develops when the wrist is flexed, and passive tension develops to produce finger extension.

There also exists a relationship between adduction and abduction with flexion and extension. In abduction and adduction with the MCP joints extended, the movements are free because the collateral ligaments are loose. When there is flexion at the MCP joint, the fingers automatically adduct, which limits the range of abduction because the collateral ligaments become tight. There is a natural tendency to abduct the fingers when they are also extended. Another combined action that occurs is that, when the fingers flex, the hand is cupped, and the hand is flattened when the fingers extend.

Synergistic relationships exist between the muscles of the wrist and the finger muscles. For example, when the little finger is abducted by means of the abductor digiti minimi, the flexor carpi ulnaris contracts to provide countertraction on the pisiform. To prevent the flexor carpi ulnaris from abducting the wrist in an ulnar direction, the abductor pollicis longus contracts.

Synergistic actions occur in the thumb as well. When the thumb is moved in a palmar direction as in flexion, the palmaris longus contributes to the movement by tensing the fascia of the palm, while the extensor carpi radialis brevis contracts to prevent the palmaris longus from flexing the wrist. Another example is the thumb extension. The extensor carpi ulnaris contracts to prevent radial deviation of the wrist by the abductor pollicis longus muscle.

Flexors of the Fingers

On the volar surface of the hand, there are five flexor tendon zones, as shown in Figure 8-9. The first zone is distal to the insertion of the flexor digitorum superficialis tendon located halfway between the PIP and DIP crease. This zone is not affected by the excursion of the flexor tendons once they enter the hand (Flinn & DeMott, 2010). The second zone is between the A1 pulley and the insertion of the flexor digitorum superficialis tendon near the distal palmar crease to the middle of the third phalanx. This zone includes the flexor pollicis longus and median nerve. If there is pain with passive extension of the digit, this may suggest flexor tendon sheath infection (Flinn & DeMott, 2010). In zones one and two, the tendons are protected in sheaths, and the annular and cruciate pulleys provide smooth gliding surfaces. Zone three is between the flexor retinaculum and A1 pulley. In this zone, the lumbrical muscle originates from the flexor digitorum profundus, and the lubricating sheath does not protect the flexor tendons to the fingers in this zone, making them prone to adhesions when injured (Flinn & DeMott, 2010). Zone four is located within the carpal tunnel. Zone five is proximal to the flexor retinaculum. An area encompassing much of the length of the flexor tendons is known as *no man's land* due to poor healing

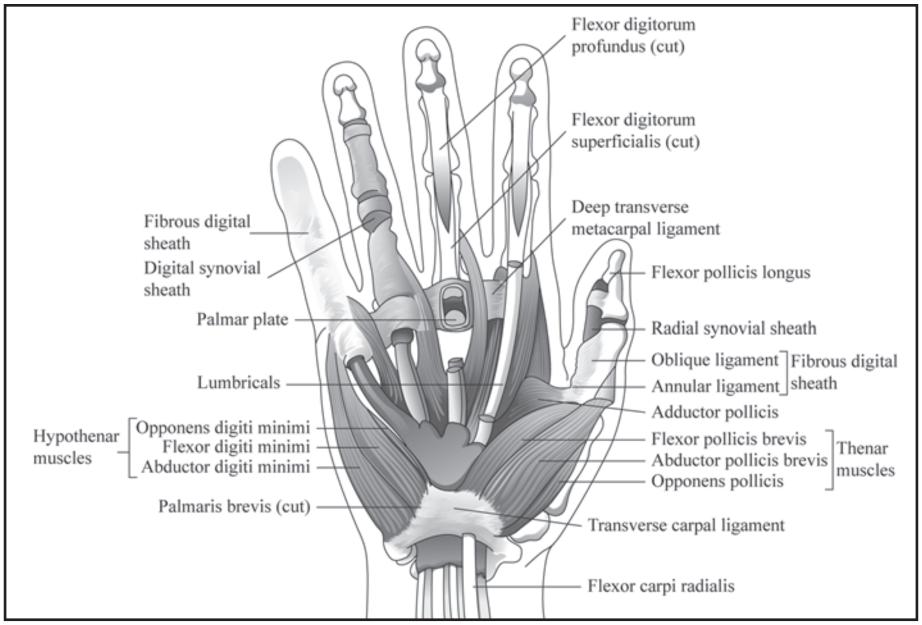


Figure 8-10. Extrinsic flexor muscles of the hand.

of tendons, precarious blood supply, and easy rupture of joint structures (Oatis, 2004).

The anterior compartment of the forearm contains the flexor-pronator group of muscles, which arise from a common flexor attachment on the medial epicondyle of the humerus. There are eight muscles in this anterior compartment, and three of these flex the digits: the flexor digitorum profundus, flexor digitorum superficialis (sublimis), and flexor pollicis longus. The flexor pollicis longus is located deep and lateral to the flexor digitorum profundus and is the sole flexor at the IP joint of the thumb.

The flexor digitorum superficialis is deep to the three wrist flexors and pronator teres. The flexor digitorum superficialis tendon splits into four tendons and passes under the flexor retinaculum in the palm of the hand. At the base of the first phalange, each tendon divides into two slips to allow passage of the flexor digitorum profundus tendon. Three-quarters of the superficialis fibers continue to the middle phalanx to insert, and one-quarter of the fibers cross under the flexor digitorum profundus to insert into the proximal phalange. While the flexor digitorum superficialis primarily flexes the PIP joint, it can also flexion all of the joints it crosses.

The flexor digitorum profundus is deep to the flexor digitorum superficialis. Once in the hand, the tendon inserts into the base of the distal phalanges of the digits after passing through the openings in the flexor digitorum superficialis tendons just opposite to the first phalange. The flexor digitorum profundus is the only flexor of the DIP joint but can assist in flexion of every joint it crosses. The flexor digitorum profundus of the index finger is relatively independent of the other profundus tendons. An example of the interconnectedness of the other finger flexor digitorum profundus tendons can be seen when all joints are extended, and you attempt to actively flex only the DIP joint of the ring finger. Isolated DIP flexion is difficult due to excessive elongation of the muscle belly of the flexor digitorum profundus due to extension of the middle finger (Neumann, 2002, p. 215).

Distal to the carpal tunnel is the ulnar synovial sheath, which surrounds the flexor digitorum superficialis and flexor digitorum profundus. The radial synovial sheath is in contact with the flexor pollicis longus. The flexor tendons are restrained by tendon sheaths and the retinaculum that keep the tendons close to the bones and planes of motion, while maintaining a relatively constant moment arm rather than producing bowstringing of the tendons. There are five dense annular pulleys and three thinner cruciform pulleys that allow for smooth curves and no sharp bends in the tendon excursions (Neumann, 2002; Nordin & Frankel, 2012).

Flexion of the DIP joint produces flexion of the PIP joint because flexion of the DIP is produced by the flexor digitorum profundus with a simultaneous flexor force produced by the muscle as it crosses the PIP. When the DIP joint begins flexing, the terminal tendon and lateral bands stretch over the dorsal aspect of the DIP, which pulls the extensor hood (from which the lateral bands arise) distally. This causes the central tendon of the extensor expansion to relax, creating a flexor force at the PIP joint. Active (flexor digitorum profundus) and passive forces (release of the central tendon) occur when the lateral bands migrate volarly (Levangie & Norkin, 2011). The coupling of the flexor action at the DIP and PIP joint can be overridden, as some people can actively flex the DIP while the PIP extends. To achieve full flexion of all joints, the long finger flexors must override the extension components of the lumbricals and interossei, which is easier if in some wrist extension (Figure 8-10; Hamill et al., 2015).

Intrinsic finger flexors include the flexor digiti minimi brevis, abductor digiti minimi, opponens digiti minimi, palmar and dorsal interossei, and lumbricals.

Flexor Digitorum Superficialis

The largest of the flexor muscles of the forearm, the flexor digitorum superficialis muscle crosses the wrist, MCP, and PIP joints anterior to the flexion-extension axis, so this muscle flexes these joints and assists with extension at the wrist. The flexor digitorum superficialis is capable of flexing each finger individually at the proximal, but not distal, IP joints.

In its location underneath the flexor carpi radialis and palmaris longus, it is difficult to palpate at the more proximal location because the attachment is widespread. Movement of the tendon can be seen and palpated on the palmar surface of the wrist in the space between the flexor carpi radialis and flexor carpi ulnaris tendons as the fingers flex to make a firm fist with the wrist flexed (Gench et al., 1995; Provident & Houglum, 2012). The flexor digitorum superficialis and profundus are used when picking up small objects, playing a guitar, tying shoelaces, and buttoning a shirt (Biel, 2016).

Flexor Digitorum Profundus

Due to the line of pull to the palmar side of the flexion-extension axis, the muscle acts in flexion of the PIP, DIP, MCP, and, finally, at the wrist, with the strength of the contraction lessening progressively. This is because the muscle gradually shortens and can therefore contribute only weakly to wrist flexion. There is a single muscle belly, so contraction of the muscle causes movements in all fingers simultaneously. As an example, flex the long finger; notice that the ring finger also moves, as would the index and small fingers if not for the neutralizing effects of the extensor indicis and extensor digiti minimi. Weakness in the flexor digitorum profundus muscle would result in decreased strength of DIP flexion, which would affect grasp and pinch.

The flexor digitorum profundus lies deep and is covered by the flexor digitorum superficialis, flexor carpi radialis, flexor carpi ulnaris, palmaris longus, and pronator teres. A contracting muscle belly can be palpated if tension is minimal in the more superficial muscles. Have the subject supinate the forearm and rest the hand in the lap while the wrist is extended by weight of the hand. Have the subject close the fist fully, and the profundus may be felt under the fingers in the region between the pronator teres and flexor carpi ulnaris about 2 inches (5 cm) below the medial epicondyle of the humerus (Gench et al., 1995; Provident & Houglum, 2012).

Flexor Digitorum Profundus and Flexor Digitorum Superficialis

The flexor digitorum profundus is more active than the flexor digitorum superficialis in finger flexion. The flexor digitorum superficialis works alone in finger flexion only when flexion of the DIP joint is not required. When simultaneous PIP and DIP flexion is required, the flexor digitorum superficialis acts as reserve, joining the flexor digitorum profundus when greater force is needed or when finger flexion with wrist flexion is required (Provident & Houglum, 2012).

The flexor digitorum profundus and flexor digitorum superficialis are dependent on wrist position for an optimal length-tension relationship. Finger flexor effectiveness would be reduced by 25% without the counterbalancing effect of the extensor muscles (extensor carpi radialis brevis or extensor digitorum) because wrist flexion would occur, reducing tension at the more distal joints. The wrist extensors also serve to stabilize the wrist as well as provide optimal length-tension relationships for these long finger flexors.

Flexor Digiti Minimi Brevis

This muscle lies parallel to and on the radial side of the abductor digiti minimi. While superficially located, it is easily confused with the abductor digiti minimi. Crossing on the palmar side of the flexion-extension axis, the flexor digiti minimi brevis flexes the fifth MCP joint.

Opponens Digiti Minimi/ Opponens Digiti Quinti

The proximal fibers of the opponens digiti minimi flex the fifth CMC joint while the distal fibers adduct it. This combination of flexion and adduction produces opposition if both contract simultaneously, actually drawing the fifth metacarpal forward, which deepens the hollow of the hand (Gench et al., 1995; Provident & Houglum, 2012). This muscle lies beneath the abductor digiti minimi and flexor digiti minimi brevis in hypothenar eminence, so it is not palpable.

Palmar Interossei

Although somewhat farther from the flexion-extension axis than are the dorsal interossei, the palmar interossei are more effective as flexors. Both the lumbricals and palmar interossei are located on the palmar side of the flexion-extension axis, and so mechanically are capable of flexion, with the lumbricals more favorably located. The role of the interossei in flexion and adduction at the MCP joint is thought to be from passive stretch (Provident & Houglum, 2012). The three palmar interossei are located deep in the palm beneath the lumbricals and dorsal interossei, so these are very difficult muscles to palpate (Gench et al., 1995; Provident & Houglum, 2012).

Dorsal Interossei

These four muscles lie between the metacarpals but are very difficult to palpate, except for the first dorsal interossei. The dorsal interossei serve to flex the MCP joints of the second, third, and fourth digits (Gench et al., 1995).

Lumbricals

The four lumbricals are not active in MCP flexion unless the IP joints are extended. The lumbricals do not participate in grip and rarely contract synchronously with the flexor digitorum profundus (Provident & Houglum, 2012). These muscles may be palpated on the radial side of the long finger flexors and are best visible in the claw hand position of MCP hyperextension and IP flexion (Biel, 2016; Provident & Houglum, 2012).

Abductor Digiti Minimi

Located superficially on the ulnar border of the hypothenar eminence, this muscle is closer to the flexion-extension axis than to the abduction-adduction axis, so the abductor digiti minimi is primarily an abductor, with a secondary role as a flexor of the PIP joint when the long extensor is relaxed. The abductor digiti minimi can be palpated next to the fifth metacarpal during resisted abduction of the small finger (Gench et al., 1995).

Flexors of the Thumb

Flexors of the thumb include the flexor pollicis longus, flexor pollicis brevis, abductor pollicis brevis, adductor pollicis, and dorsal interossei.

Flexor Pollicis Longus

The most radial of the tendons of the carpal tunnel, the flexor pollicis longus crosses the IP and MCP joints of the thumb to the palmar side of the flexion-extension axis and acts as a flexor of the IP joint. The flexor pollicis longus also crosses to the ulnar side of the CMC flexion-extension axis, so this muscle also flexes the CMC joint but is not credited with wrist motion because the muscle lies too close to both wrist axes (Gench et al., 1995).

Flexor Pollicis Brevis

The flexor pollicis brevis is a strap-like muscle with long parallel fibers with two heads. The deep head crosses only the MCP joint on the ulnar side and serves to adduct the MCP joint; the superficial head crosses the MCP and CMC joints. At the CMC joint, the flexor pollicis brevis crosses on the palmar side of the flexion-extension axis and is a flexor of the MCP and CMC joints. There is not always a clear distinction between the flexor pollicis brevis and opponens pollicis because the muscles become continuous on the ulnar side and both muscles flex the metacarpals on the carpals. Interestingly, the superficial portion is innervated by the median nerve, whereas the deep portion is innervated by the ulnar nerve.

Abductor Pollicis Brevis

The abductor pollicis brevis lies to the palmar side of the flexion-extension axis and assists with flexion and abduction of the MCP joint of the thumb (Gench et al., 1995). Weakness of the abductor pollicis brevis occurs with medial nerve palsy, and there can be atrophy of the muscle belly, resulting in flattening of the thenar eminence (Oatis, 2004). This is the most superficial muscle of the thenar eminence, so it can be palpated in the center of the eminence during resisted abduction of the CMC joint of the thumb.

Adductor Pollicis

Called the *pinching muscle* by Brand and Hollister (1999), the adductor pollicis is a fan-shaped penniform muscle favorably located on the palmar side of the flexion-extension axis to flex the first CMC joint (Gench et al., 1995). Even though the muscle is deep in the palm, the adductor pollicis can be palpated between the first and second metacarpal on the palmar surface of the thumb between the MCP and IP joints as the thumb presses against the tip of the index finger. Alternatively, you can ask the subject to hold a piece of paper between the thumb and radial aspect of the proximal phalanx of the index finger (Gench et al., 1995; Provident & Houglum, 2012).

Opponens Pollicis

Triangular in shape, the upper portion of the opponens pollicis flexes the CMC joint while the lower portion abducts it, so the muscle acts to oppose the CMC joint of the thumb. The opponens pollicis usually works with the abductor pollicis brevis and flexor pollicis brevis. When the injury is to the opponens pollicis muscle, the hand has difficulty positioning and stabilizing the CMC joint of the thumb during grasp and pinch (Oatis, 2004).

The opponens pollicis is located beneath the abductor pollicis brevis and is superficial along the radial border of the thenar eminence next to the first metacarpal and can be palpated when the thumb is pressed firmly against the tip of the long finger (Gench et al., 1995).

Dorsal Interossei

While normally considered a muscle acting on the index finger, the first dorsal interossei is important in stabilization of the thumb CMC joint. The first dorsal interossei pulls ulnarly and distally against the forces of the adductor and flexors that push the metacarpal base dorsally and radially (Brand & Hollister, 1999). Weakness in the dorsal interossei can lead to a claw hand deformity and loss of pinch and grasp (Oatis, 2004). The first dorsal interossei can be palpated in the space between the metacarpal bones of the thumb and index finger when resistance is applied to abduction of the index finger (Biel, 2016; Gench et al., 1995).

Extensors of the Fingers

The finger flexors follow a well-defined sheath toward a discrete attachment with pulleys to provide smooth movement. The finger extensor tendons do not have a defined sheath or pulley system. There are six separate compartments that describe the extensor tendons on the dorsum of the hand and five that identify the tendons of the thumb, shown in Figure 8-11. The first compartment contains the abductor pollicis longus and extensor pollicis brevis, and inflammation in this compartment can result in de Quervain's syndrome. The second compartment contains the extensors carpi radialis longus and brevis; the third compartment contains the extensor pollicis longus; the extensor digitorum indicis and extensor digitorum communis are within the fourth compartment; the extensor digiti minimi is in the fifth; and the extensor carpi ulnaris is in the sixth. If there is limited excursion of the extensor carpi ulnaris tendon in the sixth compartment, this might suggest possible radioulnar joint dysfunction (Flinn & DeMott, 2010).

Tendons of the extensor digitorum, extensor indicus, and extensor digiti minimi cross the wrist in synovial-lined sheaths in the extensor retinaculum. Distal to the extensor retinaculum, the extensor digitorum is often interconnected by several juncturae tendinae that stabilize the tendons. The extensor indicis and extensor digitorum usually travel in parallel.

Instead of having well-defined sheaths as the flexor tendons, the extensor tendons continue as a fibrous expansion along the length of each finger, and this is the extensor apparatus (also called the *extensor hood, extensor expansion, extensor mechanism, dorsal aponeurosis*, or *dorsal finger apparatus*). This moveable hood is in motion during flexion and extension. It begins on the dorsal, medial, and lateral sides of the proximal phalange of each finger and attaches to the dorsal side of the middle and distal phalanges. The extensor mechanism serves as a primarily distal attachment for the extensor digitorum (communis) muscle and several intrinsic hand muscles (lumbricals, palmar interossei, dorsal interossei, and abductor digiti

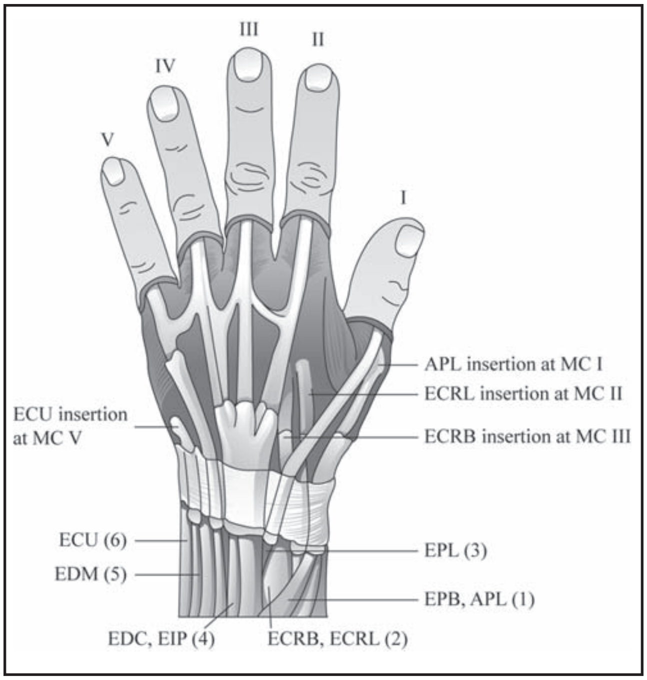


Figure 8-11. Extensor compartments of the hand. Compartment 1: EPB (extensor pollicis brevis) and APL (abductor pollicis longus). Compartment 2: ECRB (extensor carpi radialis brevis) and ECRL (extensor carpi radialis longus). Compartment 3: EPL (extensor pollicis longus). Compartment 4: EDC (extensor digitorum communis) and EIP (extensor indicis proprius). Compartment 5: EDM (extensor digiti minimi). Compartment 6: ECU (extensor carpi ulnaris).

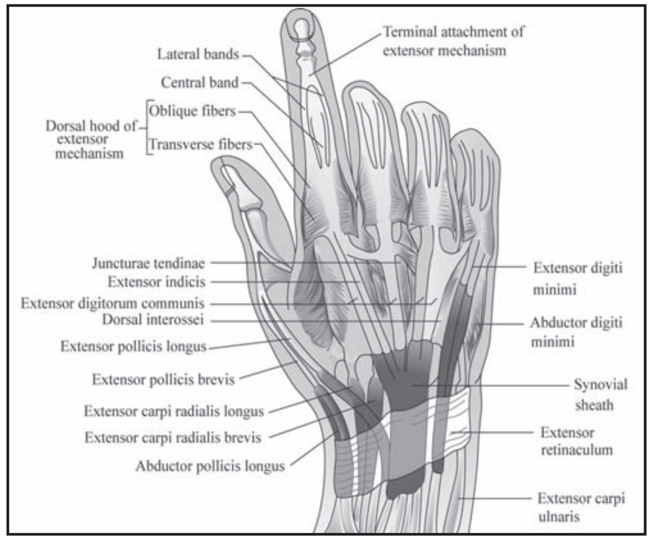


Figure 8-12. Extensor mechanism.

minimi). There is a similar mechanism for the thumb, which is formed by the distal tendon of the extensor pollicis longus muscle.

The extensor mechanism is made up of the extensor digitorum, connective tissue, and expansion fibers from the dorsal interossei, volar interossei, and lumbricals (Figure 8-12). The extensor digitorum tendons pass through the first dorsal compartment with the extensor indicis.

At the proximal phalanx, each tendon divides into three components. One portion, the central slip, inserts into the dorsum of the proximal end of the middle phalange. This central slip acts to extend the proximal phalange and to stabilize the proximal finger joint so that the lumbricals and interossei can extend the DIP and PIP joints and laterally move the digit. Two lateral bands pass on either side of the central tendon, cross the proximal phalange, reunite as a single terminal tendon on the distal phalange, then unite with the lumbricals and interossei. The fascia extends laterally from the extensor tendon that forms a hood that encircles the intrinsics (interossei and lumbricals).

If only the PIP joint is flexed, the entire trifurcated extensor assembly is pulled distally following the central slip, which is taut while a distal pull occurs at the middle phalanx. The lateral bands are slack. This creates a tension force at the PIP joint, so flexion of this joint is unavoidable. If the DIP is actively flexed, the entire assembly is displaced distally as the central slip relaxes, creating increased tension on the retinacular ligaments. This creates a flexion force at the PIP joint that is important in grasp and pinch (Nordin & Frankel, 2012). In addition, simultaneous flexion of the MCP, PIP, and DIP joints forces the extensor digitorum to stretch to its fullest. Full flexion of the wrist can only occur if fingers are allowed to uncurl.

As the extensor digitorum passes dorsally to the MCP joint, the contraction of the muscle creates tension on the extensor hood, which is pulled proximally over this joint and acts to extend the proximal phalange. The intrinsics pass volar/anterior to the MCP joint axis, so a flexor force is created. When all muscles contract simultaneously, the MCP joint will generally extend because the extensor digitorum generates greater torque (Levangie & Norkin, 2011).

The extensor digitorum, interossei, and lumbricals produce extensor forces on the PIP joint due to their attachments on the extensor hood. The extensor digitorum alone cannot produce sufficient tension in either the central slip or lateral bands to overcome the passive forces of the flexor digitorum profundus and superficialis. When the extensor digitorum contracts, the forces are distributed along all three phalanges of each finger. If the extensor digitorum contracts unopposed, a claw hand position will result (MCP hyperextension and IP flexion) due to the passive pull of the extrinsic flexor tendons (Levangie & Norkin, 2011). The intrinsics (interossei and lumbricals) act as moderators between flexion and extension forces, and the lumbricals are said to have a counter-clawing bias (Nordin & Frankel, 2012).

The influence of the extensor mechanism on DIP and PIP extension is interdependent (i.e., when the PIP joint is actively extended, the DIP joint also extends because of the combined active and passive forces applied to the lateral bands and terminal tendon; Levangie & Norkin, 2011). Extension of the IP joints can occur only if there is tension at the extensor digitorum because this forms a firm base for the interossei and lumbricals to execute their pull (Gench et al., 1995).

The extensors of the fingers include the extensor digitorum, extensor digiti minimi, extensor indicis, lumbricals, and interossei, as shown in Figure 8-13.

Extensor Digitorum/ Extensor Digitorum Communis

A fusiform muscle on the dorsal surface of the forearm, the extensor digitorum extends the MCP and proximal and distal IP joints of the four fingers and, if contraction continues, can extend the wrist. The extension of the IP joints occurs due to the attachment on the extensor hood. Several different sources cite how the function of the extensor digitorum can be used in self-defense maneuvers. Because it is not possible to simultaneously and fully flex the wrist and the IP and MCP joints, by forcing the wrist into flexion, a villain will be forced to loosen the grip on any weapon (Gench et al., 1995; Greene & Roberts, 1999; Levangie & Norkin, 2011; Provident & Houglum, 2012). Trauma (e.g., tendon lacerations) to the extensor digitorum may result in weakness or loss of extension of the MCP joints of the fingers. If the extensor digitorum is tight, this would limit full flexion ROM of the fingers, and extension of the MCP joint would be accompanied by flexion of the IP joint due to the pull of the extensor digitorum and antagonist pull of flexor digitorum profundus (Oatis, 2004).

The extensor digitorum can be palpated except where it is covered by the extensor carpi radialis longus. The four tendons can be easily seen and palpated as they cross the second through fifth metacarpal joints and are especially prominent when the MCP joint is fully extended (Gench et al., 1995) or when one finger is extended while the others are flexed into the palm (Provident & Houglum, 2012). When playing the piano or a trumpet, or releasing a handshake, the extensor digitorum muscle is being activated (Biel, 2016).

Interossei

The dorsal and palmar interossei extend the IP joints of the index, long, and ring fingers by their attachments to the extensor hood.

Lumbricals

The lumbricals extend the IP joints of the index, long, and ring fingers by their attachments to the extensor hood. The lumbricals have better leverage for extension than do the interossei (Provident & Houglum, 2012). Some authors indicate that the function of the lumbricals is to pull the flexor digitorum profundus tendon distally to decrease passive tension and, therefore, facilitate extension by the extensor digitorum. Other researchers indicate that the prevention of hyperextension of the MCP joint by the extensor digitorum contractions is an additional function of these muscles (Levangie & Norkin, 2011; Nordin & Frankel, 2012; Provident & Houglum, 2012). Of special note, the lumbricals have a high rate of variability with a low number of muscle fibers per motor unit, indicative of a skilled muscle with a high number of spindles. The lumbricals are richly innervated, and it has been hypothesized that the lumbricals may have a specialized proprioceptive function.

The line of pull of the interossei and lumbricals is dorsal to the joint centers of the IP joints, so these muscles are mechanically capable of extension. While the intrinsics are called the *primary extensors of IP joints*, this is not always true. In unresisted extension, the long extensor and lumbricals only are active. The interossei are not active unless there is forceful or resisted extension.

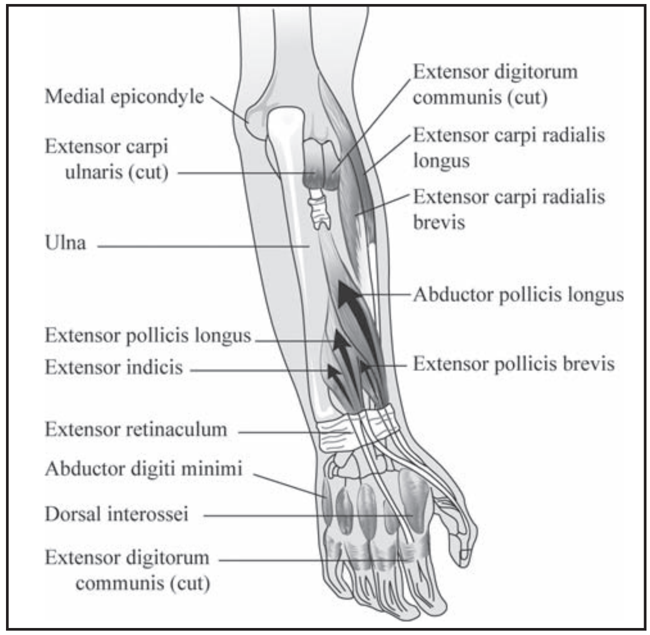


Figure 8-13. Muscles that extend the fingers.

Extensor Digiti Minimi/ Extensor Digiti Quinti Proprius

A slender muscle, the extensor digiti minimi is located to the ulnar side of the extensor digitorum and acts to extend and abduct the IP joints of the little finger due to the attachment in the extensor hood. The extensor digiti minimi also extends the fifth MCP joint and, with continued contractions, contributes to wrist extension. Weakness or injury to the extensor digiti minimi would result in the inability to extend the little finger of the MCP joint independently (Oatis, 2004). The extensor digiti minimi is superficially located slightly proximal to the wrist and can be palpated and observed on the dorsum of the hand at the fifth metacarpal when the small finger is extended against resistance (Gench et al., 1995).

Extensor Indicus/ Extensor Indicis Proprius

The extensor indicis extends the MCP joint of the index finger and, with the connection to the extensor hood, extends the PIP and DIP joints. With continued contraction, the extensor indicus can contribute to extension of the wrist. If the MCP joint is held in flexion, the ability to extend the IP joint and the wrist is improved. Because the extensor indicus inserts on the extensor digitorum tendons of the first and fourth fingers, this adds independence of action to these fingers rather than strength or additional actions (Levangie & Norkin, 2011). This muscle is superficial and runs on the ulnar side and parallel to the extensor digitorum on the dorsal aspect. It can be seen when one extends the index finger with the other fingers flexed into the palm (Gench et al., 1995; Provident & Houglum, 2012).

Extensors of the Thumb

The abductor pollicis longus, extensor pollicis longus, and extensor pollicis brevis extend the thumb.

Abductor Pollicis Longus

Because the abductor pollicis longus inserts on the radial side of the MCP joint, it acts to pull the thumb into extension at the CMC joint in addition to its actions of abduction of the CMC and radial deviation and flexion of the wrist. The thumb cannot function without the abductor pollicis longus muscle, as is seen in de Quervain's disease (Brand & Hollister, 1999).

Extensor Pollicis Longus

The extensor pollicis longus has its own compartment in the retinaculum on the dorsum of the wrist and is located dorsal to the flexion-extension axis, so it extends both the IP and MCP joints of the thumb. Weakness in the extensor pollicis longus muscle would result in weak extension at the IP joint of the thumb. Tightness is often seen with the flexor pollicis longus, resulting in weakness of the intrinsic muscles of the thumb (Oatis, 2004). The muscle belly is difficult to palpate, but the tendon can be palpated when the thumb is fully extended (Gench et al., 1995; Provident & Houglum, 2012).

Extensor Pollicis Brevis

This muscle extends the MCP and CMC joints of the thumb. At the wrist, the tendon passes posterior to the flexion-extension axis and to the radial side of the deviation axis, so the extensor pollicis brevis extends and radially deviates the wrist. At the CMC joint, it passes on the radial side of the flexion-extension axis, so it extends this joint. At the MCP and IP joints, the extensor pollicis brevis is dorsal to the flexion-extension axis, so it extends these joints. The extensor pollicis brevis is closely associated with abductor pollicis brevis with similar actions at the wrist and CMC joints, and its primary action is extension of the MCP joint. Weakness in the extensor pollicis brevis would result in decreased MCP and CMC extension of the thumb (Oatis, 2004).

The extensor pollicis brevis is different from extensor pollicis longus in three ways (Burstein & Wright, 1994):

1. The tendon of the extensor pollicis longus crosses the wrist posterior to the flexion-extension axis to become a wrist extensor; the tendon of the extensor pollicis brevis crosses directly over the axis and is ineffective as an adductor or abductor.
2. The tendon of the extensor pollicis longus passes dorsal to the adduction-abduction axis of the CMC joint to act as an adductor; the tendon of the extensor pollicis brevis crosses directly over and is ineffective as an abductor or adductor of the CMC joint.
3. The extensor pollicis brevis does not cross the IP joint of the thumb as does the extensor pollicis longus, so the extensor pollicis brevis has no action at that joint.

This muscle can be palpated beneath and to the radial side of the extensor pollicis longus. The extensor pollicis brevis tendon is superficial as it crosses the wrist and can be seen during forced extension of the thumb. The extensor pollicis brevis and extensor pollicis longus form the medial and lateral borders of the anatomical snuff box (Gench et al., 1995; Provident & Houglum, 2012).

Abductors of the Fingers

Abductor Digiti Minimi

This muscle abducts and flexes the MCP joint of the little finger. The muscle's line of pull is more favorably placed for abduction than for flexion because the muscle is further from the adduction-abduction axis than from the flexion-extension axis, so this is primarily an abductor with secondary flexion action (Gench et al., 1995; Provident & Houglum, 2012).

Dorsal Interossei

The dorsal interossei have relatively long force arms, so they act to abduct the second through fourth MCP joints in addition to radial and ulnar deviation of the third metacarpal joint (Gench et al., 1995; Provident & Houglum, 2012).

Extensor Digiti Minimi/ Extensor Digiti Quinti Proprius

This muscle extends the MCP and IP joints as well as abducts the little finger.

Abductors of the Thumb

Abductor Pollicis Brevis

While small and weak in size and tension, this muscle is considered by Brand and Hollister (1999) to be important for opposition and, therefore, in grasp and pinch. The opponens pollicis is located underneath the abductor pollicis brevis, so when the opponens pollicis contracts, it pushes the abductor pollicis brevis farther from the axis of the CMC joint and increases the moment arm and its effectiveness (Brand & Hollister, 1999). Because this is a fan-shaped muscle, different fibers contribute differently to the muscle action; the most radial portions are abductors of the CMC joint; the most distal are adjacent to the flexor pollicis brevis and so are flexor-abductors of the MCP joint. The strength of the abductor pollicis brevis is relatively weak because the action of abduction of the thumb is not one usually done against resistance, and this demonstrates that the primary function of this muscle is to position the thumb for action rather than perform the action itself. In action, it is the extensor pollicis longus muscle that most directly opposes the abductor pollicis brevis, not the adductors.

Abductor Pollicis Longus

A stout muscle, the abductor pollicis longus abducts and extends the MCP joint and stabilizes the first metacarpal joint. Because the muscle spirals from the dorsal radius to the lateral aspect of the first metacarpals, fibers are variable in length and moment arms vary. The name of this muscle does not reflect the true action. The tendon pulls the thumb laterally or radially, which is abduction in body terms but not in terms of the thumb. The muscle pulls on the back or extends the thumb, so it extends the thumb and abducts it. Stronger than the flexor pollicis longus, the abductor pollicis longus works to oppose the adductor and short flexor at the CMC joint and allows them to flex the MCP joint (Brand & Hollister, 1999).

Opponens Pollicis

The lower portion of this muscle abducts the CMC joint of the thumb. With the upper portion, which flexes the CMC, this muscle is capable of opposition. There is considerable variation in fiber length, and it is capable of producing greater tension than the abductor pollicis brevis. The action of the opponens pollicis is swinging the thumb in an arch toward the fingers (Gench et al., 1995; Hinkle, 1997; Jenkins, 1998; Nordin & Frankel, 2012; Provident & Houglum, 2012; Riley, 1998).

Adductors of the Fingers

Adduction of the fingers is achieved by contraction of the opponens digiti minimi, extensor indicis, and palmar interossei.

Opponens Digiti Minimi/ Opponens Digiti Quinti

While the proximal fibers flex the CMC joint of the fifth joint, the distal fibers adduct. By drawing the fifth metacarpal forward, this deepens the hollow of the hand (Gench et al., 1995; Hinkle, 1997; Jenkins, 1998; Nordin & Frankel, 2012; Provident & Houglum, 2012; Riley, 1998).

Extensor Indicis

The extensor indicis extends and adducts the MCP joint of the index finger, but because it passes just to the ulnar side of the axis, it is weak in adductor action. Weakness in the extensor indicis would result in difficulty with independent movement of the index finger and some weakness in extension of the MCP joint. Tightness in the extensor indicis alone is unlikely, but with limitations in the extensor digitorum, the extensor indicis would contribute to hyperextension of the MCP joint (Oatis, 2004).

Palmar Interossei

Given the medial location to the adduction-abduction axis, the palmar interossei adduct the MCP joints of the index, ring, and little fingers (Gench et al., 1995; Provident & Houglum, 2012). If the palmar interossei become tight, there would be weakness in finger adduction, and this would contribute to weakness of MCP flexion with IP extension. Without these movements, there would be limited grasp and pinch capacity, and the claw hand deformity may result (Oatis, 2004).

Adductors of the Thumb

Adductors of the thumb include the flexor pollicis brevis, adductor pollicis, extensor pollicis longus, and flexor pollicis longus.

Flexor Pollicis Brevis

The deep head of the flexor pollicis brevis crosses only the MCP joint and is on the ulnar side of the abduction-adduction axis, so it adducts the MCP joint. Injury to the flexor pollicis brevis muscle would result in decreased flexion at the CMC and MCP joint of the thumb with resultant decreased pinch (Oatis, 2004).

Adductor Pollicis

The adductor pollicis slides the thumb across the palm and bases of the fingers toward the ulnar side as it adducts the CMC joint of the thumb. This muscle is most effective when the joint is fully abducted, which pulls the metacarpal closer to the palm. When the thumb is even with the palm, the adductor pollicis is not effective because the position aligns the muscle with the adduction-abduction axis (Gench et al., 1995; Provident & Houglum, 2012). Weakness of the adductor pollicis muscle would result in weakness in flexion and adduction of the CMC joint and limited MCP thumb flexion. If this muscle becomes tight, the result would be limited abduction and extension of the CMC joint and limited extension ROM of the MCP joints, preventing movement of the thumb away from the palm (Oatis, 2004).

Extensor Pollicis Longus

Not only an extensor at the CMC and MCP joint, the extensor pollicis longus also acts as an adductor at these joints. It is an adductor at the CMC joint because it crosses to the dorsal side of the abduction-adduction axis (Bellace, Healy, Bess, Bryon, & Hohman, 2000; Gench et al., 1995; Jenkins, 1998; Provident & Houglum, 2012).

Flexor Pollicis Longus

While not the primary action, with continued contraction, the flexor pollicis longus can adduct the metacarpal joint (Goss, 1976).

Assessment of the Hand

The hand is the terminal part of the upper limb and is essential for functional activities requiring both strength and precision. The loss of hand function accounts for 90% of the loss associated with upper extremity function (Hume, Gellman, McKellop, & Brunfield, 1990). A majority of decline in occupational performance is due to disuse (Fiatorone & Evans, 1993; Rider, 2005).

The thumb is the most important digit functionally due to the relationship with the other digits in force production and mobility. With the loss of the movement of the thumb, 40% to 50% of hand function is lost (Hume et al., 1990). The index finger coordinates precise movements with the thumb, and loss of index finger function results in decreased pinch and power grips. The middle finger provides a stable base for the hand and is vital for power and prehension. The little finger has the least functional role but, due to its peripheral position, enables the hand to mold around objects and hold items against the hypothenar eminence. The loss of function of the index, middle,

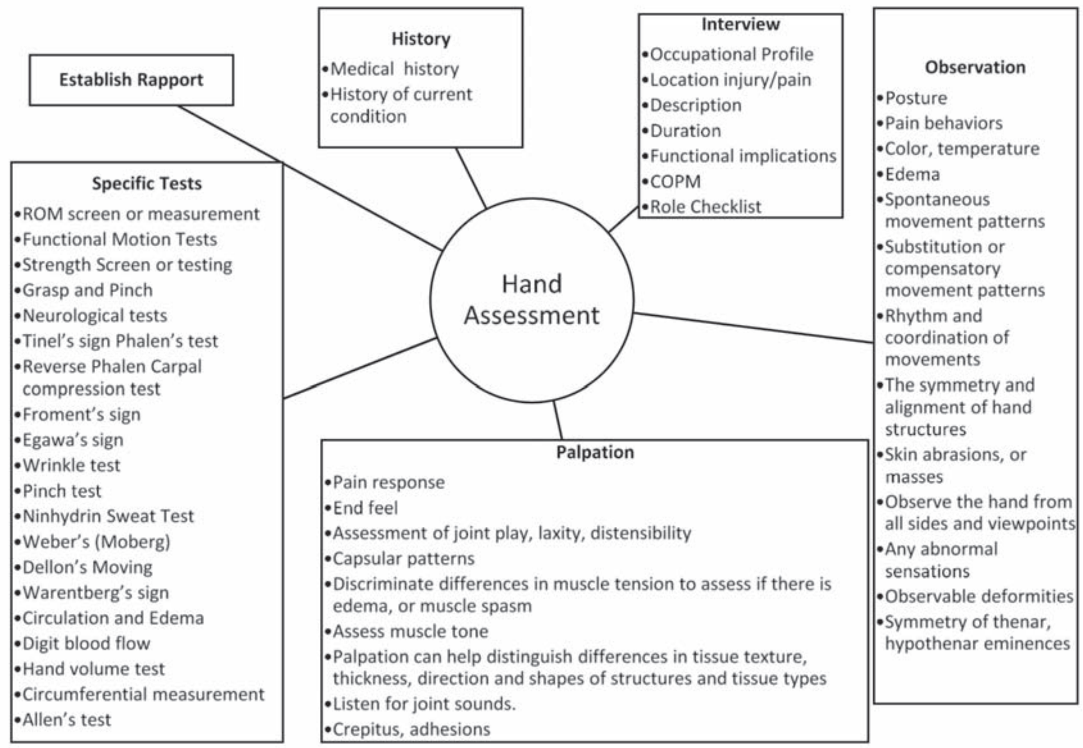


Figure 8-14. Evaluation of the hand. (Adapted from Cooper, C. [Ed.]. [2007]. *Fundamentals of hand therapy: Clinical reasoning and treatment guidelines for common diagnoses of the upper extremity* [p. 74]. St. Louis, MO: Mosby.)

ring, and little fingers has much less impact on the functional use of the hand. Figure 8-14 illustrates the process of the evaluation of the hand.

Occupational Profile

Kimmerle, Mainwaring, and Borenstein (2003) state that "the role of the occupational therapist or the hand therapist who assesses hand function is to delineate functional abilities, limitations, and activities within a meaningful and purposeful context" (p. 490). A clear understanding of how the client uses the hands in everyday activities is an essential part of the assessment of the hand. Inquiries about the client's history should reflect the needs and goals of the client in the tasks and activities associated with his or her desired occupations. Because the hand is so important to everyday activities and to upper extremity function, a clear understanding of the use of the hands is crucial.

Consideration of the psychosocial adaptation as well as physical recovery from hand injuries is important in engagement of occupations, relationships, and outcomes (Chan & Spencer, 2004). Chan and Spencer (2004) conducted a qualitative study of clients with acute hand injuries, and their findings support "the value of individualized, occupation-based therapy that addresses the mind and spirit as well as physical recovery in occupational therapy practice with hand injuries" (p. 128). Understanding the meaning that the hand injury has to the individual is essential in gaining the client's perspective of the illness experience (Cooper, 2003).

In addition, specific attention should be paid to the client's age because some conditions are more common (e.g., arthritis) after 40 years of age. Arthritis and cumulative trauma disorders may be more prevalent after years of trauma. There are physiologic changes in the elderly that may influence the ability to heal after a hand injury, such as decreased blood flow, decreased cellular activity, dryness, loss of skin elasticity, and changes in muscle (Rider, 2005).

If the client has limitations in hand function, ask how the injury or dysfunction occurred and how long ago the injury happened. This information can lead to an understanding of underlying pathology and guide intervention. Ask the client under what conditions the symptoms occur and what makes the condition less painful.

The Functional Repertoire of the Hand Model (Kimmerle et al., 2003) can be used when assessing the hand. In this model, four key components are identified. First, identification of personal constraints includes both physical and psychological limitations to hand function. The second component is that of hand roles and includes hand preference and bimanual use of the hands. Object-related hand actions is the third component and consists of reaching, grasping, and manipulating objects. Finally, inclusion of task parameters takes into account the characteristics of the objects, movement patterns, and performance demands involved in tasks using the hands. A model like this can provide a consistent language and comprehensive assessment of the hand.

Observation and Palpation

The normal hand is held in a slightly cupped position, and the wrist is positioned to provide an optimal length for the finger flexors (Neumann, 2002). The position of function of the

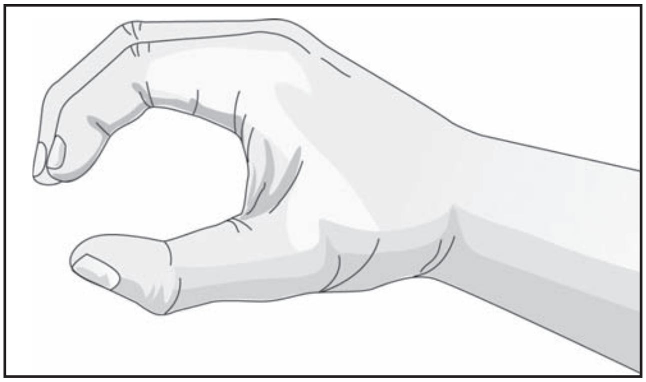


Figure 8-15. Position of function of the hand.

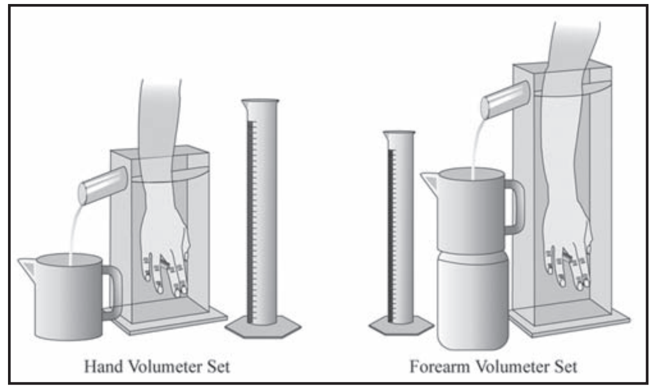


Figure 8-16. Volumeter.

hand illustrates the interaction of the wrist and hand motion. The wrist extensors are synergistic to the finger flexion, and the wrist flexors are synergistic to finger extensors. Grasp is greatest when the wrist is in 20 degrees of extension, and the wrist needs to be stable with slight ulnar deviation so that loads can be transmitted through the triangular fibrocartilage complex structures (Figure 8-15; Nordin & Frankel, 2012).

Note the position of the hand at rest. The fingers should be progressively more flexed from the radial to ulnar side. If this is not observed, it could be due to a lacerated tendon, Dupuytren's contracture, or other pathology (Magee, 2014). Postural imbalances during movement or rest can become fixed over time and less responsive to treatment, so early detection is important (Flinn & DeMott, 2010).

Comparison of both hands usually shows that the dominant hand is slightly larger than the nondominant or nonpreferred hand. Observe the normal creases and lines of the hand and palpate the bony structures, taking note of any tenderness. Look at the eminences of the hand: muscle wasting of the thenar eminence (median nerve) may be indicative of C6 nerve root problems or first dorsal interosseous muscle (C7 nerve), whereas wasting of the hypothenar eminence (ulnar nerve) may indicate C8 nerve root damage (Magee, 2014).

Notice if there are any differences between the two hands in color, temperature, appearance of the skin (shiny, sweating), loss of hair on the hand, or brittle fingernails, which may be indicative of vasomotor (blood vessels), sudomotor (sweat glands), pilomotor (hair and postganglionic sympathetic nerves that innervate them), circulatory, and trophic changes. Hot skin may indicate inflammation or rheumatoid arthritis, and cold, damp hands may indicate neurocirculatory aesthesia or Raynaud's disease (Magee, 2014). Take note of the shape of the fingers because variations in the size and shape of the hand may indicate different pathology. For example, large blunt fingers may suggest acromegaly (enlargement of the bones) or Hurler's disease, while slender fingers may indicate hypopituitarism, tuberculosis, or osteogenesis imperfecta (Magee, 2014). The thickness of the nail, presence and direction of ridges, spots or changes in color, or loosening of the nail bed can all be symptoms of pathologic processes.

Observe if there are any contusions on the hand. If there are repeated direct blows to the hand, this can cause vascular damage. If contusions occur to the palmar surface, there can be dorsal hand swelling. Thenar and hypothenar eminences can be bruised by means of a direct blow, which can occur in racquet sports or in catching a ball. Bruising of the MCP joints is common in boxing and football (Oatis, 2004).

Observation and palpation of any abnormal formations should also be noted in the documentation regarding location and description. For example, a description may be "single nodule, freely movable, nontender, 0.5 cm in diameter located over the dorsum of the ring PIP joint" (Melvin, 1982, p. 212). Nodules can occur in several conditions including Dupuytren's contracture, which is the progressive fibrosis of the palmar aponeurosis and usually affects the ring and little fingers first. Fibrous nodules can develop in the flexor tendons that can catch on the annular sheath opposite the metacarpal head, causing trigger fingers or thumb. Swelling and bony enlargement of the PIP joint may indicate secondary synovitis from rheumatoid arthritis or may be due to osteoarthritis (Bouchard nodes; Hartley, 1995). Heberden nodules are seen and palpated on the dorsal surface of the DIP joints and are associated with osteoarthritis, which weakens and destroys the articular cartilage.

Swelling of the hand can be assessed by circumferential measurement or by using a volumeter of either the hand or forearm, as depicted in Figure 8-16. The hand or forearm is inserted into a rectangular container with water until in contact with the fixed bar, and the amount of water displaced is measured. Improvement in the amount of edema is objectively determined by less water displaced in subsequent measurements.

Obvious hand deformities can be seen. Swan neck deformity is a result of contracture of the intrinsic hand muscles or tearing of the volar plate (Figure 8-17). This results in flexion of the MCP and DIP joints but extension of the PIP joint. Swan neck deformity often occurs in clients following trauma, rheumatoid arthritis, cerebral palsy, mallet finger, or congenital joint laxity (Ehlers-Danlos syndrome). Swan neck deformity of the thumb is called *duck-bill deformity* and is more common in osteoarthritis than rheumatoid arthritis. It results in CMC joint dysfunction. There is erosion of articular surfaces, stretching of the joint capsule, and dorsal and radial subluxation of the metacarpal joint (Wheeless, 2010).

Boutonnière deformity (see Figure 8-17) occurs when the central slip of the extensor hood ruptures. The lateral bands of the extensor tendons separate to allow the joint to protrude, resulting in extension of the MCP and DIP joints and flexion of the PIP joint. Boutonnière deformity commonly occurs after trauma or due to rheumatoid arthritis.

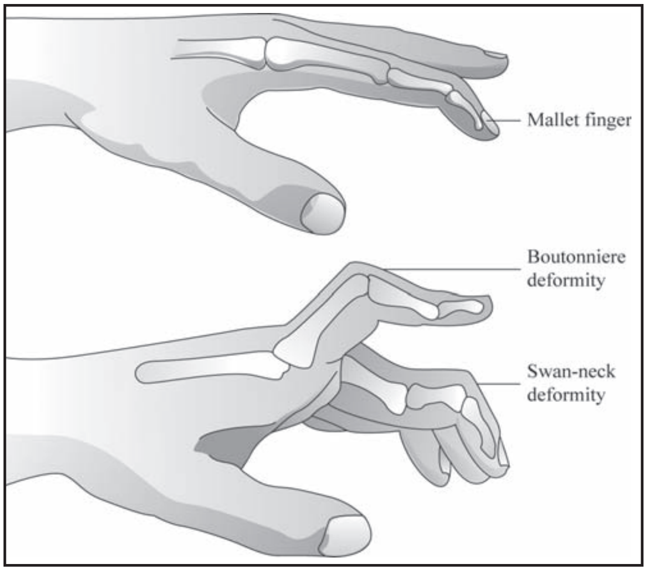


Figure 8-17. Mallet finger, Boutonnière, and Swan neck deformities.

Table 8-13

Active Range of Motion Screen for the Hands

Motion Tested	Instructions to the Client/Ask the Client to ...
Finger abduction and adduction	Spread their fingers apart and bring them back together.
Finger flexion and extension	Make a tight fist and open fingers.
Thumb flexion and extension	Bend their thumb across the palm and out to the side.
Thumb abduction and adduction	Position their thumb in line with the index finger and then move it straight out.

Another hand deformity that is easily observed is mallet finger, which usually occurs from injury to the tendons. As seen in Figure 8-17, the DIP joint of the finger is unable to extend. Ulnar drift occurs when the extensor digitorum tendon slips off the dorsal portion of the MCP joint and moves toward the ulnar side. When digits two through five are involved, this is called a *wind-swept hand*. Other observable hand deformities include the extensor plus deformity, claw fingers (intrinsic minus hand), ape hand deformity, bishop's hand or benediction hand deformity, drop-wrist deformity, Dupuytren's contracture, and "Z" deformity of the thumb.

Range of Motion

As with other joints, active and passive ROM are important assessments of the hand. Observation of the active use of the hand as well as passive movements and joint play provide initial information about the structures of the hand. Active movements will enable the assessment of physiologic movements and will provide insight into the client's willingness to use the hands.

A gross screen of hand function may involve having the client make a fist and then open the hand, noting any restrictions, deviations, or pain. Functional testing of the wrist and hand may include active movement with scoring based on the duration of the posture, the amount of weight that can be moved, or the number of repetitions done (Magee, 2014). Another functional test of hand function might be to observe the client buttoning, zipping, holding a razor, or wringing out a sponge as indicative of finger flexion. Releasing objects and pushing a door open with the hand might entail the finger extensors. Opening a bag of chips would entail lateral pinch, as would holding a key. Palmar pinch is involved in holding a pen and tip pinch in plugging in an appliance. Gross grasp can be observed by watching someone open a jar, hold a laundry basket, or drain water from a pot (Gutman & Schonfeld, 2003). Additional active ROM screening tests are listed in Table 8-13.

Each motion at each joint is assessed either by observation or by measuring via the use of a goniometer, ruler, and/or tape measure. Most activities of daily living (ADL) require 10 degrees of wrist flexion, 35 degrees of wrist extension, 60 degrees of MCP and PIP flexion, 40 degrees of DIP flexion, and 20 degrees of thumb MCP flexion and 18 degrees of IP flexion of the thumb (Hume et al., 1990; Magee, 2014).

Overpressure applied at the end of passive ROM will assist with assessment of end feel at each joint and the presence of capsular patterns. The test for tight retinacular ligaments is used to differentiate tight retinacular ligaments from capsular tightness. Accessory motions can be tested by assessing the long axis extension (distraction) of the fingers, anteroposterior glide, side glide, and slight rotation possible at the joints of the fingers.

Strength Assessment

Strength may be assessed by individually testing muscles (as in a manual muscle test), or a brief screening can be done (as in a functional motion test, as seen in Table 8-14). Handheld dynamometers are typically used to evaluate grasp, and pinch meters are used to measure pinch strength, with norms established by age and gender.

Functional muscle strength of the hand can be seen in daily activities, such as maintaining the grip on a bar of soap, squeezing a tube of toothpaste, writing (requires fair plus strength of finger flexors), releasing a can of soda, or releasing the arm of a chair when standing up (requires fair minus strength in finger extensors; Gutman & Schonfeld, 2003). A quick screen for function grip strength would be observing whether a client can open a large jar, hold a gallon of milk, and open plastic containers (Gutman & Schonfeld, 2003).

An important consideration in the assessment of hand strength is that the hand is the final link in the kinematic chain. Dysfunction in other parts of the chain can influence hand strength. For example, the use of the hand is dependent on proximal shoulder stability, and in the case of rotator cuff or humeral fractures, grip strength can be affected on the same side as the injury to the shoulder (Flinn & DeMott, 2010). Assessment of the other joints in the chain may be warranted.

Table 8-14

Strength Screen for the Hands

Muscle Action Tested	Instructions to the Client/Ask the Client to ...	Therapist's Action
Finger flexion	Squeeze your fingers or make a fist and hold that position. Tell the client, "Do not let me pull your fingers."	Attempt to pull the fingers into extension
Finger extension	Straighten the fingers and hold that position. Tell the client, "Do not let me bend your fingers."	Attempt to push the fingers at each joint into flexion
Finger adduction (palmar interossei)	Squeeze the fingers together and hold that position. Tell the client, "Do not let me pull your fingers apart."	Attempt to abduct the fingers
Finger abduction (dorsal interossei)	Open the fingers apart and hold that position. Tell the client, "Do not let me pull your fingers together."	Attempt to push the fingers into adduction
Opposition (opponens pollicis, opponens digiti minimi)	Put the little finger and thumb together and hold that position. Tell the client, "Do not let me pull your thumb and little finger apart."	Attempt to reposition the thumb and finger

Specific tests for muscles and tendons include the Finklestein test to detect the presence of de Quervain's or Hoffman's disease in the thumb. The sweater finger sign is seen when one of the distal phalanges of the fingers does not flex when making a fist. When the finger being tested is placed in 90 degrees of PIP flexion and the client is asked to extend the PIP joint, if the therapist feels little pressure from the DIP joint, then there is likely a torn central extensor hood (test for extensor hood rupture). Boyes test also tests the extensor hood, specifically the central slip. The Bunnel-Littler (Finochietto-Bunnel) test assesses the structures around the MCP joint (Magee, 2014). Additional special tests of the hand are listed in Table 8-15.

Stability Assessment

There are specific tests that, when positive, suggest that a problem exists. These might include the Test for Tight Retinacular (collateral) ligaments, which tests the structures around the PIP joint. The Axial Load Test is positive for a fracture of the metacarpal or adjacent carpal bones if there is pain or crepitation when axial compression is applied to the client's thumb. A similar test can be done with the fingers. In the Grind Test, the therapist applies axial compression and rotation to the MCP joint. If pain is elicited, then this may indicate degenerative joint disease in the MCP or metacarpotrapezial joint (Magee, 2014). The Linscheid test detects ligamentous instability in the second and third CMCs (Magee, 2014). Varus and valgus stress tests are used to assess the ligamental instability of the digital collateral ligaments.

Pain Assessment

Synovitis, degenerative joint diseases, and complex regional pain syndrome often present with the expression of pain. Pain may be due to blisters, lacerations of the fascia, disruption of superficial ligaments, disruption of superficial muscles (extensor digitorum, palmaris longus, or opponens), or due to a disruption in the periosteum. Pain may also be the result of a neural problem, bony injury, chronic capsular problems, deep muscle injury or tendon sheath problem, deep ligaments, or deep muscles. Peripheral nerve conditions, dorsal nerve root problems, systemic conditions (e.g., diabetes), and vascular occlusion can cause painful conditions in the hand. Table 8-16 lists types of pain and possible structures involved.

It is important to differentiate pain from stiffness and articular from periarticular pain (as in subcutaneous nodules, synovial cysts, osteophytes, or muscular conditions). Local tenderness may be indicative of injury to more superficial structures, while deep pain may be due to dysfunction of deeper muscles or ligaments. Immediate onset may be indicative of a more severe injury, while gradual onset suggests overuse syndromes, neural lesions, or arthritis.

Pain can be referred to other parts from specific muscles. For example, if the extensor digitorum muscle is injured, pain may be referred to the forearm, wrist, or digit. If the extensor indicis is injured, pain may be experienced on the dorsum of the index finger (Magee, 2014).

Pathology of the Hand

The hand is directly involved in nearly every activity we do associated with work, play, and self-care. Trauma from direct blows or overuse of the hand in repetitive patterns as well as disease can limit the use of the hand.

Tendons can shorten secondary to immobilization, soft tissue contractures, and spasticity. Tenosynovitis (inflammation of the tendon and sheath) can cause fluid to become trapped in the synovial sheath, leading to a proliferation of tissue interfering with tendon gliding. The integrity and strength of the tendon is compromised, which can lead to rupture over rough or subluxed bones or spurs. The rupture of the extensor tendons is more common than flexors because the extensors go over the carpal bones.

Sensory problems can be due to injury or compression. The most commonly affected nerve is the median nerve. The median nerve innervates the flexor portion of the forearm and hand (pronator teres and quadratus, flexor carpi radialis,

Table 8-15

NEUROLOGICAL AND CIRCULATORY TESTS FOR THE HAND

Type of Test	Name of Test	Structure Assessed
Neurological	• Tinel's sign (at the wrist)	• Thumb, index finger, middle and lateral half of the ring finger (median nerve distribution)
	• Phalen's (wrist flexion) test	• Thumb, index finger, middle and lateral half of the ring finger (median nerve) indicative of carpal tunnel syndrome
	• Reverse Phalen's (prayer) test	• Wrists are in maximal extension with elbow and fingers extended. Numbness or tingling may indicate carpal tunnel syndrome.
	• Carpal compression test	• Carpal tunnel syndrome
	• Froment's sign	• Paralysis of adductor pollicis longus and possibly ulnar nerve damage
	• Egawa's sign	• Interossei involvement and possible ulnar nerve palsy
	• Wrinkle (shrivel) test	• Denervated fingers do not shrivel when placed in water
	• Pinch test	• If unable to make the OK sign, it may indicate a compromised anterior interosseous nerve
	• Ninhydrin sweat test	• Nerve lesion indicated if there is no change of color on paper sprayed with Ninhydrin
	• Weber's (Moberg) two-point discrimination test	• Hand sensation and measure of innervation of the skin
	• Dellon's moving two-point discrimination test	• Mechanoreceptor system
	• Warentberg's sign	• Ulnar nerve neuritis/paralysis
Circulation and edema	• Digit blood flow	• Distal blood flow
	• Hand volume test	• Edema
	• Circumferential measurement	• Edema
	• Allen's test	• Occlusion of radial or ulnar artery

Adapted from Magee, D. J. (2002). *Orthopedic physical assessment.* Philadelphia, PA: Saunders.

palmaris longus, flexor digitorum superficialis and profundus, flexor pollicis longus, abductor pollicis, opponens pollicis, flexor pollicis brevis, and first and second lumbricals). Carpal tunnel syndrome is an example of compression of the median nerve affecting the motor and sensory abilities of the hand and fingers. The radial nerve (which innervates the extensor muscles of the arm and forearm, including the triceps, anconeus, brachioradialis, extensor carpi radialis, and part of brachialis) is the least commonly injured nerve. The radial nerve innervates the skin on the dorsum of the wrist and hand to the lateral surface of the thumb and the index and middle fingers. The muscles and skin on the ulnar side of the hand and forearm are innervated by the ulnar nerve. The muscles innervated include the flexor carpi ulnaris, flexor digitorum profundus, palmaris brevis, muscles of the little finger, third and fourth lumbricals, all of the interossei, adductor pollicis, and flexor pollicis brevis. A loss of the intrinsic muscles, coupled with the inability to abduct the fingers or adduct the thumb with hyperextension of the MCP and flexion at the PIP joint, is claw hand due to damage to the ulnar nerve as a result of trauma or nerve entrapment behind the medial epicondyle with loss of motor and sensory innervation.

While fractures do occur in the hand, fractures and subluxation of the metacarpals are more common than phalangeal fractures, often due to direct blows to the metacarpal shaft or metacarpal head. Proximal phalange fractures are more common than middle or distal fractures that cause damage to flexor or extensor tendons. Table 8-17 provides an overview of pathology of the hand.

OUTCOME MEASURES FOR THE HAND

Outcome measures have been developed to assess change in a client over time. The changes need to impact the meaningful areas of the person's life based on collaboration between the therapist and client throughout the treatment process. Not only is quality of service delivery measured as improvements in physical function and engagement in occupations, but client satisfaction and active involvement are important parts of the intervention outcome.

Some specific hand outcome measures have been developed. The Arthritis Hand Function Test consists of 11 test items designed to measure pure and applied strength and dexterity of both hands in clients with rheumatoid arthritis and osteoarthritis (Backman, Mackie, & Harris, 1991). There is some administrative and respondent burden since the test takes 20 to 30 minutes to administer and needs equipment and training. The Jebsen Hand Function Test involves seven hand function tests designed to simulate ADL, such as feeding, writing, and turning pages (Jebsen, Taylor, Trieschmann, & Howard, 1969). Poole (2011) suggests that the norms be updated and revised, and he cites Mathiowetz, who reported that several of the simulated tasks do not duplicate actual tasks. The Rheumatoid Hand Function Disability scale (also known as the *Cochin Hand Function Scale*) is a questionnaire assessing the client's perception of functional difficulty in 18 ADL tasks without any assistive device (Duruoz et al., 1996). While some of the items probably need to be updated to reflect hand activities such as keyboarding, texting, and cell phones, psychometric properties support the use of this tool in clinical practice and research (Poole, 2011). The Disabilities of the Arm, Shoulder, and Hand (DASH; Hudak, Amadio, & Bombardier, 1996) measure limitations in ADL and instrumental ADL using the upper extremities. The Australian Canadian Osteoarthritis Hand Index (Bellamy et al., 2002) is a self-report measure with three scales to asses pain, stiffness, and function with osteoarthritis. Psychometric evaluation supports clinical and research usability. Another tool to assess osteoarthritis is the Functional Index for Hand Osteoarthritis, which asks how the person uses a key, cuts different objects, lifts, buttons, uses tools, writes, and shakes hands (Dreiser, Maheu, Guillou, Caspard, & Grouin, 1995). Responsiveness with this tool is not high (Poole, 2011). The Grip Ability Test (Dellhag & Bjelle, 1995), with three items (putting a sock over one hand, putting a paper clip on an envelope, and pouring water from a jug) was intended to be a rapid test for persons with rheumatoid arthritis. However, the psychometric properties of the test currently are not strong enough to support clinical usability (Poole, 2011). The Michigan Hand Outcomes Questionnaire (Chung, Hamill, Walters, & Hayward, 1999; Chung, Pillsbury, Walters, & Hayward, 1998) has 37 items and 6 subscales to assess the client's perception of his or her hands relative to function, appearance, pain, ADL, work performance, and satisfaction. While it takes 5 to 20 minutes to administer, the validity and responsiveness of the Michigan Hand Outcomes Questionnaire has been demonstrated for a variety of hand conditions as a measure of improvement and well-being.

Most outcome measures cover more than one component of the World Health Organization's *International Classification of Functioning, Disability and Health* (2001) but can be loosely classified according to their main purpose and component of measurement. For example, outcome measures for rheumatoid arthritis include the client's own assessment of the level of disability, client and physician global assessments, and evaluation of specific physical characteristics (joint pain/tenderness, joint swelling; Brooks & Hochberg, 2001). The Goal Attainment Scaling is designed to be used collaboratively by the client and therapist in establishing individualized goals and outcomes (Malec, 1999). Outcome measures predominantly assessed impairment, body structures, and self-care (Hershey, Stanton, Tiedgen, Mulcahey, & Lesher, 2015).

MacDermid, Richards, and Roth (2001) compared the results of the DASH, Patient-Related Wrist Evaluation, and Short Form Health Survey (SF-36) for clients who had distal radius fractures and found that the most gains were made in wrist function and the least in role resumption and quality of life. Case-Smith (2003) conducted a study to determine changes in performance, satisfaction, and health-related quality of life in clients with upper extremity injury. In addition to the DASH and SF-36, clients were also asked to develop individualized client-centered goals by using the Canadian Occupational Performance Measure (COPM). This tool identifies occupational performance problem areas and considers the client's perception of his or her level of performance and satisfaction with everyday task completion. The tool helps in clarifying client-centered goals and evaluating the success of goal attainment over time. The use of the COPM ensures that intervention "remains true to the client's goals and priorities" (Case-Smith, 2003, p. 499), and the COPM "helped therapists focus intervention and supported development of measurable, achievable goals that were meaningful to clients" (Case-Smith, 2003, p. 504). Several tools ensure a comprehensive assessment of hand rehabilitation outcomes.

Table 8-16

Pain in the Hand and Possible Structures Affected

Type of Pain	Possible Structures Affected
Sharp	• Skin, fascia • Tendons • Superficial ligaments • Superficial muscles • Acute bursitis
Numbness in elbow to fingers	• "Opera glove" anesthesia (hysteria, leprosy, diabetes)
Dull	• Neural problem • Bony injury • Chronic capsular problems • Deep muscle injury • Tendon sheath problems
Painful, swollen, hot	• Causalgic states
Cold	• Raynaud's disease • Neurocirculatory aesthesia
Pins and needles	• Peripheral nerve • Dorsal nerve root • Systemic condition • Vascular occlusion

Table 8-17

Hand Pathology

Neurological		
Radial Nerve	• Injuries	• Cervical cord injuries • Dermatome sensory and brachial plexus lesions • Peripheral nerve injuries • Dislocation of the shoulder • Fractured humerus and radius • Radial nerve palsy
	• Severance	• Extensor paralysis • Inability to extend thumb or proximal interphalangeal joint • Wrist drop (inability to extend wrist) • Possible loss of elbow extension • Loss of grip since lacks stabilizing function of wrist extension
	• Compression (entrapment neuropathy)	• Radial tunnel syndrome • Thoracic outlet syndrome (C8T syndrome) • Posterior interossei syndrome
	• Diseases	• Lead poisoning • Alcoholism • Polyneuritis • Trauma • Diphtheria • Polyarteritis • Neurosyphilis • Anterior poliomyelitis
Median Nerve	• Injuries	• Cervical cord and brachial plexus • Peripheral nerve injuries • Prolonged compression • Dislocated ulna • Fractured elbow or lower radius
	• Severance	• Weak wrist flexors • Inability to flex and abduct thumb • Inability to flex index and middle finger • Tendency for thumb and index to hyperextend • Loss of thumb opposition
	• Compression	• Carpal tunnel syndrome • Pronator teres syndrome • Anterior interosseous nerve syndrome • Rheumatoid arthritis
	• Diseases	• Amyloidosis • Gout • Plasmacytoma • Anaphylactic reaction • Myxedema

(continued)

Table 8-17 (continued)

Hand Pathology

Neurological		
Ulnar Nerve	• Lesions	• Cervical cord and brachial plexus • Peripheral nerve injuries • Fracture and dislocation of humeral head and elbow • Pressure during sleep
	• Severance	• Inability to flex ring and little fingers • Loss of hypothenar muscles and interossei • Hyperextension of ring and little fingers • Limited radial deviation • Loss of thumb adductor
	• Diseases	• Polyneuritis • Trauma
	• Complex regional pain syndrome (shoulder-hand syndrome, reflex sympathetic dystrophy)	• Myocardial infarction • Pancoast tumor • Brain tumor • Neoplasm • Spondylosis • Vascular occlusion • Hemiplegia • Osteoarthritis
	• Polyneuritis	• Carcinoma of the lung or gastric • Hodgkin's disease • Pregnancy • Diabetes mellitus • Chemical neuritis • Arteriosclerosis
Muscles and Tendons		
Tendons	• Mallet finger	• Extensor tendon torn from insertion • DIP drops into flexion
	• Trigger thumb	• Thumb snaps as it flexes • May become locked in flexion or extension • Due to thickening of the sheath or tendon or nodule • Prevents gliding of tendon
	• Trigger finger (digital tenovaginitis stenosis)	• Thickening of flexor tendon sheath and tendons stick • Usually occurs in middle or ring finger • Often due to direct, severe, or multiple trauma
	• Extensor mechanism pathology	• Boutonnière deformity • Ulnar drift
	• Flexor apparatus pathology	• Swan neck deformity • Wrist drop • Z deformity of thumb • Dupuytren's contracture

(continued)

Table 8-17 (continued)

Hand Pathology

Muscles and Tendons		
Sprains	• Thumb	• Skier's thumb • Forceful hyperextension often combined with abduction of first MCP joint • Also seen in baseball, basketball, and volleyball, which can lead to sprain of ulnar collateral ligament or fracture or displacement of proximal phalanx or thumb
	• Fingers	• Second to fifth MCP commonly injured through hyperextension usually resulting in ligamental damage • With proximal IP hypertension, the joint capsule, transverse retinacular ligaments, or volar plate can be injured • Hyperextension of the DIP is common in basketball and volleyball; sprained with anterior capsular damage, ligament, and sometimes volar plate damage • A flexed finger that is violently extended can cause the flexor digitorum profundus to rupture from insertion on distal phalange as in football or rugby • With forced ulnar deviation of the PIP joint, radial collateral ligaments can be injured, volar plate can be ruptured, or complete dislocation can occur
Muscular	• Muscle wasting or atrophy	• Hypothenar: C8 nerve root problem • Thenar: C6 nerve root problem • Hypothenar, interossei, and medial lumbricals: Median nerve • Amyotrophic lateral sclerosis • Charcot-Marie-Tooth peroneal atrophy • Syringomyelia • Neural leprosy
	• Muscle loss	• Intrinsic loss: Clawed position overpowered by extrinsic muscles • Dupuytren's contracture of palmar aponeurosis pulling fingers into flexion • Intrinsic minus hand position • Extrinsics acting alone lead to a position of MCP (hyper) extension and DIP flexion • Intrinsic plus hand position • Intrinsics acting alone would give a position of MCP flexion and IP extension
	• Ligamental	• Incomplete injuries at PIP most common but usually no dislocation of PIP joint due to capsular support • MCP: Hyperextension injuries to radial collateral ligament • Thumb: Collateral ligament on the ulnar side often requires surgery
Overuse/Cumulative Trauma		
	• Carpal tunnel symdrome	• Any lesion that significantly reduces the size of the carpal tunnel • Swelling of tendons in synovial sheaths • Paresthesia, hypoesthesia, or anesthesia may occur • Motor loss may result
	• Extensor intersection syndrome	• Overuse of thumb or wrist • Inflammation of abductor pollicis longus and extensor pollicis brevis • Often seen in paddlers or weight lifters
	• de Quervain's disease (constrictive tenosynovitis)	• Overuse of thumb or wrist • Tendonitis of abductor pollicis longus and extensor pollicis brevis as pass through first compartment • Seen in paddling, baseball, javelin, hockey

(continued)

Table 8-17 (continued)

Hand Pathology

Hand Deformities		
	• Dupuytren's contracture	• Progressive shortening, thickening, and fibrosis of the palmar fascia and aponeurosis • Ring and little fingers into partial flexion at the MCP and PIP joints • Frequently bilateral • Common in men older than age 50 years
	• Claw (ulnar) hand	• Ulnar nerve injury • Extensive motor and sensory loss to the hand • Difficulty making a fist because they cannot flex their fourth and fifth digits at the DIP joints
	• Simian (ape) hand	• Thumb movements being limited to flexion and extension in the plane of the palm • Inability to oppose the thumb
	• Bishop's (benediction) hand	• Wasting of hypothenar muscles, interossei muscles, and two medial lumbricals • Due to ulnar nerve palsy
Vasomotor Changes		
	• Redness, blanching	• Suspect circulatory problem
	• Diseases	• Raynaud's disease • Rheumatoid disease • Causalgia • Acromegaly

Adapted from Magee, D. J. (2002). *Orthopedic physical assessment*. Philadelphia, PA: Saunders.

In a scoping review of 18 instruments used by hand and upper extremity rehabilitation occupational therapists, the focus was on assessment of body function and ADL and less emphasis in the areas of the environment, and in personal, social, and virtual dimensions of participation (Hershey et al., 2015).

Summary

- The hand is amazingly complex with many articulations between carpal bones, metacarpals, and phalanges. As a result, the following joints are formed: CMC, MCP, DIP, and PIP.
- By observation, one can identify three arches in the hand: two transverse and one longitudinal. Many creases are visible in the hand as well.
- The CMC joint provides the most movement for the thumb and the least amount for the fingers.
- The thumb is capable of flexion/extension, adduction/abduction, circumduction, and opposition/reposition.
- The IP joints of the fingers are closely congruent during movement so these are relatively stable joints.
- The flexor apparatus is made up of the flexor digitorum superficialis and flexor digitorum profundus muscles.
- The extensor apparatus or extensor hood comprises the extensor digitorum, connective tissue, fibers from the interossei muscles, and lumbricals.
- Hand muscles, while many in number, are often distinguished by those that are intrinsic to the hand and those that are extrinsic.
- Synergistic relationships exist between the muscles of the wrist and the finger muscles.
- Prehension is the use of the hand in precise ways. Defining how the hand moves has proved challenging. Grasp usually involves more fingers and often the thumb, whereas pinch usually only involves one or two fingers. Pinch is usually described as tip, palmar, lateral, and pulp. Cassanova and Gernert (1989) has described a more detailed description of grasp and pinch patterns that demonstrates the variety of ways hands are used in everyday activities.
- Evaluation of the hand includes assessment of pain, edema, symmetry, movement, and observation and palpation. In addition, grasp and pinch measurements are taken to determine the strength of the muscles in the hand.

Figures 8-3 and 8-8 are adapted from Muscolino, J. E. (2006). *Kinesiology: The skeletal system and muscle function*. St. Louis, MO: Mosby.

Figure 8-7 is adapted from Neumann, D. A. (2002). *Kinesiology of the musculoskeletal system: Foundations for physical rehabilitation*. St. Louis, MO: Mosby.

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9

Posture

Melinda F. Rybski, PhD, MS, OTR/L and Lisa Juckett, MOT, OTR/L, CHT

This chapter will discuss variables related to the major structural support systems of the human body: the axial and appendicular skeletons. The axial skeleton consists of the cranium, vertebral column, ribs, and sternum and is essential in providing stability as well as mobility during functional tasks such as walking, driving, and carrying objects. The portion of the axial skeleton that largely influences posture, the vertebral column, will be discussed in detail. The appendicular skeleton, consisting of bones that support the appendages, will be discussed in other chapters. The sacroiliac joint, which serves as the transition between the caudal end of the axial skeleton and lower appendicular skeleton, aids in postural alignment because this joint is designed for stability and is relatively rigid. The pelvis includes bones of the axial skeleton of the spine (sacrum and coccyx) and of the appendicular skeleton (ileum, ischium, and pubis), which are pelvic girdle bones of the lower extremity (both the pelvis and sacroiliac joints are discussed in Chapter 10). The appendicular skeleton for the upper extremity, consisting of the shoulder girdle and bones of the arm, are discussed in Chapters 5 (shoulder), 6 (elbow), 7 (wrist), and 8 (hand). Collectively, these structures provide the body with foundational support, allowing for more dynamic movement to occur during meaningful, daily activities (Figure 9-1)

The vertebral column and ribs serve to protect the spinal cord and internal organs, provide a means for breathing, support the head and extremities, transmit loads between the extremities from the head and trunk to the pelvis, and stabilize and mobilize the body for hand function and ambulation (Carcia, 2012; Nordin & Frankel, 2012).The vertebral column is divided into five sections: cervical, thoracic, lumbar, sacral, and coccygeal. There is much variation in the structures and function of each section of the spine (Figure 9-2).

Figure 9-1. The spine, pelvis, and thorax in action.

The main function of the cervical spine is to support the skull; act as a shock absorber for the brain; and protect the brainstem, spinal cord, and neurovascular structures. The cervical spine also serves a biomechanical function, which is to facilitate transfer of weight (Nordin & Frankel, 2012). Structures of the cervical spine provide movement at the neck and also influence upper extremity function. The most

Rybski, M. F.
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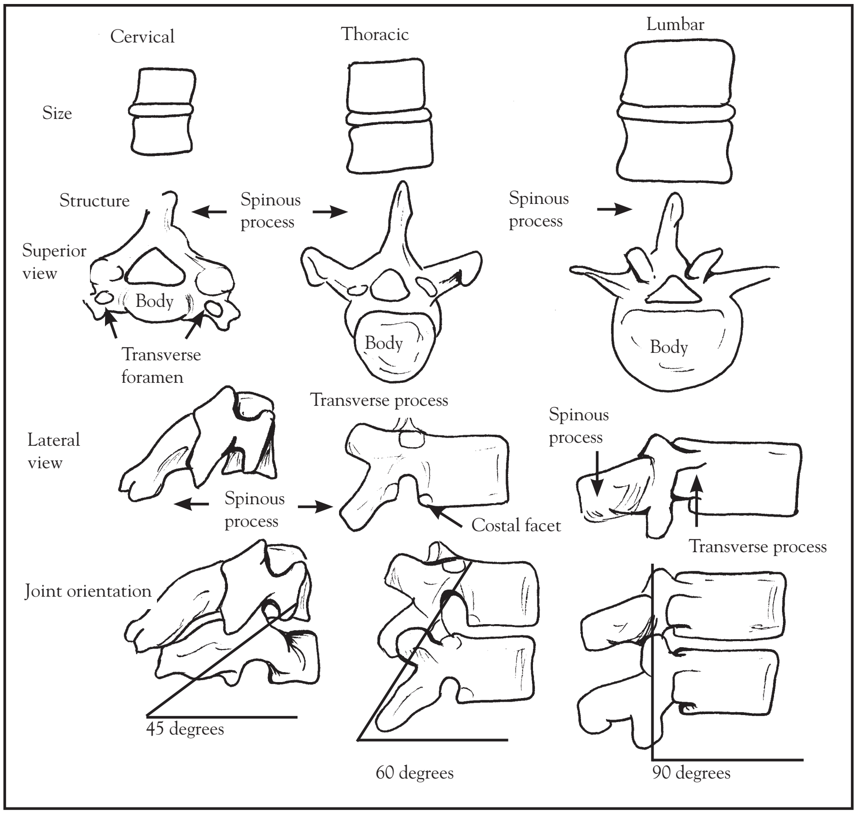

Figure 9-2. Comparison of vertebrae.

superior portion of the entire vertebral column is known as the *craniocervical region*. As its name implies, this region is where the cranium articulates with the first cervical vertebra. Movements at the craniocervical region and the lower cervical vertebrae allow for positional adjustments of the head and enhance vision beyond the limits of eye movement. The cervical spine and its surrounding structures also play a role in influencing upper extremity movement and sensation (McLean, Moffett, Sharp, & Gardiner, 2011).

The thoracic spine, located in the mid-back area of the spine, holds the rib cage; protects the heart, blood vessels, and lungs; supplies articulations for respiration; and provides attachment sites for muscles (Houglum & Bertoti, 2012). The lumbar vertebrae (low-back area of the spine) are the largest vertebrae of the spine, which is consistent with their role of weightbearing of the head, arms, and trunk in an erect posture. The large lumbar vertebrae can absorb the stress of external loads as when lifting or carrying heavy objects. The lumbar spine also protects and supports the spinal cord and spinal nerves. The sacrum connects the spine to the hip and the coccyx provides attachment sites for ligaments and muscles of the pelvic floor. The coccyx also functions to support and stabilize the body, especially when leaning back in a seated position.

Bones of the Spine and Palpable Structures

The spine is formed by 33 vertebral bones that are labeled according to location: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 coccygeal. Each vertebra consists of a body, pedicles, discs, spinous process, vertebral arch, and laminae (see Figure 9-2).

The differences depend on the purpose and function of each vertebral segment, how movement occurs, and the level of participation in load bearing in which the vertebra is involved. In general, the posterior portions of the vertebrae serve to protect the spinal cord and stabilize the spine, while anterior portions function as a shock absorber, to bear weight and loads, and to mobilize the trunk (Carcia, 2012; Dalton, 2011).

Parts of the Vertebra

The body of the vertebra is the anterior portion of the vertebra and is cylindrical in shape. The body is the largest part of the vertebra and the size of the body becomes progressively larger caudally as loads on the spine increase. In the midthoracic region, the body is the primary weightbearing portion of the vertebral column (Neumann, 2002), bearing primarily compressive loads.

Two pedicles project dorsally from the body. These short, thick projections connect the vertebral bodies to the posterior segment of the vertebra. Pedicles transmit bending forces to the vertebral bodies (Levangie & Norkin, 2011). The pedicles merge with a pair of lamina (which protect the posterior aspect of the spinal cord and resist and transmit forces to the pedicles), creating the vertebral arch with the vertebral foramen (enabling passage of nerve roots and the spinal cord) in the center. The neural foramen, also known as the *intervertebral foramen*, is the opening between every two vertebrae where the nerve roots exit the spine. There are two neural foramina between each pair of vertebrae, one on each side. Of particular clinical importance is the neural foramen of C5 to T1, serving as the nerve root, or ventral root, origin of the brachial plexus. The cervical vertebrae also contain superior and inferior articular facets on the left and right side, making for a total of four articular facet joints. Facet joints allow for each of the vertebrae to articulate with its adjacent vertebra, except for the atlas, which articulates with the occiput superiorly. As the name implies, the articular facets provide joint motion between the vertebrae, allowing for flexion, extension, and rotation at the cervical spine. The vertebral arch supports seven processes: four articular, two transverse, and one spinous process. The processes help to increase the leverage for the muscles of the trunk and extremities (Houglum & Bertoti, 2012).

Between the vertebral bodies of the thoracic vertebrae are the tough, rubbery intervertebral discs. The intervertebral discs of fibrocartilage attach to the superior and inferior surfaces of the vertebrae, and this enables each vertebra to articulate with the vertebra above and below it. The outer shell of fibrocartilage, known as the *annulus fibrosus*, holds the vertebrae in place while providing a small range of motion (ROM). The annulus fibrosus resists tensile, torsional, and shear forces. Inside the annulus fibrosus is the gel-like nucleus pulposus that acts as a soft shock absorber to prevent impact between the vertebrae, and resists compression and tensile forces. The discs also bear and distribute loads, serve a hydrostatic function storing energy, restrain excessive motion, and provide spaces throughout the vertebral column (Nordin & Frankel, 2012). Since the discs have no blood supply, they rely on diffusion generated by motion for nutrition. The spinous process, which serves for the attachment of various muscles and ligaments, is the posterior portion of the vertebra and is the bony ridge easily palpated down the back.

Palpation

Appreciation of the axial skeleton can be achieved by palpating key anatomical structures. Palpation can also assist novice practitioners in identifying and orientating themselves to bony landmarks that serve as attachment sites for various muscles and ligaments. Accurate palpation can aid practitioners in determining which structures influence pathologies related to the spine and posture. On a partner, begin to identify the following key structures in a cephalic to caudal manner.

Cranial Region

The Mastoid Process

This is the hard, bony notch behind the ear that is the insertion point for the sternocleidomastoid (SCM). The SCM muscle attaches to the mastoid and has two points of origin: the manubrium (upper portion of the sternum) and medial clavicle. The length of the SCM can be best palpated by rotating the subject's head to the opposite side of the SCM being palpated and flexing the neck forward slightly. To palpate:

- Place one finger posterior to the earlobe.
- Locate the mastoid process, which is the bony notch of the temporal bone.
- Palpate the SCM by locating the mastoid process attachment site and following the SCM until reaching the two sites of origin.

The Occiput

The occiput, colloquially known as the *base of the skull*, is composed of two structures: the external occipital protuberance and the superior nuchal lines. The external occipital protuberance is a superficial bump in the center of the occiput. The superior nuchal lines are fainter, project laterally from the medially-oriented external occipital protuberance, and serve as the attachment site for the trapezius and splenius capitis muscles (Biel, 2016). The occiput can be best palpated with the subject in the prone position. To palpate:

- Place the hand on the base of the skull, between the ears. Note the superior portion of the occiput, which is the external occipital protuberance.
- Slide the fingers inferiorly and under the protuberance. This is known as the *suboccipital region* and is composed of tendon and muscle.
- Slide the fingers laterally to palpate the superior nuchal lines, which extend toward each mastoid process.

Cervical Vertebrae

The cervical spine consists of seven cervical vertebrae numbered C1 to C7.

The cervical vertebrae are the smallest, but most mobile, of the vertebrae and are different from the thoracic and lumbar vertebrae due to a foramen in each of the transverse processes. This foramen allows for passage of the vertebral arteries as they ascend to provide blood supply to the brain and spinal cord. The cervical vertebra body is generally smaller, oval, and broader than other vertebrae. The seven cervical vertebrae are composed of the atlas (C1), the axis (C2), and individual vertebrae (C3 to C7).

Spinous and Transverse Processes

The spinous and transverse processes of the cervical vertebrae can be palpated with the subject positioned in prone or supine. The two vertebrae that are easiest to palpate are C2 and C7. Once locating the occipital protuberance on the subject, slide the fingers inferiorly along the midline of the neck until palpating a wide bony nodule-like structure, which is the spinous process of C2:

- As seen in Figure 9-3, the C2 spinous process is larger than the processes of the rest of the cervical vertebrae.
- C7 is the most easily palpable spinous process of the cervical vertebrae. C7 lies at the base of the neck, with a spinous process that protrudes further than C4, C5, and C6 (Biel, 2016). Slide the fingers toward the base of the neck to feel for the largest protuberance of the cervical spine.

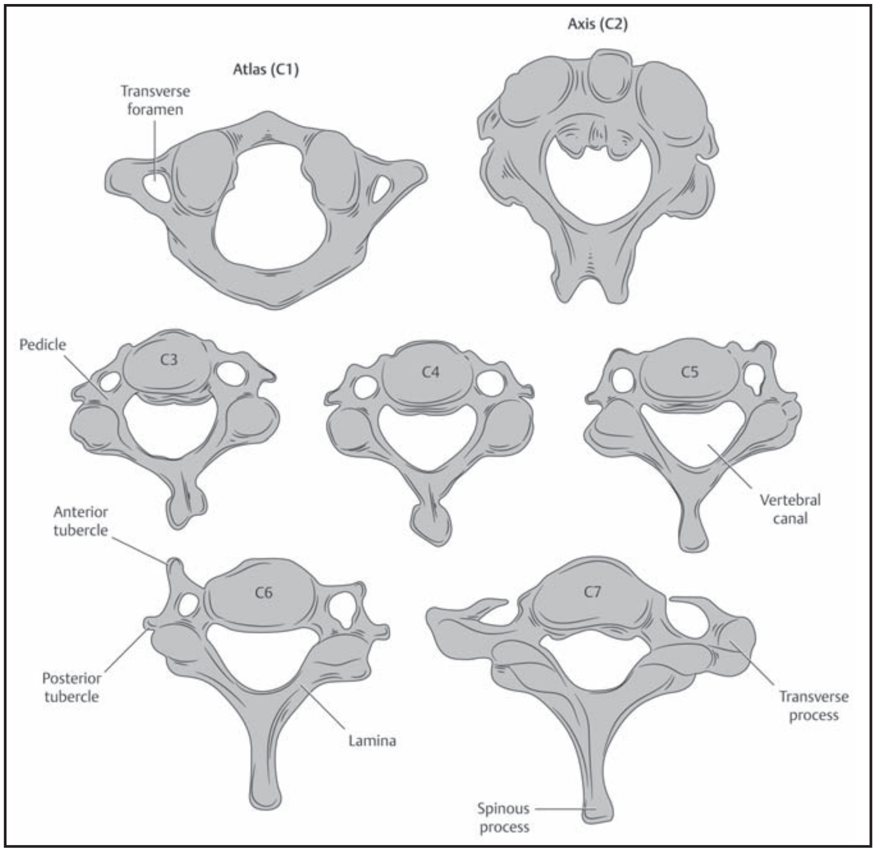

Figure 9-3. Seven cervical vertebrae (superior view).

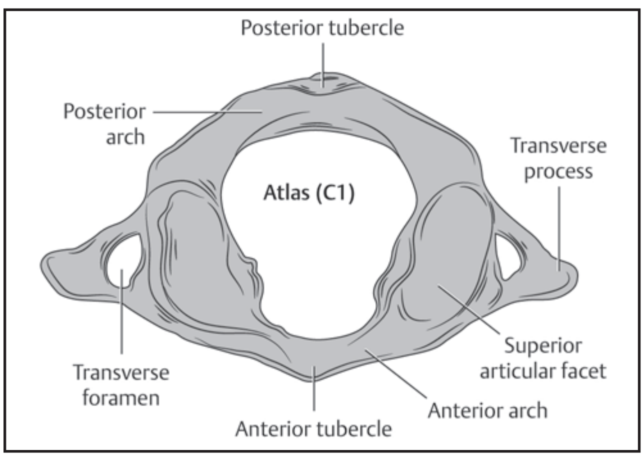

Figure 9-4. The atlas C1 (superior view).

By identifying the occipital protuberance, C2, and C7, accurately identifying the remaining cervical vertebrae can be achieved by palpating the spinous processes superior and inferior to these landmarks.

The transverse processes are more difficult to directly palpate as compared to the more superficial spinous processes. With the head in a neutral position, the transverse processes should align longitudinally with the posterior region of the ear:

- Position the subject in supine.
- Palpate the transverse processes by identifying the spinous processes and then shifting the fingers laterally until feeling a ridge at the posterolateral portion of the neck. This ridge is the landmark for the transverse process, which is difficult to palpate directly due to the numerous muscle attachments.

The Atlas

There are two large concavities on the superior surface that articulate with the occipital condyles of the skull, allowing flexion and extension around a frontal axis (Figure 9-4; Gench, Hinson, & Harvey, 1995).

The second cervical vertebra, C2 or the axis, forms a pivot around which the first vertebra, carrying the head, rotates. This rotational movement permits extensive ROM around a vertical axis, allowing for functional movement, such as turning the head side to side to scan the environment. The most conspicuous difference of C2 is the superior extension of the body, called the *dens*, where it articulates with the atlas. The axis provides the largest spinous process of the cervical spine (Figure 9-5), characterized by its wide shape and two bony projections, making the axis the most easily palpable vertebra of the upper cervical spine.

Vertebrae C3 to C7

These vertebrae have a wide vertebral body and are similar in shape and bony features. Unique to the cervical vertebrae are the transverse processes due to their termination as anterior and posterior tubercles. These tubercles serve as the attachment site for various muscles acting on the neck. The small opening within the transverse process is known as the *transverse foramen* and allows for passage of the ascending vertebral artery, which provides blood supply to the brain and

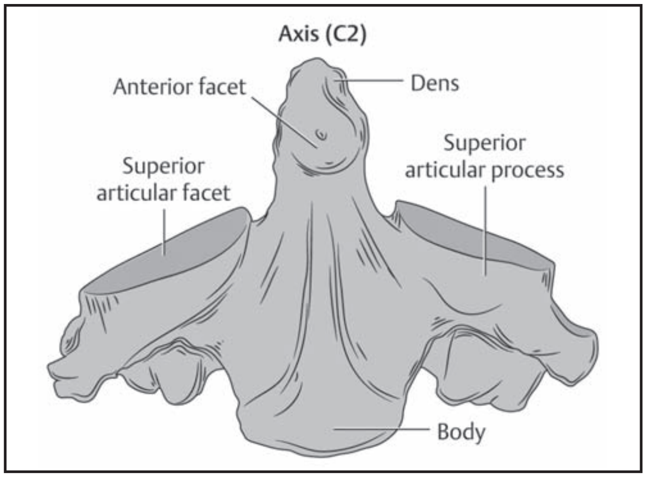

Figure 9-5. Axis (anterior view).

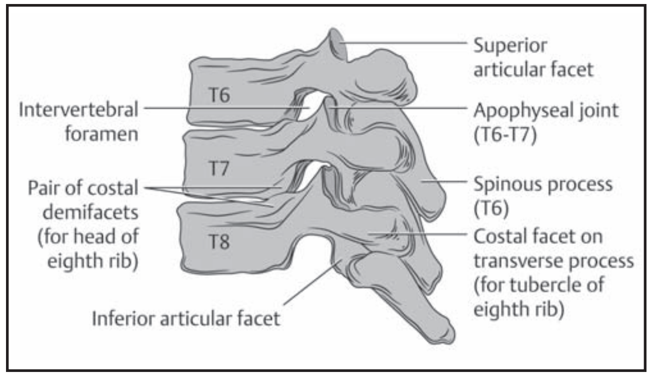

Figure 9-6. Thoracic vertebrae (sixth to eighth, lateral view).

spinal cord. The seventh cervical vertebra is distinctive due to its long and prominent spinous process. Because this spinous process protrudes further than all other cervical vertebrae, it is easily palpated and useful as a skeletal landmark.

Thoracic Vertebrae

Knowledge of the layout of various bony structures can aid practitioners in locating the 12 different thoracic vertebrae. In particular, orienting oneself to C7, the scapula, the sternum, and the ribs. To palpate:

- After palpating C7 on the subject, the spinous process of T1 can be palpated by simply shifting the fingers to the next level of vertebrae just inferior to C7.
- The spinous process of T2 can be located by first identifying the superior angle of the scapula. T2 is positioned at the same level as the superior angle of the scapula. If the subject bends forward, the spinous processes become separated and more easily palpated. In this region of the spine, the spinous processes are directed downward and overlap so that the spinous process of one vertebra is above the vertebral body of the subsequent vertebra.
- T4 can be located by first identifying the manubrium. T4 is at the same level where the manubrium transitions into the body of the sternum.
- T7 can be palpated by identifying the inferior angle of the scapula, which lies in alignment with the spinous process of T7.
- T10 is in alignment with the xiphoid process of the sternum (Carcia, 2012).
- T12 can be located by first identifying the twelfth rib, which ultimately articulates with the twelfth thoracic vertebra via the costal facets. If palpation of the twelfth rib is difficult, ask the subject to stand, laterally flex the trunk to the opposite side, and raise the upper extremity overhead (Carcia, 2012). This rib, which is 3 to 6 inches long, has a slender, spear-like shape and angles inferiorly. Following the shaft, move inferiorly and palpate the spinous process. The thoracic transverse processes can be palpated by first locating the spinous process, then move about 1 inch laterally until you feel the "subtle, knobby shape" (Biel, 2016).

The transverse processes of the thoracic vertebrae can be palpated using the strategy described previously for the cervical vertebrae. Key landmarks of the thoracic vertebrae are labeled on Figure 9-6. To palpate:

- The ribs articulate posteriorly with the thoracic vertebrae. The ribs vary in their angles and size as courses around the trunk but can be palpated at their lateral, forward, and downward angles (Biel, 2016; Houglum & Bertoti, 2012).
- The spaces between the ribs are easily palpated and can be followed laterally. The ribs are more easily palpated if the subject puts a hand on the head and leans to the ipsilateral side, which helps to separate the ribs for easier palpation.

Lumbar Vertebrae

Similar to the location of the thoracic vertebrae, the five individual lumbar vertebrae can be identified by first locating key bony landmarks of the pelvis, primarily the iliac crest. To palpate:

- The spinous process of L1 can be palpated by first locating T12 and simply sliding the fingers inferiorly until reaching the next vertebral level, L1.
- The spinous process of L4 can be located by first palpating the iliac crest. The most superior portion of the iliac crest is aligned with the L4 vertebra. The spinous processes are large, directed nearly horizontally so are approximately the same height as the vertebral body in this region of the spine. Attempt to locate the adjacent lumbar vertebrae superior and inferior to L4.

The lumbar transverse processes can be palpated with the subject in prone. First locate the lumbar spinous processes and move approximately 2 inches laterally and direct pressure at a medial or anterior angle. While the individual processes may not be identified, the solid ridge formed by the processes may be felt (Biel, 2016).

Sacral Vertebrae

There are five sacral vertebrae, which are fused together to form a triangular structure. The base of the sacrum, which is broad and expanded, is directed upward and forward. There are variations in the sacrum where there may be six bony pieces or as few as four, depending on the ability or failure of the bones to unite. The sacrum varies with respect to the degree of curvature and in shape and due to gender differences.

In identifying the location of the sacrum, it is approximately at the same height as the posterior superior iliac spine (PSIS).

Table 9-1

ACTIVE RANGE OF MOTION FOR CERVICAL MOVEMENTS (IN DEGREES)

	ATLANTO-OCCIPITAL JOINT	ATLANTO-AXIAL JOINT	APOPHYSEAL JOINTS OF C2 TO C7	TOTAL ROM OF CRANIOCERVICAL REGION	LIGAMENTOUS STRUCTURES LIMITING MOVEMENTS
FLEXION	5	5	5	45 to 50	Ligamentum nuchae, interspinous and supraspinous ligaments, ligamentum flava, capsule of the apophyseal joints, posterior annulus fibrosus, posterior longitudinal ligaments
EXTENSION	10	10	Negligible	85	Cervical viscera, anterior annulus fibrosus, anterior longitudinal ligament
ROTATION	Negligible	40 to 45	35	90	Annulus fibrosus, capsule of apophyseal joints, alar ligaments
LATERAL FLEXION	5	Negligible	40	40	Intertransverse ligaments, contralateral annulus fibrosus, capsule of the apophyseal joints

Adapted from Neumann, D. A. (2002). *Kinesiology of the musculoskeletal system: Foundations for physical rehabilitation.* St. Louis, MO: Mosby.

The dimples medial to the PSIS indicate the location of the sacroiliac joints (Biel, 2016; Carcia, 2012). At the sacrococcygeal articulation, there is a noticeable posterior convexity.

Coccyx Vertebrae

The coccyx is a series of small, triangular bones located at the bottom of the spine. It is composed of three to five coccygeal vertebrae, which may be fused together to form a single bone. The first three segments have a rudimentary body and articular and transverse processes, most notable on the first coccygeal bone, which is the largest and resembles S5. All of the coccygeal vertebrae lack pedicles, laminae, and spinous processes.

ARTICULATIONS OF THE SPINE

There are two types of joints present throughout in the spine. Cartilaginous (amphiarthrodial) joints are located between the vertebral bodies and discs and are called *interbody joints*. Movements include sliding in anterior to posterior, medial to lateral, and torsional directions; distraction; compression; and rotation (anterior to posterior and lateral directions; Levangie & Norkin, 2011).

Synovial (diarthrodial) joints occur between vertebral arches, specifically between the zygapophyseal facets of the superior articular surfaces of one vertebra and the inferior zygapophyseal facets of the adjacent vertebra (Levangie & Norkin, 2011). These are zygapophyseal (apophyseal or facet) joints. There are 24 pairs of apophyseal (facet) joints in the vertebral column. They have thin and loose articular capsules, synovial membranes, and menisci. Synovial joints also occur at the articulations of spine with the ribs, skull, and pelvis.

Cervical Articulations

The seven cervical vertebrae create seven pairs of joints. The joints within the cervical spine are the most mobile of the spinal column but are inherently less stable. This decrease in stability leaves the cervical spine highly susceptible to injury.

The seven pairs of cervical joints create 14 individual facet joints. These joints can be divided into three joint regions. The three joint regions of the cervical spine are termed the *atlanto-occipital*, *atlanto-axial*, and *apophyseal joints*. Each joint region contributes to the main motions of the cervical spine: flexion, extension, rotation, and lateral flexion. Other references may refer to rotation as *axial rotation* and lateral flexion as *side-bending*. ROM approximations for each of the cervical movements are further explained in Table 9-1.

Thoracic Articulations and the Thorax

The thorax is generally considered to be the area of the body between the neck and the abdomen, formed anteriorly by the articulation of the first seven ribs with the sternum through cartilages (true or vertebrosternal ribs) and the next three ribs (vertebrochondral ribs), which join together via costal cartilage. The remaining ribs, known as *vertebral ribs*, do not articulate with the thoracic vertebrae. Posteriorly, the thorax is composed of the thoracic vertebrae and discs and articulations of the ribs with the vertebrae. In addition, the vertebrae come into contact with each other and the pelvis. Sternal articulations (manubriosternal joint, xiphisternal joint, sternocostal joints, chondrosternal, and sternoclavicular joints) will be discussed in the shoulder chapter, while pelvic articulations (sacroiliac joints) will be discussed in the hip chapter.

The thoracic vertebrae are intermediate in size and have articular demi-facets (a facet that is split between two adjacent vertebral bodies) not found on other vertebrae. These demi-facets are located on the lateral, superior, and inferior portions of the vertebral bodies as well as the transverse process region. The demi-facets on the vertebral body articulate with the head of the rib, whereas the transverse process demi-facets articulate with the tubercle of the rib. Demi-facets are also referred to as *costal facets* (costal meaning *rib*) and serve as the only location where each of the 12 ribs articulate with the spine. The thoracic vertebrae are also the only vertebrae that support the ribs and have overlapping spinous processes, which project downwardly. In addition to ligamentous restrictions, these downward projections help to limit hyperextension of the thoracic spine. The superior and inferior articular facet joints of the upper thoracic spine begin in a frontal plane and transition to a sagittal plane at the lower thoracic vertebrae levels.

Aside from facet joint arrangement, the thoracic spine is different from the lumbar and cervical spinal regions in several additional ways. First, the intervertebral discs between the vertebra are thinner in the thoracic region, which may partially explain the inflexibly of this region of the spine. Also, due to the location of the thoracic pedicles, in general a more posterior and lateral orientation, the spinal canal is more narrow, creating the potential for spinal cord damage if a thoracic vertebra is injured (Levangie & Norkin, 2011)

The first and twelfth thoracic vertebrae are transitional so that changes in vertebral shape is gradual throughout the spine. Also, the ninth through twelfth vertebrae have features that differentiate them from the other thoracic vertebra. The first thoracic vertebral body has the typical cervical shape being broad transversely and with a long and prominent spinous process that is thick and nearly horizontal. The superior segment of T1 is not a demi-facet, as this is the only vertebra to articulate with the first rib (Gray & Lewis, 2000; Levangie & Norkin, 2011). In addition, the first thoracic vertebra supports two pairs of ribs through a pair of facets and a pair of demi-facets.

The general characteristics of the second through eighth thoracic vertebrae reflect regional variations in the vertebral structure. The thoracic body is larger than the cervical, and the anteroposterior and transverse diameters are equal (Gray & Lewis, 2000; Levangie & Norkin, 2011). The body is thicker posteriorly than anteriorly, which generates the normal kyphotic curve of the thoracic spine. The pedicles are directed posteriorly and upward and the laminae are broad and thick, overlap subjacent vertebrae, and connect to pedicles surrounding and protecting the spinal cord (Gray & Lewis, 2000). The spinous processes are long and triangular, are directed downward, and overlap from the fifth to eighth thoracic vertebrae. The transverse processes are thick, long, and strong, directed obliquely posteriorly and laterally with thickened ends.

There is variability in the number and location of articular facets in the ninth through twelfth thoracic vertebrae. The ninth thoracic vertebra may have no demi-facets or may have two demi-facets on either side. If this occurs, then the tenth has demi-facets only superiorly (Gray & Lewis, 2000). The tenth thoracic vertebra may have an articular facet on either side on the lateral surface of the pedicle. The body of the eleventh and twelfth thoracic vertebra is large, with large articular facets, thick and strong pedicles, and short spinous processes. The transverse processes are short with no articular facets (Gray & Lewis, 2000). The eleventh and twelfth thoracic vertebra have costal facets rather than demi-facets since ribs 1, 11, and 12 articulates correspond only with vertebral bodies (Levangie & Norkin, 2011). In the twelfth thoracic vertebra, a transitional vertebra between the thoracic and lumbar regions of the spine, the inferior articular surfaces are oriented in a lateral direction and the structure of the body, laminae, and spinous process resembling lumbar vertebrae. These two vertebrae contain a pair of full facets on the vertebral body to support the ribs.

Costotransverse Articulations

The joints formed between the facet of the rib and the transverse process of the thoracic vertebrae is a plane synovial joint permitting gliding motion. This articulation is present in all but the last two ribs. The articular capsule is a thin membrane and the joints are supported by the anterior and posterior costotransverse ligaments. The first rib has no anterior costotransverse ligament, and the lumbocostal ligament connects the twelfth rib to the first lumbar vertebra.

Costovertebral Articulations

These synovial joints are formed between the heads of the ribs and the transverse process of the thoracic vertebrae, and this occurs at the head and tubercle of the rib. There is greater movement at the costovertebral joints of ribs 1, 10, 11, and 12 since the rib articulates with only one vertebra and the interosseous ligament is absent here (Levangie & Norkin, 2011). Movements possible are rotation and gliding.

Elevation and depression of the ribs occurs by pivoting motion through the costovertebral and costotransverse joints. These two joints also contribute to respiration, protect vital organs, and contribute to the stability of the thoracic spine (Carcia, 2012).

Interchondral Joints

The interchondral articulations are formed between the costal cartilages of the sixth, seventh, and eighth ribs, and sometimes those of the ninth and tenth ribs. These articulations articulate with each other by small, smooth, oblong facets, creating synovial joints, enclosed by thin joint capsules and lined by synovial membranes. These joints are supported by intercostal ligaments and strengthened by interchondral ligaments.

Costochondral Joints

The costochondral joints are cartilaginous (synchondroses) joints between the ribs and costal cartilage and, normally, there is very little movement at these joints.

Vertebrosternal Ribs

The first rib and the manubrium move together and, while the attachment to the sternum is rigid, the lack of an interarticular ligament enables movement necessary for respiration.

Vertebrochondral Ribs

The movements of these ribs assist in enlarging the thorax for respiratory purposes and increasing the upper abdominal space for viscera displaced by the action of the diaphragm (Gray & Lewis, 2000).

Vertebral Ribs

These ribs are capable of slight movements in all directions.

Costocentral Articulations

A series of gliding joints are formed by the articulation of the heads of the ribs with the facets of the thoracic vertebrae and intervertebral fibrocartilages. They include an articular capsule and are supported by interarticulate and radiate ligaments.

Lumbar Articulations

This area of the spine has five vertebrae, which are the largest segments of the moveable spine. The body of the lumbar vertebrae has a greater transverse diameter than anteroposterior diameter and is greater than the height of the vertebrae (Levangie & Norkin, 2011). The pedicles are short and thick, very strong, and directed backward.

The spinous process is thick and broad, extending horizontally. The transverse processes are long and slender and are located in front of the articular processes instead of behind them, as in the thoracic vertebrae. The vertebral foramen are triangular, and while they are larger than in the thoracic region, they are smaller than in the cervical region.

The fifth lumbar vertebra is different from L1 to L4 since its body is much deeper anteriorly to create the sacrovertebral articulation. The L5 inferior facets face more anteriorly, and there are smaller, rounded spinous processes. In addition, the lumbar facets move from a sagittal plane to a frontal plane orientation at the lumbosacral junction (Kisner & Colby, 2012).

The lumbar vertebrae are important because they support the weight of the body. However, the lumbar vertebrae are also quite mobile, moving freely in all ranges except rotation. The orientations of the facets are nearly vertical, permitting flexion and extension until the lower lumbar region, where the facet orientation changes to the frontal plane. Because of the change in orientation of the facets and differences in movement, and due to joint capacity for both mobility and stability, this area of the spine is injured a lot.

In the sagittal plane around a mediolateral axis, there is a total of 30 to 50 degrees of flexion and 15 to 25 degrees of extension. Greater flexion and extension are possible in the upper portions of the lumbar spine. In the frontal plane around an anteroposterior axis, 25 degrees of lateral flexion are possible. Rotation in a transverse plane around a vertical axis of 5 degrees occurs at the lumbar joint, and there is gliding translational movement in all directions. The lumbar spine is reinforced by the iliolumbar ligaments at L4 to L5 and sacrolumbar ligaments, which restrict lateral bending, flexion, extension, and rotation (Carcia, 2012).

The lumbosacral joint is located between the fifth lumbar vertebra and the sacrum. While not structurally special, this is the joint at which the pelvis can move relative to the trunk (Muscolino, 2006; Neumann, 2002). The L5 vertebra articulates distally with the sacrum through the lumbosacral joint, so there is greater movement here than elsewhere in the lumbar spine (Gench et al., 1995). The L5 disc carries most of the loads placed on the back, which is then dispersed to the sacral base, sacroiliac joint, and acetabulae. The anterior portion of the lumbar vertebrae are designed for weightbearing, so excessive posterior loading may cause structural failure (Carcia, 2012).

Sacral Articulations

The body of the first segment is of a large size and resembles a lumbar vertebra, with the remaining sacral vertebrae decreasing in size. The central part is projected backward, providing increased capacity in the pelvic cavity. The apex is formed by the fifth sacral vertebra, is directed downward, and articulates with the coccyx. The lateral part of the sacrum articulates with the iliac on both sides at the sacroiliac articulations.

The sacrum articulates with four bones; the last lumbar vertebra above (junction of L5 to S1), the coccyx below (sacrococcygeal joint), and the hip bone on either side (sacroiliac joints). The sacrococcygeal joint is an amphiarthrodial cartilaginous joint between the apex of the sacrum and the base of the coccyx, supported by anterior, posterior, and lateral sacrococcygeal ligaments, and a fibrocartilage disc. It is capable of slight movement.

Coccyx Articulations

An amphiarthrodial joint connects the coccyx with the sacrum through the sacrococcygeal joint, where there is only slight movement.

Movements of the Spine

The movements in 24 of the 33 vertebrae of the spine are made by the articulation of two adjacent vertebrae, three intervertebral joints, soft tissues (intervertebral disc, longitudinal and intersegmental ligaments), and the facet joint capsules (Houglum & Bertoti, 2012; Levangie & Norkin, 2011; Magee, 2014). While motion of the spinal column is small between each vertebra, the combined motion of the spine is much more. ROM differs at various spinal levels, and skeletal structures that influence the motion of the trunk are the ribs (which limit thoracic movement) and the pelvis (which augments trunk movements by tilting; Nordin & Frankel, 2012). The intervertebral discs increase the motion available by enabling the vertebrae to tilt on each other because of the deformable disc. Flexion and extension occur in the sagittal plane around multiple axes, lateral flexion occurs in the frontal plane around sagittal axes, and rotation occurs in a transverse plane.

The articular processes allow some movements but restrict others. Horizontal facet surfaces enable axial rotation, and vertical facet structures in either the frontal or sagittal plane block axial rotation. This helps to explain why axial rotation is greater in the cervical region than in the lumbar. Other things influencing motion include the variability in the size of the discs, different shapes of the vertebrae, different muscle actions, and attachment of the ribs and ligaments (Neumann, 2002).

The average ROM for the entire spine is flexion 135 degrees, extension 120 degrees, lateral flexion 90 degrees, and rotation 120 degrees (Muscolino, 2006). It has been found that men are more mobile in flexion and extension, while women have more movement in lateral flexion. Loss of spinal ROM is age dependent (Bible, Biswas, Miller, Whang, & Grauer, 2010; Nordin & Frankel, 2012).

Pure planar motion rarely occurs in the spine but instead occurs as combinations of motions called coupling. Coupling has been defined as the "consistent association of one motion about an axis with another motion around a different axis" (Levangie & Norkin, 2011, p. 150). This occurs because of the orientation of the planes of the left and right facet joints as well as limitations imposed by the discs, ligaments, fascia, and muscles. The amount of motion produced at any spinal region depends on the size of the discs, and the direction of movement is determined by the orientation of the facets (Levangie & Norkin, 2011). The coupling motions vary considerably among individuals and within regions of the spine, and the greatest coupling occurs with rotational movements and with lateral flexion and extension.

Anterior and posterior vertebral structures have different biomechanical functions. Anterior structures (bodies of vertebrae, intervertebral discs, and longitudinal ligaments) are weightbearing structures that provide resistance to compressive forces, muscle contractions, and external loads.

The posterior vertebral structures include the vertebral arches, transverse and spinous processes, bilateral facet joints, joint capsules, and ligaments (ligamenta flava, supraspinous ligaments, ligamentum nuchae, and intertransverse ligaments). These facet joints, formed by the inferior process of one vertebra with superior process of an adjacent vertebra, serve to control vertebral motion and to protect the disc from excessive shear, flexion, lateral flexion, and rotation. The amount and direction of motion depends on the location in the spine (Carcia, 2012). Movements of the total spine include flexion and extension, lateral flexion and extension, and rotation.

Flexion

Flexion (forward bending) and extension (backward bending) have a range of 110 to 140 degrees, with limited motion in the thoracic area and free movement in the cervical and lumbar regions. Flexion of the whole trunk occurs primarily in the lumbar area for the first 50 to 60 degrees, and then more flexion is achieved by forward tilting of the pelvis and backward movement of the sacrum (Nordin & Frankel, 2012). The axis of rotation moves anteriorly with flexion and posteriorly with extension. In flexion, the superior vertebra glides anteriorly over the lower vertebra, causing compression of the anterior annulus fibrosus and stretching of the posterior annulus fibrosus. Posteriorly, the upper portions of the facet joints slide up on the lower facets. The compression and shear forces are controlled by the posterior ligament, capsules, muscles, fascia, and posterior annulus fibrosus fibers (Hamill, Knutzen, & Derrick, 2015). In both flexion and extension, the inferior facets slide upward in all sections of the spine, with the exception of the craniovertebral joint and sacrum (Kisner & Colby, 2012).

Extension

Extension is achieved by posterior pelvic tilting, gliding, and anterior sacral movement, followed by lumbar spine extension. In extension, the anterior portion of the bodies separate while the spinous processes get closer together. The amount of extension is limited by bony contact of the spinous processes; the size of the intervertebral disc; and passive tension in the joint capsules, annulus fibrous, ligaments, and muscles.

Rotation

Rotation occurs in the transverse plane in each spinal area but the kinematics vary greatly by region due to differences in the shape of the facet joints (Levangie & Norkin, 2011). Rotation of the spine is described as right or left rotation and occurs in a transverse plane around the long axis from the top of the head through the discs to the sacral region. If rotation to the right occurs, the superior vertebral body moves right while the spinous process moves to the left. As much as 90 degrees of rotation can occur, with free movement in the cervical region. The arthrokinematic motion at all segments of the spine (except the craniovertebral and sacrum) is that, as the ipsilateral facets slide downward, the contralateral facets slide upward for both rotation and lateral flexion and extension (Kisner & Colby, 2012).

Lateral Flexion and Extension

Lateral flexion (side-bending) and extension occurs in the frontal plane. Lateral flexion of 75 to 85 degrees occurs mainly in the thoracic or lumbar spine and is often accompanied by rotation. With lateral flexion, the superior vertebra laterally tilts, rotates, and moves over the adjacent vertebra, and the sides of the vertebral bodies become closer on the side to which the spine is bending.

Movements at the Cervical Spine

Flexion and extension occur within a sagittal plane around a mediolateral axis. In the craniocervical region, there is 45 to 50 degrees of flexion and 70 to 85 degrees of extension. At the atlanto-occipital joint, the convex occipital condyle rolls backward in extension and forward in flexion on concave superior facets of the atlas. Simultaneously, the condyle slides slightly in the direction of the roll. Further rolling motion of the condyle is due to tension in the tectorial membrane, articular capsule, and atlanto-occipital membranes (Neumann, 2002). The atlanto-axial complex has slight flexion and extension (about 15 degrees). At the intercervical articulations of C2 to C7, 70 degrees of extension occurs as the inferior articulating surfaces slide inferiorly. Extension is considered the close-packed position for most of the spine. Thirty-five degrees of flexion occurs as the inferior articular facets of the superior vertebrae slide superiorly and anteriorly on the superior articular facets of the inferior vertebrae (Neumann, 2002).

Rotation within a transverse plane around a vertical axis occurs at the cervical region. Axial rotation is seen as an important mechanism for attaining visual and auditory cues from the environment (Neumann, 2002). A total of 180 degrees of total rotation is possible, 90 degrees to each side. The atlanto-axial complex permits 40 to 45 degrees of rotation in each direction as the concave inferior articular facets of the atlas slide on the superior convex facets of the axis. There is also a slight lateral flexion to the opposite side. At the intracervical articulations, the inferior facet slides posteriorly and inferiorly to the same side for about 45 degrees of rotation and anteriorly and superiorly on the opposite side to the rotation. Rotation is greater in the more cranial portions of the cervical region. Lateral flexion permits one to touch the ear to the shoulder. In the craniocervical region, 40 degrees of lateral flexion to each side is possible.

Protraction and retraction of the head within the sagittal plane also occurs. Protraction flexes the lower to mid cervical spine and extends the upper craniocervical region; retraction extends the lower to mid cervical spine and flexes the upper craniocervical region (Neumann, 2002).

Movements at the Thoracic Spine

Since the rib cage is connected to each level of the thoracic spine, the thoracic spine is less mobile than either the cervical or lumbar portions of the spine. However, with the thoracic spine and rib cage anchoring each level of the spine from T1 to T10, this provides both stability and protection for the heart, lungs, liver, and other vital organs. The rib cage and sternum limit lateral flexion in the frontal plane and rotation in the transverse plane, while extension is limited by contact with the spinous processes in backward bending (Carcia, 2012; Neumann, 2010). The thoracic facets are oriented in the frontal plane around an anteroposterior axis for 20 to 40 degrees of lateral flexion. In the sagittal plane around a mediolateral axis, there is 20 to 45 degrees of flexion and 25 to 45 degrees of extension. At the thoracic joint, 35 to 50 degrees of axial rotation in a transverse plane around a vertical axis is possible, as are gliding translational movements in all directions (Magee, 2014; Muscolino, 2006; Neumann, 2010).

In the costotransverse articulations, there are only slight gliding motions possible due to the close connection of ribs with bodies of the thoracic vertebrae. The costocentral and costotransverse joints move simultaneously and in the same directions, with the rib acting as a lever with the costocentral and costotransverse articulations at each end.

The thoracolumbar region consists of the thoracic and lumbar spine. These joints together produce 85 degrees of flexion, 40 degrees of extension, 45 degrees of lateral flexion, and 35 degrees of rotation. The thoracolumbar junction is more prone to stress due to the restricted motion of the thoracic region and the relative mobility of the lumbar spine. Most of the rotation of the thoracic spine occurs at the lower segments, which are not restricted by the rib cage.

Movements at the Lumbar Spine

As with all of the regions of the spine, the lumbar spine produces flexion (40 to 60 degrees) and extension (20 to 35 degrees), lateral flexion (15 to 20 degrees), and rotation (3 to 18 degrees; Magee, 2014). Due to their sagittal plane orientation, the facet joints of the lumbar spine favor flexion and extension (Dalton, 2011). There is considerably less forward or backward facet gliding during lumbar flexion and extension than seen in other areas of the spine. Widening of the anterior disc space on extension or of the posterior disc space on flexion does not occur until movement nears its full ROM (Schafer, 1990).

Lateral flexion and rotation occur most in the upper lumbar spine, notably at L2 and L3. Rotation is limited because the inferior articular processes face laterally and anteriorly and the superior processes face medially and posteriorly, restricting this motion. Coupled motion is lateral flexion and rotation, but this is inconsistently reported in the literature and there is wide variability among individuals. The most mobile portion of the lumbar spine is at the lumbosacral junction where 75% of the spinal motion occurs, followed by 20% of the total lumbar motion at L4 to L5 and 5% at the remaining lumbar levels (Saunders, 1985).

Internal Kinetics: Muscles

While little discussion will be made about the spinal muscles, generally, the muscles are anterior or posterior in location. Anterior muscles flex the spine, whereas posterior muscles extend spinal segments. Lateral flexion occurs when one side of each pair of anterior and posterior muscles contracts, and rotation occurs when anterior and posterior muscles contract, but only if they do not lie parallel to the long axis (Gench et al., 1995). Understanding the location of muscles is key to determining muscle imbalances, especially with regard to faulty postures. For instance, the forward head, rounded shoulder presentation can result in shortening of the anterior spinal musculature and lengthening of the posterior spinal musculature.

Cervical spine motion occurs due to the synchronous relationship of various muscles, ligaments, and bony articulations. In addition to producing movement, muscles of the craniocervical spine stabilize the head and vertebral column in space, which facilitates the positioning of sensory organs. A stable craniocervical region also contributes to movement of the scapula as well as the glenohumeral (GH) joint. Dysfunction and/or instability of the craniocervical spine have previously been associated with pain and disability of the periscapular and shoulder region due to the interconnectedness of these structures.

Many of the muscles of the thoracic spine are extensions of the craniocervical muscles. Similar to the craniocervical region, muscles of the thoracic spine also provide stability to the vertebral column, which enables movements of the scapula and GH joint. In particular, these muscles include the latissimus dorsi, middle/lower trapezius, and rhomboids. The serratus anterior, a key muscle located in the thoracic region that facilitates scapular stability, protraction, and upward rotation, originates on the eighth and ninth ribs and inserts on the medial margin of the scapular, but does not have any direct attachments to the thoracic spine. Muscles with direct influence on the spine and their associated functions are listed in Table 9-2. Deeper muscles of the spinal column are not considered to be prime movers but are, however, key in stabilizing the different spinal segments. At the craniocervical region, the scalenes, longus colli, and longus capitis help to stabilize the neck; the erector spinae, transversospinal, and short segmental

Table 9-2

Spinal Muscles

	Posterior	Action	Anterior-Lateral	Action
Craniocervical and Upper Thoracic	• Splenius cervicis	• Bilateral: CC extension • Unilateral: Ipsilateral rotation	• Sternocleidomastoid	• Bilateral: CC flexion • Unilateral: Contralateral rotation
	• Splenius capitis		• Scalenus anterior	• Cervical (upper) lateral flexion; first rib elevation
	• Rectus capitis posterior major	• Bilateral: CC extension and ipsilateral rotation	• Scalenus medius	• Cervical (upper) lateral flexion; first rib elevation
	• Rectus capitis posterior minor	• CC extension, considered to be more of a sensory organ than a prime mover	• Scalenus posterior	• Cervical (lower) lateral flexion; second rib elevation
	• Obliquus capitis superior	• CC extension and ipsilateral lateral flexion	• Longus colli	• CC flexion and lateral flexion
	• Obliquus capitis inferior	• CC ipsilateral rotation	• Rectus capitis anterior	• CC flexion
			• Rectus capitis lateralis	• CC lateral flexion
Thoracic and Lumbopelvic	• Trapezius	• Upper: Scapular elevation, retraction, and upward rotation • Middle: Scapular retraction and upward rotation • Lower: Scapular depression, retraction, and upward rotation	• Rectus abdominis	• Spinal rotation and flexion
	• Latissimus dorsi	• GH abduction and internal rotation; scapular depression	• Obliquus internus abdominis	• Vertebral column ipsilateral rotation
	• Rhomboids	• Scapular retraction	• Obliquus externus abdominis	• Contralateral thorax rotation; rib inspiration
	• Levator scapula	• Scapular elevation; CC ipsilateral rotation and extension	• Transverse abdominis	• Rib and internal organ compression; core stabilization
	• Serratus anterior	• Scapular protraction and upward rotation	• Iliopsoas	• Hip flexion
	• Serratus posterior superior	• Assist with respiration	• Quadratus lumborum	• Bilateral: Lumbar extension • Unilateral: Lumbar lateral flexion and pelvic elevation

(continued)

Table 9-2 (continued)

SPINAL MUSCLES

	POSTERIOR	ACTION	ANTERIOR-LATERAL	ACTION
THORACIC AND LUMBOPELVIC	• Serratus posterior inferior	• Assists with respiration; depresses lower ribs		
	• Erector spinae group (spinalis, longissimus, iliocostalis)	• Thoracic extension, rotation, and lateral flexion		
	• Transversospinal group (semispinalis muscles, multifidi, rotatores)	• Thoracic rotation, lateral flexion and extension of cervical and lumbar spine		
	• Short segmental group (interspinalis muscles, intertransversarus muscles)	• Extension and lateral flexion of the lower vertebral column		

CC = craniocervical.

Adapted from Neumann, D. A. (2002). *Kinesiology of the musculoskeletal system: Foundations for physical rehabilitation.* St. Louis, MO: Mosby.

muscle groups stabilize the thoracic region; and the transverse abdominis and quadratus lumborum assist in lumbosacral stabilization. Muscles such as the serratus posterior superior, serratus posterior inferior, intercostals, levator costarum, and internal obliques are in the thorax region and assist with respiration and organ compression.

STABILITY OF THE VERTEBRAL COLUMN

Stability of the spine is essential to protect the spinal cord and neural elements and to prevent deterioration of spinal structures (Izzo, Guarnieri, Guglielmi, & Muto, 2013). A stable spine enables the transfer of forces between the trunk, upper extremities, and lower extremities and active force generation in the trunk. While there is a lack of consensus in defining spinal stability, the American Academy of Orthopedic Surgeons defines stability as "the capacity of the vertebrae to remain cohesive and to preserve the normal displacements in all physiological body movements" (Kirkaldy-Willis, 1985, p. 254).

Spinal joint stability normally depends on the size of the joint surfaces, height of the segmental centers of gravity above the joint surface, horizontal distance of the gravity line to the joint's center, and integrity of the ligaments supporting the joint surfaces. While the size, height of the centers of gravity, and distance to the joint's center vary throughout the spine, stability is especially important in the lumbar region due to increased loads placed on the spine (Schafer, 1990).

The spine has three stabilizing systems: passive or inert musculoskeletal structures, active musculoskeletal structures, and a neural feedback system (Hamill et al., 2015; Penjabi, 1992).

Passive Musculoskeletal Structures

The passive structures include the vertebrae, facet articulations, joint capsules, intervertebral discs, and spinal ligaments. The joint capsules and ligaments provide very little resistance to motion and the spine has high flexibility during initial to midrange motion (known as the *neutral zone*). With greater movement (into the elastic zone), these inert structures provide passive resistance and greater stability (Carcia, 2012; Izzo et al., 2013; Penjabi, 1992). The stabilizing action of a ligament depends not only on its intrinsic strength, but also on the length of the lever arm. A very strong ligament with a short lever arm may contribute to stability less than a less-strong ligament working by a longer lever due to greater mechanical advantage (Izzo et al., 2013). The disc has both tension-resisting properties (similar to a ligament) and compression-resisting properties (characteristic of joint cartilage). The disc allows and controls all of the movements of the spine, and the water content and thickness of the disc continuously change during normal daily activities under the opposite influences of hydrostatic and osmotic pressures (Izzo et al., 2013). Annulus fibrosus fibers are taut in whatever direction the segment moves—slack on the side of concavity and taut on the side of convexity. When a disc degenerates, the loss of tension allows the disc to bulge and permits increased movements and less spinal stability. The facet joints become incongruent due to the loss of disc height.

Stabilizing forces that occur during flexion are a taut cervical capsule at the end of flexion; frontal plane orientation of the lumbar spine facets and flexion is limited by the interspinous and supraspinous ligaments, capsular ligaments, ligamentum flavum, and posterior longitudinal ligament. The anterior longitudinal ligament limits extension, and the contralateral intertransverse ligaments, ligamentum flavum, and capsular ligaments limit lateral flexion and extension.

Rotation is restricted in the lumbar spine and limited by the capsular ligaments. The ribs restrict forward bending, lateral flexion, and rotation in the thoracic region, and the spinous processes restrict extension, especially in the thoracic region.

Active Musculoskeletal Structures

Muscle action is needed to stabilize the spine during standing, lifting, and bending activities. Stability of the spine is decreased when there is decreased muscle activity and increased when joint compressive forces increase. The smaller, deep muscles of the spine control posture and the relationships of the vertebrae, while the larger, more superficial muscles move the spine and disperse loads. The transverse abdominis, erector spinae, and internal oblique are especially important in spinal stabilization. The transverse abdominis muscle and obliques create intra-abdominal pressure providing segmental stability, while the erector spinae muscles counteract the force of gravity and provide global stability to the trunk. The obliques also stabilize the pelvis and control against loads that would cause extension or lateral flexion (Carcia, 2012).

Neural Feedback System

During movement, sensory receptors in joint capsules and ligaments are activated and provide feedback to the central nervous system about changes in length and tension of the muscles and inert structures. Damage to any spinal structure gives rise to some degree of instability.

Posture and Balance

Posture is the position of the head, limbs, and trunk and their relationships to each other. The stability of one's body is dependent on the relationship of the center of gravity (COG) with the base of support (BOS). The COG is a point of the body at which the entire weight of the body is concentrated. This is the balance point at which the vertical and horizontal planes meet (Greene & Roberts, 1999). In an upright position, the COG in humans is generally accepted to be at sacral level 1 or 2 (S1 or S2), although the precise COG for each person depends on the proportions of that individual. Specific centers of gravity for each body segment have been determined as well.

Changes in posture occur when any part is moved as in adjusting the position of the head and limbs in relation to trunk, adjusting the trunk in relation to the head or limbs when these are fixed, and making finely adjusted vertebral movements. Movement begins from a posture, so posture and movement are closely related. The position of the body affects the COG so that changes in movement produce changes in the COG. Stability is maintained if the line of gravity is maintained within the BOS. Try this exercise: put an object on the floor in front of you a few feet away from a wall, put your heels up against the wall, and then try to pick up the object while your feet remain against the wall. What happens? You lose your balance. Why? It is not because the weight of the object changes, nor because the force of gravity has changed, nor because your mass has changed. What has changed is the BOS relative to your COG. Your COG was no longer within your BOS, and being unable to make postural adjustments, balance and stability were lost. Had you not been standing against the wall, your hips would have moved posteriorly as you bent forward, thereby maintaining your COG over the BOS.

The function of the upper extremity is dependent on a stable base on which to work. Poor pelvic stability and posture will result in inefficient and uncoordinated activity of hands and arms (Trew & Everett, 2005). Symmetry and alignment of the spine with the pelvic girdle provides proximal stability, which, in turn, supports distal control of the extremities. A symmetrical position can minimize the risk of subsequent orthopedic deformities by keeping the bones and joints in alignment. Good posture minimizes fatigue because muscles are used correctly, with less strain and overuse in potentially deforming positions. There is a reduction of stress on ligaments, minimizing the likelihood of injury. Good posture also enables full use of the upper extremities and hands and aligns vision with the salient features of the environment.

Postural control enables the body to remain in equilibrium or in balance. Balance is maintained by automatic postural adjustments (equilibrium reactions) that serve to keep the COG over the BOS, to provide a wide base and lower COG (protective extension reactions), and to move the base to keep it under a moving COG.

The larger the BOS, the greater the stability. Consider a toddler who is learning to walk and the wide BOS that the toddler uses to maintain balance. This concept is further elucidated when considering the use of proper body mechanics in transfer and mobility activities with clients. Widening your BOS so that your vertical gravity line falls within a wider BOS and maintaining your COG close to the client's COG provide greater stability and safety in transfers.

Crutches, canes, and walkers are excellent means of improving mobility by increasing stability; these devices provide a broadened BOS. Clients need to learn to shift their COG so that it lies within the newly broadened BOS when using these devices. In addition to having a wider BOS, if the line of gravity falls at the center of the BOS, this, too, provides greater stability.

Individual client variables also affect balance and stability. Greater mass increases stability. If one considers a football player crouched at the beginning of a play, this position affords much in terms of stability. Not only is there a great deal of mass, but the crouched position also permits a lower COG and a wide BOS, which helps to stabilize the player. Changes in posture will cause the COG to move.

Another individual variable is level of skill. While we have automatic adjustments to postural displacement, we also can train ourselves to have better balance. Gymnasts, for example, have a high level of learned balance and are skilled in maintaining equilibrium and in the use of spatial judgments. Age is also an individual variable, and both static and dynamic balance are most efficient in young adults and middle-aged people. The elderly are especially at risk for falls due to problems with balance and mobility secondary to medical conditions, sensory loss, inattention, mental confusion fear of falling, weakness, and environmental hazards (e.g., illumination, surface characteristics, clothing and footwear, noise, clutter).

The importance of visual, vestibular, tactile, and proprioceptive sensory input can be clearly seen in the maintenance of balance. The vestibular system is vital in detecting motion

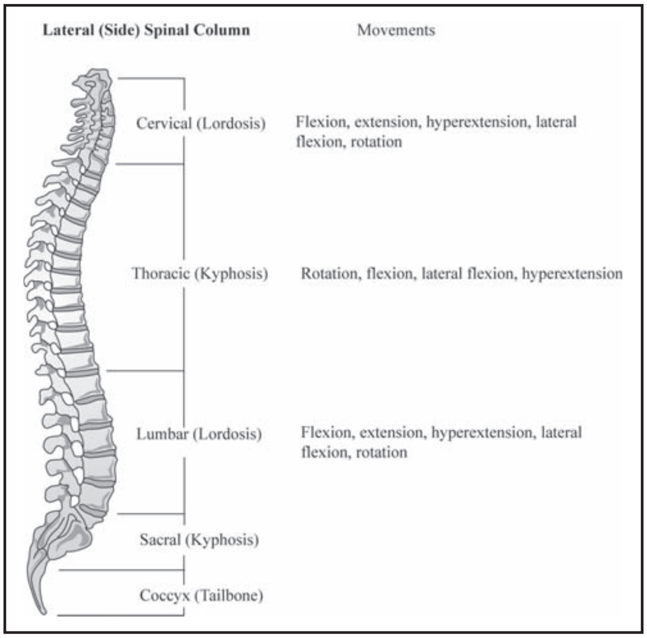

Figure 9-7. Normal curves of the spine.

and the position of the head in space in relation to gravity. This system influences muscle tone, especially in the antigravity extensor muscles, and helps to maintain stable visual perception when the person or environment moves. Proprioception is important in informing the body where the head is in relation to the body. The muscle spindles, Golgi tendon organs, and proprioceptors are instrumental in informing the body about the current position of joints, whether the joint is static or moving, the range and duration of movement, the velocity and acceleration of body segments, the pressure and tension in joint structures, and the relative lengths of muscles. Tactile input relays information regarding the focus of pressure on the soles of the feet, which is indicative of the location of the line of gravity within the BOS. Vision tells us the relation of the head to the object. The role of vision cannot be overemphasized because vision is the most far-reaching sensory system and strongly dominates our perception of the environment and our adaptation to it.

Posture and balance depend on the functional relationship between the spine and the hips as it relates to movement of both the upper and lower extremities. Balance needs to be maintained between the pelvis and feet, the trunk and pelvis, and the head on the trunk. Weight is distributed over each foot and between the two feet. Postural adjustments are made based on sensory input from the visual, proprioceptive, and vestibular systems.

Postural control has been defined as "the ability to maintain stability of the body and body segments in response to forces that threaten to disturb the body's equilibrium" (Levangie & Norkin, 2011, p. 485). It is influenced by a person's size, age, gender, and body type. External forces affecting standing posture include inertia, gravity, and ground reaction forces, while internal forces are muscle activity and passive tension in inert structures. Disruptions in equilibrium can occur in dynamic postural movements, such as walking, running, jumping, throwing, or lifting, or can interfere with stability in static postures, such as sitting, standing, lying, or kneeling.

Normal Spinal Curves

The spine has four naturally occurring curves, as seen in Figure 9-7.

The structures of the spine with the four curves provides balance and strength, and the junction of one curve with the next is often a site of much mobility (Magee, 2014). The thoracic and sacrococcygeal regions curve in a convex direction posteriorly; the cervical and lumbar areas bend in a convex direction anteriorly. The cervical and lumbar curves exist before birth and are called *primary curves*, whereas the thoracic and sacrococcygeal curves are secondary curves that develop in infancy and young childhood (Gench et al., 1995). Other curves associated with the spine occur when there is an increase in an anterior curve (lordosis), an increase in the posterior curve (kyphosis), or the existence of a lateral curve (scoliosis).

Standing

The stability of one's body is dependent on the relationship of the COG with the BOS. The COG is a point of the body at which the entire weight of the body is concentrated. This is the balance point at which the vertical and horizontal planes meet (Greene & Roberts, 1999). In an upright position, the COG in humans is generally accepted to be at S1 or S2, although the precise COG for each person depends on the proportions of that individual. Specific centers of gravity for each body segment have been determined as well.

Standing upright depends on the weight distribution on each foot; weight distribution between the two feet; and the balance of the pelvis over the feet, trunk over the pelvis, and head over the trunk. Posture and balance have been compared to stacking movable blocks, where balance is achieved between each block and the weight is distributed between two sides of the body. Changes in the position of the pelvis result in automatic realignment of the spine, especially in the lumbar region. Being in an upright stance has definite advantages for using one's hands in complex tasks, but it also creates a position that is inherently unstable because the COG of the body is over a relatively small BOS (Galley & Forster, 1987). Different standing postures, ideal and faulty, are shown in Figure 9-8.

If the head is too far forward or too far back, tension, strain, and pain in neck muscles; headache; and eye strain may result. The line of gravity continues to a point just in front of the shoulder, a point just behind the center of the hip joint, a point just in front of the center of knee joints, and approximately 5 to 6 cm in front of the ankle (Cook & Hussey, 1995). The cervical, thoracic, and lumbar regions of the spine maintain the normal curve, and the scapula is flat against the upper back (no winging or tipping). The pelvis and hips are in neutral position, and the hip and knee are neither flexed nor extended. The ankle is also in a neutral position relative to plantarflexion and dorsiflexion.

One cannot maintain a symmetrical stance for long, and standing is not a static activity. There is a continuous slight sway, and the magnitude of the sway tends to be larger in those who are very old or very young. Small motions occur automatically and continually as the body reestablished equilibrium in response to ongoing motion produced by respiration, cardiac contractions, and neural adjustments (Carcia, 2012). The alternating activity enables muscle spindles to be activated irregularly, so fatigue in any one motor unit is prevented and venous return is assisted. Sitting provides a more stable posture because the supporting surface area of the buttocks, back of thighs, and feet are greater. The COG is lowered, and this posture allows relaxation of the lower extremity muscles and less energy use. Pelvic stability, though, is greater in standing than sitting due to the passive locking mechanism at the hip by ligaments when the hips are fully extended during standing. When seated, the hips are flexed, and the locking mechanism is lost.

Anterior-lateral muscles that are involved in posture include the deep neck flexors (four on each side), scalenes (three on each side), SCM, and abdominals (rectus abdominis, external oblique, internal oblique, and psoas minor). The anterior muscles flex the spine. The abdominal muscles pull upward while the hip flexors pull downward in a synergist action to maintain posture. The posterior trunk muscles include levator scapulae, splenius, suboccipitals, erector spinae, semispinalis, multifidus, long rotator, short rotator, intertransversarii, interspinales, quadratus lumborum, and trapezius. Posterior muscles extend or hyperextend spinal segments. A similar muscle synergy exists for the posterior muscles, where the back muscles pull upward and the hip extensors pull downward to create stability. Lateral flexion occurs when one side of each pair of anterior and posterior muscles contract. Rotation occurs when anterior and posterior muscles contract, but only if they do not lie parallel to the long axis.

Faulty Postures

Faulty postures occur when one or more of the natural curves of the spine are exaggerated or diminished (see Figure 9-8). These can include kyphosis, lordosis, and scoliosis. Kyphosis is a pathological curve in which there is a forward curving of the spine that causes bowing of the back. Often, this posture is accompanied by posterior pelvic tilt. Parts of the spine lose the normal lordotic curve, which can cause slouching, breathing difficulties, and discomfort. Most descriptions of kyphosis pertain to the thoracic region (dowager's hump, hump back, or round back), resulting in abnormal rounding of the spine greater than 50 degrees, resulting in extreme curvature of the upper back. If a client has a flat scapula or winging of the scapula, this can give the appearance of a kyphotic curve (Magee, 2014). In rounded back, there is decreased pelvic inclination (tilt) with thoracolumbar or thoracic kyphosis usually caused by tight soft tissues. In a round back, increased compression on the anterior bodies of the vertebrae may lead to degenerative osteoarthritic changes (Muscolino, 2006). Abnormal humped back posture usually presents with a localized, sharp posterior protuberance called a *gibbus*.

Kyphosis can also occur in the lumbar region, where it is known as *flat low back* when there is decreased lumbar lordosis, decreased lumbosacral angle, hip extension, and posterior pelvic tilt. In the flat low back posture, there is decreased pelvic inclination. People with flat low back tend to lean forward when walking or standing. People who have a habitual slouching position of the spine may develop this posture. There can also be a curve in the cervical region, called *flat upper back and neck*. In this posture, there is a decreased thoracic curve, depressed scapulae, depressed clavicle, decreased cervical lordosis, and increased flexion of the occiput on the atlas. In addition, there may be one or more lateral curves in the lumbar or thoracic spine (notably in the Hunchback of Notre Dame). If there is a lateral curve in the cervical spine, this is called *torticollis*.

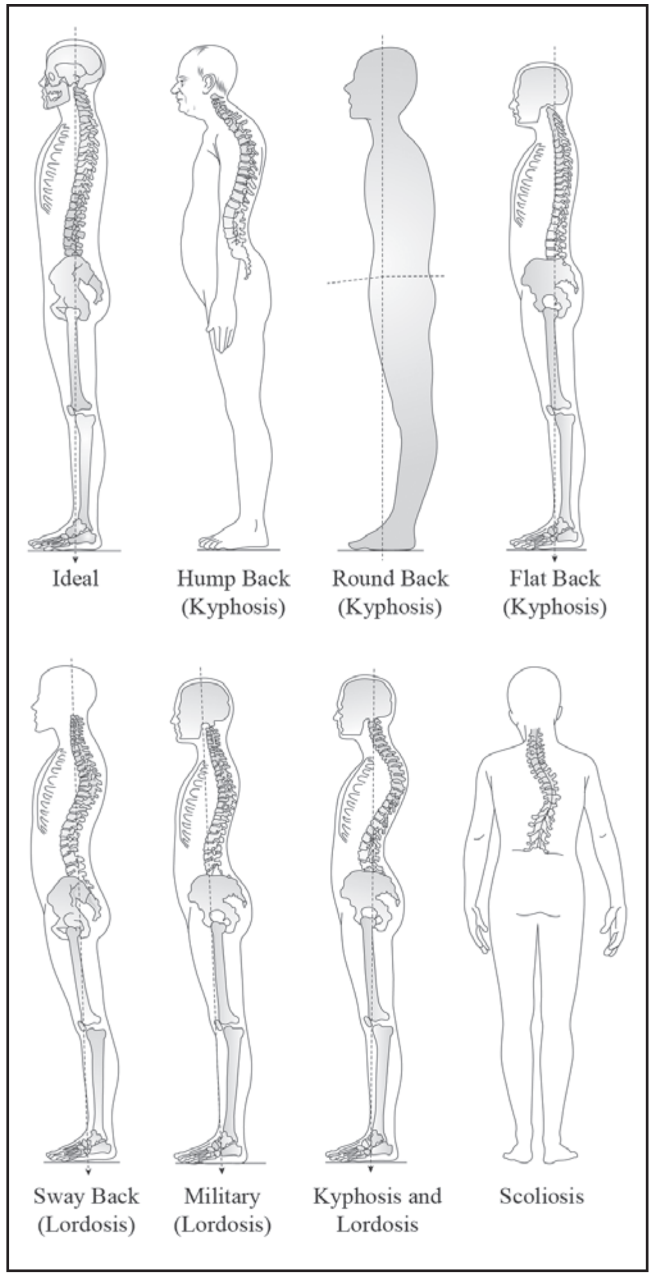

Figure 9-8. Standing postures.

Kyphosis may be due to degenerative diseases (osteoarthritis), congenital or developmental problems, osteoporosis with compression fractures, or trauma. Older women with osteoporosis often get kyphotic postures (called *dowager's hump* or *hyperkyphosis*), often caused by a wedge fracture where the front of a vertebra collapses. In adults, quite a few diseases may contribute to the degeneration of the vertebra and development of kyphosis, which may include hyperparathyroidism, Cushing disease, prolonged corticosteroid treatment, Paget disease, polio, fractured vertebrae, cancer, and tuberculosis. Scheuermann kyphosis is considered a form of juvenile osteochondrosis of the spine and can affect teenagers between the ages of 12 and 16 years (girls more often than boys). It may be due to growth retardation, blood circulation problems during rapid growth spurts, or poor posture. In this disease, infection, inflammation, and disc degeneration put the vertebrae under stress. There can also be congenital kyphosis in which infant spines do not develop normally, are malformed, or are fused.

When there is an extreme curve in the lumbar area of the spine, this produces a faulty lordotic posture (hyperlordosis). Usually, this spinal movement is accompanied by anterior pelvic tilt. Other names attributed to this posture are hollow back, saddle back, sway back, or relaxed. In the sway-back position, the cervical spine is slightly extended, there is increased flexion in the thoracic spine, and there is increased flexion with flattening of the lower lumbar curve and extended hips and knees. In the sway-back posture, the weightbearing is shifted through the facet joints rather than the discs, which can lead to degenerative osteoarthritic changes (Muscolino, 2006). Common causes might include tight low back muscles, excessive visceral fat, or pregnancy, and conditions such as achondroplasia, discitis, obesity, osteoporosis, and spondylolisthesis may contribute to the development of this posture.

Exaggerated lumbar curvature is also called *military curve*. In this position, there is a slight posterior tilt of the head, normal curves in the cervical and thoracic spines, hyperextension and increased lumbosacral angle in the lumbar spine, and the lumbosacral angle is determined by drawing a line parallel to the ground and the other line along the base of the sacrum. In the military stance, the pelvis is in anterior tilt and the hip is in flexion. The knee is slightly hyperextended and the ankle is slightly plantarflexed. Causes of this posture may include pregnancy, obesity, or weak abdominal muscles. Lordosis and kyphosis can also be present in the same individual.

Scoliosis is the lateral curvature of the spine or a frontal plane distortion in the thoracic or lumbar spinal regions. If viewed from the side, there would be mild roundness in the cervical or thoracic regions and a degree of sway back in the lumbar area of the spine. Causes of scoliosis are unknown and generally fall into the idiopathic scoliosis category. Neuromuscular scoliosis is seen in people with cerebral palsy, spina bifida, and muscular dystrophy. Degenerative scoliosis may be due to trauma, bone collapse, or osteoporosis. The abnormal curve tends to develop during growth spurts just before puberty. Since the articular surfaces are incongruent, there is articular friction that can lead to erosion, arthrosis, and nerve impingement. A summary of faulty postures is provided in Table 9-3.

Sitting

Effective seating promotes posture and comfort. The goal of stable sitting is to produce alignment of the body with the least expenditure of energy and least amount of stress on the body (Hamill et al., 2015). Sitting produces less load on the lower extremities as the additional contact forces that interact with body and chair are distributed over a wider area, offering a measure of physiologic maintenance and tissue protection. In an optimal seated position, vision, breathing, swallowing, and upper extremity function is optimized. A stable BOS can also enhance appearance and possibly social acceptance. Occupational therapists are able to adapt seating around existing deformities to achieve these objectives.

Various sitting postures are possible. One can be sitting supported, in a relaxed unsupported or erect unsupported position, or in a forward sitting posture. This has been called the *functional task position* or the *posture of readiness* (Cook & Hussey, 1995), in which the person's COG shifts in the direction of the activity. In unsupported sitting, the muscles of the spine are activated to overcome the backward rotation of the pelvis and lumbar kyphosis and achieve erect or lordotic sitting posture. The pelvis rotates forward, and the line of gravity is through the ischial tuberosities (Cook & Hussey, 1995; Hamill et al., 2015).

Optimal sitting posture is described as no pelvic obliquity or rotation with a slight anterior pelvic tilt. The trunk will have slight lumbar lordosis, slight thoracic kyphosis, and slight cervical extension. There will be neutral hip rotation (no internal or external rotation) and slight hip abduction. There will be 90 degrees of flexion of the hips, knees, and ankles. The hips should be higher than the knees, and the back should be supported. In the upper extremities, the elbows should be located slightly forward of the shoulders, and the forearms should be supported with the hands in the midline. The head is also in midline with eyes facing forward (Perr, 1998).

When seated and working, the head and neck should be vertically in line with the spine. The trunk should be straight with no torsion. The elbows should be close to the body with forearms approximately parallel to the floor. Wrists should be in neutral. Feet should be flat on the floor with thighs parallel to the floor.

The correct sitting posture has the following health benefits: decreased ligamentous strain to prevent overstretching, decreased muscular strain and overstretching of the back muscles, and decreased intradiscal pressure. This results in a healthy spine along the whole kinetic chain because of a reduction in stress on the thoracic and cervical spine and shoulder girdle. The muscles work more efficiently with a reduction in fatigue because the postural muscles are used to support the spine and rib cage while the extremities are used to conduct work. Greater ROM of the upper extremities is possible, and more efficient diaphragmatic breathing is achieved. More air entering the lungs ensures more oxygenated blood to vital organs, including the brain. With proper seat depth and tilt, there is improved lower extremity circulation (Jacobs & Bettencourt, 1995).

Prolonged sitting can have deleterious effects on the lumbar spine. Unsupported sitting requires higher muscle activity in the thoracic region and more of a load on the lumbar spine because of the backward tilt and flattening of the low back and the forward shifting of the COG, which adds an additional load on the discs. Jacobs and Bettencourt (1995) indicate that "research has provided a dichotomy: disc pressures are reduced when a person sits in an erect posture and maintains the three natural spinal curves but the trunk muscles exert less energy when a person sits in a slightly flexed or slouched position" (p. 140). For this reason, periodic changes in position and properly designed chairs are essential to the maintenance of good posture.

Table 9-3

Faulty Postures

Posture	Description	Muscle Imbalance and Structural Issues	Potential Pain	Potential Causes

Lordotic posture	• Increase in:
	  ◦ Lumbosacral angle
	  ◦ Lumbar lordosis
	  ◦ Anterior pelvic tilt
	  ◦ Hip flexion
		• Stress to:
		  ◦ Anterior and posterior longitudinal ligament
		  ◦ Iliofemoral ligament
		• Narrowing of the intervertebral foramen
		• Compression of the dura and blood vessels of nerve roots
			• Tight hip flexors
			• Tight lumbar extensors
			• Imbalanced or stretched abdominal muscles
			• Synovial irritation and joint inflammation
				• Faulty posture
				• Pregnancy
				• Obesity
				• Weak abdominal muscles

Kyphosis: Flat low back	• Decrease in:
	  ◦ Lumbosacral angle
	  ◦ Lumbar lordosis
	  ◦ Hip extension
	  ◦ Posterior tilt
		• Lack of normal physiologic lumbar curve
		• Stress to posterior longitudinal ligament
		• Increase in posterior disc space (nucleus pulposus may protrude posteriorly)
			• Tight trunk flexors and hip extensors
			• Stretched and weak lumbar extensor and hip flexor muscles
			• Reduced shock absorption
				• Continuous slouching
				• Overemphasis on flexion exercises

Kyphosis: Flat upper back	• Decrease in:
	  ◦ Thoracic curve
	  ◦ Depressed scapulae and clavicle
		• Fatigue of muscles
		• Compression of neurovascular bundle in thoracic outlet between clavicle and ribs
			• Tight:
			  ◦ Thoracic erector spinae
			  ◦ Intercostals
			  ◦ Scapular protractors
			• Potentially restricted scapular movement
				• Exaggerating the upright posture

Kyphosis: Round back	• Increase in:
	  ◦ Pelvic angle
	  ◦ Thoracic curve
	• Protracted scapulae
	• Forward head position
		• Stress to posterior longitudinal ligament
		• Fatigue in thoracic erector spinae and rhomboid muscles
		• Potential for:
		  ◦ Thoracic outlet syndrome
		  ◦ Cervical posture syndromes
			• Tight anterior thorax (intercostal muscles)
			• Pain in muscles of cervical spine
				• Continuous relaxed lumbar posture or the flat low back posture
				• Continuous slouching
				• Overemphasis on flexion exercises

Kyphosis: Lordosis posture	• Forward head • Hyperextension of cervical and lumbar spine • Knee extension • Increased flexion of thoracic spine	• See both lordosis and kyphosis	• Weakness in anterior neck and upper back muscles and muscles of lower abdomen	• See both lordosis and kyphosis

The height of a properly fitted chair should be equal to length of the leg from the back of the knee to the base of the heel, with knee bent to 90 degrees and feet flat on the floor. If the seat is too long, there is pressure behind the knee. If too short, there will be pressure on the posterior surface of the thigh and more pressure on the feet. The chair back should be inclined back slightly and with a lumbar support.

An ergonomically well-designed chair would include the following:

- Seat height that is easily adjustable, as in a pneumatic chair
- Backrest that is easily adjustable to support the lumbar spine vertically (height) and horizontally (forward and backward) and is narrow enough so that the operator's arm or torso does not strike it if rotation is required
- The seat tilts forward and backward independently of the backrest. This feature is useful with fine detail work and office work.
- The seat edge is curved to reduce pressure under the legs.
- There is enough space between the back of the chair and the seat to accommodate the buttocks.
- The adjustable armrests (optional) are small and low enough to fit under the work surface and to support the back when the worker works close to the work surface.
- The base has five points of contact on the floor (safety).
- The worker can make adjustments easily with one hand while seated.
- The upholstery fabric is comfortable, reduces heat transfer in warm climates and static electricity in cold weather, and is stain resistant and easily cleaned.
- Training is provided to ensure that workers are familiar with the features and adjustments of an optimally fitting chair.

By having an adjustable chair, you can avoid many of the awkward seating positions. A seat that is too low may cause you to laterally flex the trunk or to rest the body on the arm, fatiguing the neck, shoulders, and back. A seat that is too high will elevate the scapula, resulting in muscle tension and fatigue in the neck and shoulders. Armrests made of hard materials or with sharp corners can irritate the nerves and occlude blood vessels, creating pain or tingling in the fingers, hand, and arm.

Sitting in a wheelchair presents several challenges that this text will only briefly discuss. Many wheelchairs have a sling seat, which is good for transport of the chair because it can be easily folded and placed in a trunk or backseat. However, the position of the person in the wheelchair is one where the hips slide forward and rotate inward, which brings the knees together. This position encourages "sacral sitting," which is an exaggerated posterior pelvic tilt. This position in the wheelchair is not particularly comfortable for long periods of time and makes it more difficult to effectively use one's hands in activities. There are ramifications related to pressure distribution as well as to posture and comfort. With the posterior pelvic tilt, there is additional weight on the ischial tuberosities, coccyx, and possibly lower sacrum, which may precipitate scoliosis or promote pelvic obliquity. Cook and Hussey (1995) add that a:

> [S]ling seat conforms to the forces generated by the individual instead of providing forces that resist and stabilize. This is an application of Newton's Third Law: each action (force) has an equal but opposite reaction. The internal forces of the body are not balanced by external forces from the sling seat. (p. 257)

These present challenges for the comfort, safety, and function of our clients in wheelchairs.

Assessment of the Spine and Posture

Assessment of the Spine

Occupational Profile

Once rapport is established with the client, the next step in the assessment process is to gather information from the client about his or her occupational history, habits and patterns of daily living, interests, and valued occupations. Find out why the client is seeking occupational therapy services and what specific areas of occupation are especially important for successful participation. Consider the client's physical and social environment, especially important in considering ambulation, balance, and fall potential. Contextual information can be gleaned about customs and beliefs and personal history. The priorities and outcomes desired by the client and the occupational therapy assessment will determine the intervention goals. Figure 9-9 displays areas of assessment for the spine and thorax.

Observation and Palpation

Observational assessment of the client begins the minute the client enters the room. Notice if there was ease in the movement and if it was produced due to action in the spine, or was it motion in the pelvis and hips. As the client stands relaxed with arms at the side, check points of reference at the trochanter, sacral, and iliac crest and shoulder levels for evenness. Ask the client to look up and transfer from sit to stand and, lifting one or both arms overhead, deviations, compensations, or discrepancies between the two sides of the body can be observed. Do you notice any postural deformity or unusual pelvic tilt or slight limp in the person's gait pattern? How comfortable is the person when walking and sitting? Observe how the client gets up from the chair.

It is important to observe the client in standing and sitting, from anterior, posterior, and lateral orientations. Different postures provide different information about how the spine is functioning. For example, the lumbar spine falls into full flexion during relaxed or prolonged sitting, but prolonged standing in a relaxed posture places the lower lumbar spine into full extension.

Note any abnormalities in the chest or thorax and observe how the client breathes (quality of breath, rate, and effort). Age and gender have been found to differentiate how people breathe: children breathe abdominally, women breathe in the upper thoracic area, and men breathe in the upper and

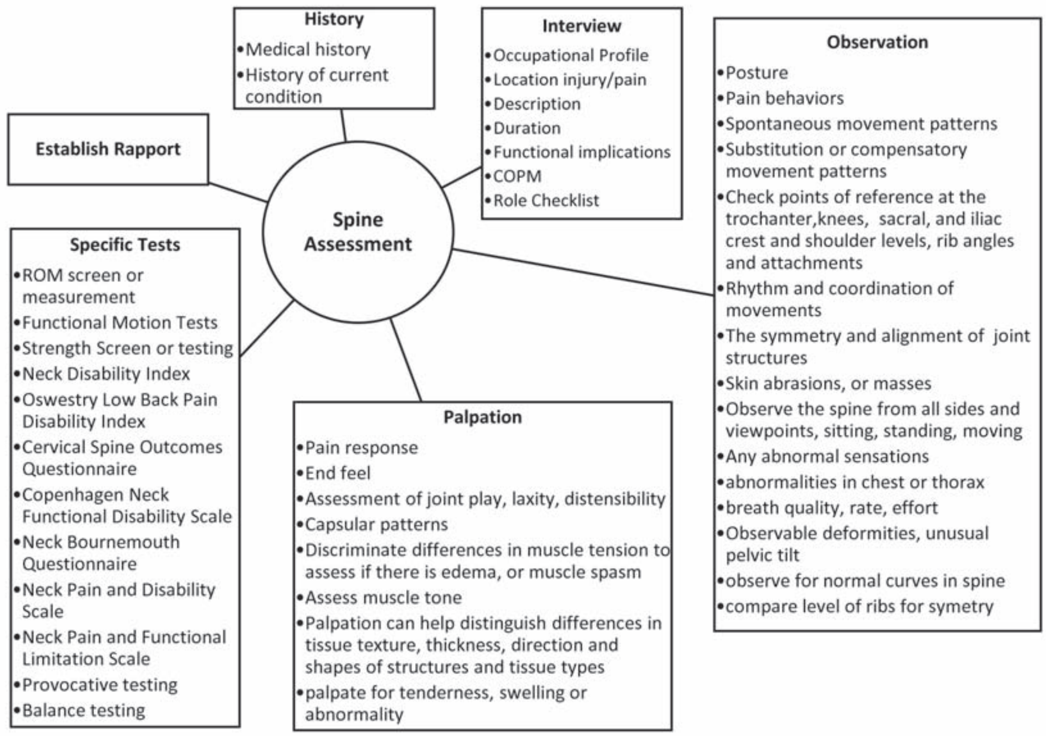

Figure 9-9. Evaluation of the spine and thorax. (Adapted from Cooper, C. [Ed.]. [2007]. *Fundamentals of hand therapy: Clinical reasoning and treatment guidelines for common diagnoses of the upper extremity* [p. 74]. St. Louis, MO: Mosby.)

lower thoracic region. Elderly people tend to use the lower thoracic and abdominal areas when breathing (Magee, 2014). Costovertebral expansion also can be measured during respiration. Pain around the chest is often costovertebral, and pain during respiration may indicate rib involvement. Breathing problems could also be due to many other reasons such as fractures, scoliosis, trauma, pneumonia, or pericarditis.

Observe grossly if the cervical, thoracic, and lumbar regions of the spine maintain the normal curves and that the scapula is flat against the thorax, with the pelvis, hips, knees, and ankles in a neutral position. Observe if the anterior, posterior, and lateral plumb lines of the ideal posture aligned. Also note if there is any abnormal rotation or tilt of the client's head. Compare both sides of rib motion to see if they are equal or if there is any restriction (Sidebar 9-1).

Sidebar 9-1 Practice

Using small markings, identify the areas listed below that are used as landmarks to assess postural alignment. Mark bilateral structures where appropriate.

- Mastoid process
- Anterior, lateral, and posterior acromion
- Sternal notch
- Anterior superior iliac spine
- PSIS
- Acetabulofemoral joint (hip joint)
- Lateral epicondyle of femur
- Spinous processes of C7, T3, T8, T12, and L3
- Lateral malleolus of ankle
- Posterior surface of the calcaneus (ankle)

Once all areas are marked, assess the subject from the anterior, posterior, and lateral views.

Note any asymmetries as landmarks are compared from left to right.

From the lateral view, note any landmarks that are out of alignment with the imaginary plumb line. Laterally, the plumb line should pass through the mastoid process, acromion, hip joint, anterior lateral epicondyle of the knee, and anterior to the lateral malleolus.

Figure 9-10. Client presentation of forward head, rounded-shoulder posture.

Watch the client move and observe the client's posture in sitting and standing, from the front and back. Posture is influenced by many factors, including general health status, body build, gender, strength and endurance, visual and kinesthetic awareness, personal habits, and maintenance of one's COG over a sufficient BOS. Anatomic factors that affect posture are body contours, laxity of ligamentous structures, musculotendinous tightness (e.g., hamstrings, tensor fasciae latae, pectorals, hip flexors), muscle tone (particularly in gluteus maximus, abdominals, erector spinae), pelvic angle, joint mobility, and neurogenic flow (Magee, 2014).

Consider the upper and lower extremity together because movement and positions in the upper extremity, neck, and back influence posture and balance of the trunk and lower extremity. Look to see if the right and left sides are symmetrical and at the same height at the hip and shoulder. Check for symmetry between bony landmarks, including the rib angles and attachments. Observe if the knee joints are straight and aligned. Notice if each body part (or blocks stacked on each other) is balanced over the part below. Are the normal spinal curves present, or are they excessive or decreased? Is the head protracted? These postural relationships can easily be observed.

Students and novice practitioners can become more familiar with postural bony landmarks by identifying key anatomical features on a partner and assessing for symmetry. Individuals with neutrally aligned posture should have symmetrical anatomical features when comparing side to side in an anterior/posterior view. From the lateral view, landmarks should align in a longitudinal manner from the ear to the lateral malleolus of the ankle. A plumb line assessment can help practitioners in identifying postural abnormalities.

A faulty scapular position can influence posture. If there is a forward tilt of the scapula, this results in a forward head position and increased thoracic kyphosis (Figure 9-10). Client presentation of forward head and rounded shoulder posture is a position often assumed when working at a desk on a computer. The forward head, rounded shoulder posture can lead to imbalance of the musculature acting on the cervical spine. Specifically, the forward head, rounded shoulder posture can cause shortening of the deep neck flexors, shortening of the suboccipital muscles, and lengthening of the trapezius and levator scapulae muscles. There may be weakness in the serratus anterior, rhomboid, and trapezius muscles. This posture is accompanied by cervical lordosis in the midcervical region and extension of the atlanto-occipital joint, which can lead to suboccipital muscle shortening, causing referred pain known as *cervicogenic headaches*. These headaches can also arise if the greater occipital nerve is pinched due to muscle shortening. The forward head, rounded shoulder posture can result in shortened anterior cervical and chest musculature and might lead to brachial plexus pathology and diminished respiratory capacity. It is important to inquire about posture during routine activities, such as sitting, sleeping, driving, and working.

Abnormal cervical alignment can lead to possible temporomandibular joint pain and increased lower cervical mobility that may result in degenerative changes in the intervertebral discs and actual cervical vertebrae. With the forward head posture, the cervical vertebrae are no longer able to maintain their 45-degree orientation with the adjacent vertebrae, causing a shearing force throughout the vertebral column. This shearing force can lead to the formation of osteophytes (or bone spurs), which can ultimately impinge the cervical nerve roots at the neural foramen region. Nerve root impingement can result in cervical radiculopathy, which is characterized by radiating pain, weakness, or sensory changes in the upper extremity.

The forward head position is also a posture commonly seen in the elderly. The altered lordotic curve (either flattened or exaggerated) and rounded shoulders are often accompanied by flexed hips and knees. Flexed or stooped posture can result in a chronically stretched neck, trunk, hip, and knee extensor muscles, and a compensatory shift in the vertical displacement of the COG in a backward direction (Bonder & Bello-Haas, 2009).

Wearing high heels is another example of how changes in one part of the body affect balance and posture in other areas. When high heels are worn, the body weight is displaced anteriorly, leading to an increased curve in the lumbar spine (hyperlordotic lumbar spine or sway back) in order to counterbalance the weight of the body. Due to the increased lumbar curve, the thoracic spine curvature also increases (round back or hyperkyphotic thoracic curve), leading to a rounded shoulder position and anterior movement of the neck. The wearing of heels raises the COG but over an unnaturally narrow BOS, placing an unstable mass onto the forefoot. There is also a narrow side-to-side BOS, with the tendency to invert or evert the ankle. The weight is shifted onto the toes, and the arch of the foot collapses into inversion. Prolonged lordosis causes a shortening of the hip flexors, which can ultimately lead to degenerative changes in the discs. The Achilles tendon will shorten, as will the gastrocnemii and hamstrings. Combined with weakened quadriceps, this can lead to low back pain, injury, and alterations in gait (Greene & Roberts, 1999).

The structures of the anterior thoracic region (sternum, ribs, clavicle) can be palpated to identify any areas of tenderness, swelling, or abnormality. Posteriorly, the thoracic spinous processes can be palpated, but the facet joints are difficult to isolate and may elicit muscle spasms or tenderness, which may be indicative of internal organ injury (e.g., gallbladder, spleen, kidney; Magee, 2014). Thoracic spine pain and visceral pain can mimic each other due to shared afferent innervation from the autonomic nervous system. In addition, pseudoanginal pain may be elicited in T4 to T7. Other referred pain to the thoracic region may indicate cardiac ischemia, thoracic aneurysm (sudden chest pain radiating to upper back), peptic ulcer (pain from epigastric area to middle thoracic region), or cholecystitis.

There is much individual variability in the movement of the lumbar spine. Most movement is in L4 to L5 and L5 to S1. It is visually difficult to see the movement that is occurring due to the shape of the facets, tight joint ligaments, and size of the vertebral bodies (Magee, 2014). Clients may describe symptoms that their low back seems to "give away," "lock," or is painful during transitional activities or sustained postures. Low back pain is a common problem at the lumbar and lumbosacral regions due to a large amount of stresses on this section of the spine. Lumbar instability is associated with pain, fibrosis, and spondylolisthesis. The low midline sill sign test is used to detect spondylolisthesis. The test is positive if lumbar lordosis increases and the spinous processes form an L with the upper spinous process displaced anterior to the lower spinous process. The interspinous gap change (LI) test is for palpation of LI during lumbar flexion-extension motion. While some authors believe that these tests are effective for the detection of both low midline sill sign test and LI, others state that the tests have not been shown to be reliable or valid, and an x-ray is needed to confirm this hypothesis (Ahn & Jhun, 2015; Alqarni, Schneiders, Cook, & Hendrick, 2015; Collaer, Mckeough, & Boissonnault, 2006).

Movement Patterns

Movements of the spine include flexion/extension, lateral flexion, and rotation.

ROM measurement of each vertebra is difficult to measure, so indirect measures are often used. Flexion, extension, and lateral flexion may be measured with a double inclinometer method, but no normative values have been found, and reliability of these measurements has not been researched. Rotation and combined movements are measured purely on observation. The most accurate assessment of vertebral motion is with radiography. When the client is actively moving, look for his or her willingness to move, the quality of movement, where movement occurs, the ROM, if there is pain, and any deviations in movement.

Intervertebral motion can be assessed passively by applying pressure in a posterior to anterior direction to the thoracic spine either directly on the spinous process or unilaterally located just lateral to the spinous process, and feel for movement while the client flexes or extends the spine. Rib motion may be accessed in two locations, with posterior to anterior pressure applied to the rib angles and anterior to posterior pressure applied at the costosternal joints (Magee, 2014). Passive motion in the spine is characterized by a firm end feel.

Functional active ROM for the cervical spine is 20 degrees of flexion and extension, 9 to 21 degrees for lateral flexion, and 13 to 57 degrees for rotation. In a review of 15 activities of daily living (ADL), including standing to sitting, backing up a car, cutting food with a knife, tying shoelaces, washing hair, walking, and picking up objects from the floor, backing up a car required the most active ROM (67.6 degrees rotation). Tying shoes required 66.7 degrees of flexion/extension, while washing the hair in the shower required 42 degrees of flexion/extension. Personal hygiene items entailed more active ROM than ambulation. From this study, the authors concluded that most people only use a small percentage of cervical ROM for most ADL (Bennett, Schenk, & Simmons, 2002; Bible et al., 2010).

In a study to determine the lumbar ROM required for 15 ADL, Bible et al. (2010) concluded that only a small percentage of full, active ROM is required to complete most of the activities. The median percentages of full active ROM for the ADL activities was 11% of flexion/extension, 17% of lateral flexion/extension, and 13% of total rotational motion. Overall, personal hygiene ADL (e.g., hand washing, washing hair, shaving, makeup application) required a similar amount of motion in the lumbar spine, as in the locomotion tasks of walking and going up and down stairs.

Strength

Muscle strength, length, and tightness testing is recommended for the muscles in the thoracic region. Tests of muscle length of the latissimus dorsi, pectoralis major, and pectoralis minor generally have moderate to substantial interrater reliability (Cleland, Childs, Fritz, & Whitman, 2006). Manual muscle testing of the middle and lower trapezius have no reported interrater reliability, and the serratus anterior and rhomboids have fair and moderate interrater reliability, respectively (Cleland et al., 2006). Tests for muscle tightness might include the 90-90 straight leg raising test, Ober test, rectus femoris test, and Thomas test (Magee, 2014). In addition to muscle testing in the lumbar region, additional tests may include the dynamic abdominal endurance test, dynamic extensor endurance test (erector spinae and multifidus), double straight leg lowering test (abdominal eccentric test), dynamic horizontal side support (bridge) test (quadratus lumborum), and back rotators/multifidus test (Magee, 2014).

Functional Assessment

Assessment of the cervical spine is necessary for clients with cervical pathologies; however, practitioners must also appreciate how the cervical spine can influence upper extremity dysfunction as well. Many scholars and expert practitioners recommend screening the cervical spine of clients with upper extremity involvement. Based on the results of the cervical screen, practitioners can create a more accurate intervention plan to best address the client's needs.

There have been many assessments developed to assess the cervical spine. The Neck Disability Index (Vernon & Mior, 1991) is the most extensively studied assessment for the cervical spine and was based on the Oswestry Low Back Pain Disability Index (Fairbank, Couper, Davies, & O'Brian, 1980). The Neck Disability Index is used to assess pain intensity, personal care, lifting, reading, headache, concentration, work, driving, sleeping, and recreation. Other cervical and neck pain assessments include the Cervical Spine Outcomes Questionnaire (BenDebba, Heller, & Ducker, 2002); Copenhagen Neck Functional Disability Scale (Jordan, Manniche, & Mosdal, 1998); Neck Bournemouth Questionnaire (Bolton & Humphreys, 2002); Neck Pain and Disability Scale (Wheeler, Goolkasian, Baird, & Darden, 1999); Neck Pain and Functional Limitation Scale (Leonard et al., 2009); Neck Functional Status Questionnaire (Wang et al., 2015); Neck Outcome Score (Bohannon, Wang, Bubela, & Gershon, 2017); Northwick Park Neck Pain Questionnaire (Leak et al., 1994); and ProFitMap Neck (Björklund, Wiitavaara, & Heiden, 2017).

In reviews of the cervical assessments, most included more items related to activity and participation categories than to body function. The focus was on daily life activities and participation rather than physical function. Of the activity and participation items, there were more mobility items than other areas, followed by personal care and community and social participation. Body function items that were included focused on mental function, sensory function, and pain. Few of the assessments reviewed included neuromusculoskeletal function (Schellingerhout et al., 2012; Wiitavaara & Heiden, 2018).

Since the thoracic vertebrae play an important stabilizing function for the spine, cervical and lumbar function may be impaired if there are limitations in the thoracic region. Activities such as lifting, rotation of the trunk, and heavy work require intact thoracic vertebrae (Magee, 2014). The squat is one way to screen for biomechanical deficits that can affect neuromuscular control, strength, stability, and mobility within the kinetic chain. The squat movement pattern is required for essential ADL, such as sitting, lifting, and most sporting activities (Myer et al., 2014).

The Oswestry Low Back Pain Disability Index (Fairbank et al., 1980) can be used for a functional rating index for all parts of the spine. It has been extensively tested, demonstrating good psychometric properties and applicability in a wide variety of settings. Functional items include intensity of pain, lifting, ability to care for oneself, ability to walk, ability to sit, sexual function, ability to stand, social life, sleep quality, and ability to travel. Similar to assessments of the cervical spine, many assessments of the thoracic and lumbar spine include functional items as well as items related to pain. A few of the spinal screening and functional tests include the Back Pain Functional Scale (Stratford, Binkley, & Riddle, 2000); STarT Back Screening Tool (Hill et al., 2008); Numeric Pain Index (McCaffery & Beebe, 1989); Quebec Back Pain Disability Scale (Kopec et al., 1995); 10-Minute Screening Test for Chronic Back Pain Clients (Hendler, Viernstein, Gucer, & Long, 1979); Roland-Morris Disability Questionnaire (Roland & Fairbank, 2000); Functional Rating Index (Feise & Michael, 2001); Dallas Pain Questionnaire (Lawlis, Cuencas, Selby, & McCoy, 1989); Japanese Orthopedic Association Scale (Izumida & Inoue, 1986); and Aberdeen Back Pain Scale (Ruta, Garratt, Wardlaw, & Russell, 1994). Despite the large number of spine assessments that have been developed, there is still no single outcome measure that is reliable, valid, and sensitive to clinically relevant changes in client conditions (Sidebar 9-2; Longo, Loppin, Denaro, Maffulli, & Denaro, 2010).

Sidebar 9-2 Practice

For the practitioner evaluating clients with pain that is thought to be originating from the cervical region, various techniqes can be applied to help gather a robust depiction of the client's symptoms. The following points should be considered during assessments of the cervical spine:

- ROM evaluation
    - Cervical flexion, extension, rotation, and lateral flexion
    - Consider assessing protraction and retraction of the cranium as well.
    - Note ROM asymmetries.
- Trigger points/tender of soft tissue that cause radiating symptoms
    - Applying slight pressure to these tender areas may result in pain radiating to the head, behind the eye, behind the ear, or down the arm.
- Palpate key landmarks to detect asymmetries
    - Scapulae, acromions, lateral rib cage, pelvic girdle, acetabulofemoral joint, tibiofemoral joint, and lateral malleolus should be marked to allow for easy identification of postural asymmetries during a plumb line assessment.

Special tests, otherwise known as *provocative tests*, can be used to confirm or refute the presence of conditions related to the cervical spine (Table 9-4). The cervical cluster (Wainner et al., 2003), for example, can be used to detect cervical radiculopathy. The cervical cluster consists of the upper limb tension test—A, cervical rotation, cervical distraction, and Spurling's test. According to Wainner et al. (2003), if three out of the four tests are positive, then the client has a 65% likelihood of experiencing cervical radiculopathy. If all four tests are positive, the client has a 90% likelihood of experiencing cervical radiculopathy. The upper limb tension test—A has been the single-most accurate test in detecting cervical radiculopathy.

Cervical nerve root impingement and trigger points may lead to the development of pain and/or noxious symptoms that radiate away from the neck (e.g., to the orbital region, periscapular region, or the distal upper extremity). Familiarity with myotomes, dermatomes, and trigger point referral patterns can enable practitioners to identify potential sources of clients' pain. Myotomes (*myo*, meaning muscle) refer to the spinal nerves that innervate a particular muscle group(s). For instance, C6 spinal nerves are responsible for providing motor function to the wrist extensors. Dermatomes (*derma*, meaning skin) refer to the spinal nerves that provide sensory innervation to a region of the body. In the same example, C6 provides sensory innervation to the lateral region of the upper extremity and radial portion of the hand. Both myotome and dermatome distributions are listed in Table 9-5.

Table 9-4

PROVOCATIVE TESTS FOR CERVICAL SPINE

TEST	INSTRUCTIONS	INTERPRETATION
Upper limb tension test–A	Client is supine; practitioner passively positions client's affected upper extremity through the following: 1. Shoulder internal rotation, elbow 90 degrees flexion, wrist/fingers neutral 2. Shoulder neutral, elbow 90 degrees flexion, wrist/fingers neutral 3. Shoulder 100 degrees abduction, elbow 90 degrees flexion, wrist/fingers neutral 4. Shoulder remains at 100 degrees abduction, 90 degrees shoulder external rotation, forearm supination, wrist/fingers neutral 5. As above, with elbow fully extended 6. As above, with wrist/fingers fully extended	Mark position as positive or negative. Positive if less than half of the movement can be achieved. Also, compare ease of movements from affected to unaffected sides, as differences may be attributed to impaired brachial plexus mobility.
Cervical rotation	Client is seated; client rotates head to affected side and unaffected side; practitioner measures ROM with goniometer	Mark position as positive or negative. Positive if ROM is 60 degrees or less to affected side. Also, compare ease of movements from affected to unaffected sides.
Cervical distraction	Client is supine; grasp client's chin and occiput, position neck in slight flexion, apply distraction force of approximately 14 kg	Mark position as positive or negative. Positive if maneuver decreases or alleviates symptoms. Also, compare ease of movements from affected to unaffected sides.
Spurling's test	Client is seated; place client in lateral cervical flexion and apply compression of approximately 7 kg in the direction of the base of the cervical spine	Mark position as positive or negative. Positive if maneuver is painful or reproduces client's symptoms. Also, compare ease of movements from affected to unaffected sides.

Assessment of Posture

Postural assessment is multidimensional. Because of the functional triad of vestibular, visual, and proprioceptive sensory modalities, these are all specific areas of assessment. Spatial awareness and spatial orientation are perceptual aspects of balance. Awareness of posture and position in space is fundamental to the assessment. Kinesiologic factors, such as achieving and maintaining the COG over the BOS and the ability to move easily and without restriction, are important to consider. Poor balance coupled with decreased vision and other sensations (especially proprioception and vestibular), lower extremity muscle loss, cognitive impairment, blood pressure fluctuations, and medication side effects are often cited as intrinsic fall risks.

ROM and flexibility, particularly for knee extension and dorsiflexion/plantarflexion, are evaluated with careful attention to the amount of ankle control in ambulation. Muscle tone, peripheral innervation, and involuntary movements are also assessed. Vital signs in lying, sitting, and standing are taken to determine if there are any differences based on position because fluctuations in blood pressure can directly influence balance.

Strength and muscle length assessments of not only the lower extremity but also grip and the upper extremity are done. Essential strength tests would include the rectus abdominis, internal oblique, external oblique, and transverse abdominis muscles. In the lower extremity, the strength of the iliopsoas, gluteus maximus, hamstrings, gluteus medius, quadriceps, and tensor fascia latae should be assessed. The serratus anterior, trapezius, infraspinatus, teres minor, and subscapularis should also be tested for strength in the upper extremity (Hall & Brady, 1999). Testing the muscle length of the hamstrings, gastrocnemius, tensor fascia latae, hip flexors, and hip rotators in the lower extremity should be done, as well as testing of the teres major, latissimus dorsi, rhomboid major, rhomboid minor,

Table 9-5

MYOTOME AND DERMATOME DISTRIBUTIONS OF THE SPINE

KEY SPINAL NERVE ROOT	MYOTOME PATTERN	DERMATOME PATTERN
C4		Clavicle
C5	Shoulder abduction	Lateral shoulder
C6	Elbow flexion	First digit (thumb)
C7	Elbow extension	Third digit
C8	Wrist flexion	Fifth digit
T1	Finger abduction	Medial arm
L2	Hip flexors	Mid-anterior thigh
L3	Knee extensors	Medial femoral condyle
L4	Dorsiflexors	Medial malleolus
L5	Long toe extensors	Dorsal second/third toe web space
S1	Plantar flexors	Lateral heel

levator scapula, pectoralis major, pectoralis minor, and shoulder rotators in the upper extremity.

Discuss with the client any fears he or she has about moving or falling, and identify if the client engages in any risk-taking behaviors that would increase the risk of falls (e.g., climbing on high ladders). Anticipatory and reactive sensory processing can be seen in functional tasks, such as opening a door and lifting objects of different weights. Observation during ADL can also reveal balance and postural dysfunction.

A comprehensive evaluation would include both the intrinsic and extrinsic elements related to posture and balance. A thorough history of falls, periods of dizziness, and frequency of episodes of imbalance are important pieces of information to gather from the client. Does the client have a history of depression or cognitive impairments?

Cognition is often overlooked as a variable in balance, posture, and falls. If proprioception diminishes (as occurs with advanced age), people tend to look at the feet when walking as a compensatory strategy. This requires attention because walking is no longer automatic, and there are limits to the number of tasks one can attend to simultaneously (Chronister, 2003). Establishing the client's level of alcohol consumption and the medications that he or she uses is also a part of the occupational profile. Understanding what occupations the client does and when and where they are done will facilitate any environmental adaptations that may be necessary.

Extrinsic factors that can lead to postural disturbance and falls include unstable chairs, steep stairs, poor or inadequate lighting, loose rugs or cords on the floor, improper footwear, or excessive clutter. Visual aspects in the environment such as patterned carpets or flooring, glare, and poor lighting also contribute to falls. Diminished sensory and neurological function can impair balance, as seen in slowed reaction times, failure of protective responses, and lack of awareness of body parts in space. Coupled with intrinsic factors of decreased muscle strength, diminished bone strength, and failure of shock absorbing structures, it is not difficult to see why there are fractures of the hip following a fall in the elderly that are functionally devastating. If a home visit is not possible, a home assessment completed by the client or family member can be very helpful in identifying environmental hazards.

Assessment Tools

Balance can be assessed by means of standardized assessments and during activities. Static posture is posture without motion, whereas dynamic posture occurs during active movement (Jacobs & Jacobs, 2009). Simple balance screens can be done by observing the client sitting or standing, bending to reach something from the floor, having the client look over his or her shoulder and up at the ceiling, or having the client reach for something at the side. Ask the client if he or she felt unstable or dizzy in addition to observing for any loss of balance or unsteadiness.

Different scales have been developed to classify balance. The Performance Oriented Mobility Assessment is a task-oriented scale that measures gait and balance of older adults (Tinetti, 1986). The balance portion of this test uses nine different maneuvers to test balance, including sitting, standing, sit to stand, turning around 360 degrees, receiving a nudge on the sternum, turning the head, leaning back, standing on one leg, and reaching objects from the floor and from overhead. This test has good inter-rater reliability (85% agreement between raters) and good concurrent validity with the Berg Balance Scale and is predictive of fall risks.

A grading scale for balance is used as a basic guideline in many U.S. facilities, although evidence to support the use of the scale has not been documented (Jacobs & Jacobs, 2009). The scale is similar to manual muscle grades (zero, trace, poor, fair, good, normal), with plus and minus given to further refine the scale. A minus rating in the fair and good ranges indicates an inconsistent ability, and notation of assistive devices needs to be included when assessing the client's abilities. Table 9-6 provides the balance guidelines.

Tests of static balance include the Frailty and Injuries: Cooperative Studies of Intervention Techniques (Rossiter-Fornoff, Wolf, Wolfson, & Buchner, 1995), the Clinical Test of Sensory Interaction and Balance or Sensory Organization Test (Shumway-Cook & Horak, 1986), and the Romberg test. In the Frailty and Injuries: Cooperative Studies of Intervention Techniques, there are two balance scales comprising three or four tests of static balance. This tool has acceptable reliability, validity, and discriminate ability (Rossiter-Fornoff et al., 1995). The Clinical Test of Sensory Interaction and Balance test assesses the interaction of somatosensory, visual, and vestibular elements on stability. The Romberg test assesses stance as a test of proprioception, when a client stands with his or her eyes open and then with the eyes closed.

There are many dynamic assessments of balance. The Berg Balance Scale (Berg, Wood-Dauphinee, Williams, & Gayton, 1995) looks at balance components common to many

Table 9-6

Balance Guidelines

Grade	Posture	Movement	Ability of Individual
0	Sitting	Static	Needs max assistance to maintain sitting without back support
0	Sitting	Dynamic	N/A
0	Standing	Static	Needs max assistance to maintain
0	Standing	Dynamic	N/A
P	Sitting	Static	Needs moderate assistance to maintain
P	Sitting	Dynamic	N/A
P	Standing	Static	Needs moderate assistance to maintain
P	Standing	Dynamic	Needs moderate assistance during gait
P+	Sitting	Static	Needs minimal assistance to maintain
P+	Sitting	Dynamic	N/A
P+	Standing	Static	Needs minimal assistance to maintain
P+	Standing	Dynamic	Needs minimal assistance during gait
F	Sitting	Static	Maintains without assistance but unable to take any challenges
F	Sitting	Dynamic	N/A, cannot move trunk without losing balance
F	Standing	Static	Maintains without assistance but unable to take any challenges
F	Standing	Dynamic	Needs contact guard assistance during gait
F+	Sitting	Static	Able to take minimal challenges from all directions
F+	Sitting	Dynamic	Maintains balance through minimal active trunk motion
F+	Standing	Static	Takes minimal challenges from all directions
F+	Standing	Dynamic	Needs close supervision during gait; able to right self with minor loss of balance
G	Sitting	Static	Takes moderate challenges in all directions
G	Sitting	Dynamic	Maintains balance through moderate excursion of active trunk motion
G	Standing	Static	Takes moderate challenges in all directions
G	Standing	Dynamic	Needs supervision only during gait; is able to right self with moderate loss of balance
G+	Sitting	Static	Takes maximal challenges in all directions
G+	Sitting	Dynamic	Maintains balance through maximum excursion of active trunk motion
G+	Standing	Static	Takes maximum challenges in all directions
G+	Standing	Dynamic	Independent gait with/without devices
N	No deviation seen in posture held statically or dynamically		

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functional tasks, such as reaching, bending, transfer, stand, and arise. It has high inter-rater reliability (0.98, intraclass correlation coefficient [ICC] = -0.98), high internal consistency (Cronbach's alpha = 0.96), and good concurrent validity (r = 0.91 with Tinetti, r = 0.76 with Get Up and Go). The Four Square Step Test is a test of dynamic stepping ability and standing balance (Dite & Temple, 2002). The Functional Reach Test measures self-initiated movement within a fixed BOS while standing (Duncan, Weiner, Chandler, & Studenski, 1990). The Functional Reach Test has 89% test-retest reliability with ICC = 0.99. The Physical Performance Test has seven out of nine items that are related to static and dynamic balance, including making a 360-degree turn, donning/doffing a jacket, picking up a heavy book, picking up a penny from the floor, stair climbing, and walking 50 feet (Ruben & Slu, 1990). The Timed Up and Go Test (Podsiadlo & Richardson, 1991) times how long it takes a person to go from sit to stand, walk 3 meters, and return. Inter-rater reliability is 0.99 with ICC = 0.99 with 0.81 concurrent validity with the Berg Balance Scale. The complexity of the test can be modified by having the client count backward from a randomly selected number between 20 and 100 (cognitive aspects) or by carrying a full glass of water during the test. A self-administered interview about the client's confidence in doing activities without loss of balance or unsteadiness is the activities-specific balance confidence (Powell & Myers, 1995). Many standardized balance measures have established norms for age and gender.

In a review of balance assessments, Whitney, Poole, and Cass (1998) concluded that many of the balance assessments require minimal equipment and time to administer. Timed or ratio measurement tools, such as the Timed Up and Go Test and the Physical Performance Test, were more sensitive to change. The Berg Balance Scale, Functional Reach Test, and Tinetti Balance Test are helpful in setting goals and seem to be good predictors of falls.

Sensory Triad: Visual, Proprioception, and Vestibular

The physiologic basis for many of the balance tests (particularly the Romberg test) is the combination of visual, proprioception, and vestibular sensory systems. One part of the Romberg test is done with the client's eyes open, which tests whether the sensorimotor integration (cerebellum and dorsal column-medial lemniscus tract) and motor pathways (corticospinal tract and medial and lateral vestibular tracts) are functioning. Vision is occluded in another part of the test, so a loss of proprioception or vestibular sensation is more obvious. Maintaining balance relies on these intact sensory pathways, sensorimotor integration, and motor pathways.

In the sensory triad related to balance, each sensory modality adds an important piece to the ability to remain balanced. The vestibular system detects motion and the position of the head in space in relation to gravity. This influences muscle tone and helps to maintain stable visual perception when moving. Proprioceptive input informs the body where the head is in relation to the body and monitors the intensity, velocity, and tension of body segments. Vision tells us the relation of the head to the object and aids in head and neck alignment.

Visual Assessment

Visual assessment related to balance and posture would focus primarily on assessment of oculomotor skills. These would include an evaluation of smooth visual pursuit, saccades, nystagmus, gaze stabilization, and convergence/divergence. Visual field and visual acuity testing is also important. In addition, eye-hand coordination and visual-vestibulo-ocular reflex interaction would be additional areas to assess.

Proprioception Assessment

Tests of gross sensory evaluation often include tests of proprioception (position sense) and kinesthesia (movement sense). Tests of proprioception have the therapist move the client in one position, and then the client describes the position or assumes the position on the opposite side.

Vestibular Assessment

A comprehensive vestibular assessment includes many of the motor and sensory components already discussed. In addition, gross cerebellar tests of coordination are helpful to identify specific deficits in eye-hand function.

Primary symptoms of vestibular dysfunction include vertigo or dizziness, imbalance, decreased safety, falls, visual-motor dysfunction (e.g., blurred vision, spatial disorientation), and nystagmus. Secondary symptoms may also be present, which may include nausea, muscle tension, postural rigidity, anxiety, decreased conditioning, decreased activity levels, and fear of movement (Cohen, Burkhardt, Cronin, & McGuire, 2006). The assessment of the vestibular system needs to involve moving the head to elicit these feelings of spinning or whirling and its intensity and frequency.

The client may report avoiding tasks that require bending over or bending down (e.g., looking into low cupboards, bending to put on a pair of socks), bending forward (e.g., grooming the hair, brushing teeth), bending the head back (e.g., to swallow medication), repetitive head movements (e.g., driving), navigating their way in stores, carrying objects, or scanning grocery shelves (Cohen et al., 2006).

A vertigo assessment would start first with an evaluation of the vertebrobasilar artery to determine if it is safe for more provocative testing. The client will be seated and is asked to actively rotate and hyperextend the head to each side for 3 to 5 seconds. A positive sign is if the client experiences vertigo, nystagmus, nausea, pupil dilation, or syncope indicative of vertebral, basilar artery insufficiency. If these symptoms occur, do not proceed with additional testing. Other tests of vascular insufficiency resulting in symptoms of vertigo, nystagmus, or dizziness include George's screening procedure, Barre-Leiou test, Dekleyn test, and Hallpike test.

In the Hallpike test, the client is in a supine position with the head extended off the end of the table. The head is then passively moved into extension, rotation, and lateral flexion to each side for 15 seconds. A modified Hallpike test has the client in supine with the head tilted comfortably and then gently passively moved 45 degrees to one side. Other modifications include testing the client in sidelying. The Dix-Hallpike test (Nylen-Barany test) is performed with the client seated with the legs extended and the head rotated 45 degrees. The client then lies down backward with the head in 20 degrees of extension.

Have the client change the position of the head and assess the intensity of the symptoms and the time required to recover. Moving the head from side to side with the eyes open and closed, moving the head up and down with eyes open and closed, tilting the head to the right and left with the eyes open and closed, bending forward from the waist with eyes open and closed, and moving from sit to supine and then supine to sit are positional head movements that may elicit vestibular dysfunction symptoms (Cohen et al., 2006; Cohen & Gavia, 1998).

Vestibular intervention done by occupational therapists includes prepositioning strategies, vertigo habituation exercises, gaze stabilization activities, balance therapy, environmental modification and assistive devices, client education, mobility training, and task modification (Cohen, Miller, Kane-Wineland, & Hatfield, 1995; Cohen et al., 2006). Evidence supports the use of vestibular home programs to decrease symptoms of vertigo and improve ADL (Cohen & Kimball, 2003).

Summary

Without the axial and appendicular skeletal systems, the human body would not have the structural foundation for performing functional and meaningful movements. Even static sitting and/or standing postures would not be possible without the axial and appendicular skeletons. Occupational therapy practitioners in all practice settings must appreciate the importance of the skeletal system when evaluating and implementing interventions for clients with movement dysfunction. Alignment and motion at the cranial, vertebral, costal, scapular, and pelvic regions must be considered among various neurological, musculoskeletal, cardiovascular, and congenital-related client populations. Knowledge of the structures discussed in this chapter can aid practitioners in selecting the most appropriate assessment and intervention strategies to address clients' pain and dysfunction and maximize occupational performance.

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10

The Hip and Pelvis

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The lower extremity is composed of the hip, pelvis, knee, and ankle joints as well as multiple joints in the feet. The appendicular skeleton of the lower extremity includes the pelvic girdle, pelvic spine, and bones of the legs. The pelvic girdle includes the hip bones (ilium, ischium, and pubis) and the pelvic spine (sacrum and coccyx—see Chapter 9). The sacroiliac joint, which serves as the transition between the caudal end of the axial skeleton and lower appendicular skeleton, aids in postural alignment because this joint is designed for stability and is relatively rigid. The pelvis performs a primary mechanical function of bearing the weight of the upper body when sitting or standing and transferring weight to the lower extremities during locomotion. The pelvic region also provides attachments for muscles and ligaments necessary for motion at the lumbosacral and hip joints. A secondary function of the pelvis is protection of the pelvic and abdominal viscera (e.g., inferior parts of urinary tracts, reproductive organs).

The hip joint, located between the femur and acetabulum of the pelvis, functions to support the weight of the body in static and dynamic postures. The hip provides the main connection between the lower limb and the axial skeleton.

The joints and muscles of the pelvis and hip are important in balance, movement, and posture, and every movement or posture in the lower extremity is interrelated. When considering posture or positioning of a client, the relationship between the trunk and hips is essential. Additionally, a strong, stable, coordinated lumbopelvic system (or the "functional core") is essential in successful movement and injury prevention (Donatelli & Wooden, 2010).

The lower extremities absorb high forces and support the body weight, as well as providing a mechanism for movement. Forces from the lower extremity are transmitted through the hips to the pelvis and trunk, and the pelvis supports and transfers the weight of the head, arms, and trunk to the femurs in standing or to the ischial tuberosities in sitting (Donatelli & Wooden, 2010; Houglum & Bertoti, 2012).

Bones and Palpable Structures

Structures of the Pelvis

The pelvic girdle is made up of the sacrum, the coccyx, and two coxal (innominate) bones, which comprise the fused ilium, ischium, and pubis. These bones form seven joints: the lumbosacral, sacroiliac (two), sacrococcygeal, symphysis pubis, and hip (two; Houglum & Bertoti, 2012). The pelvic girdle attaches posteriorly to the axial skeleton at the sacroiliac joint. The two coxal bones attach anteriorly to the pubic symphysis and form a strong arch that is slightly movable and is able to transmit the weight of the body to the femur (Jenkins, 1998).

Innominate Bones

The innominate bone of pelvis is the union of ilium, ischium, and pubic bones. The right and left innominate bones articulate anteriorly with each other at the pubic symphysis and posteriorly at the sacroiliac joint.

Rybski, M. F.
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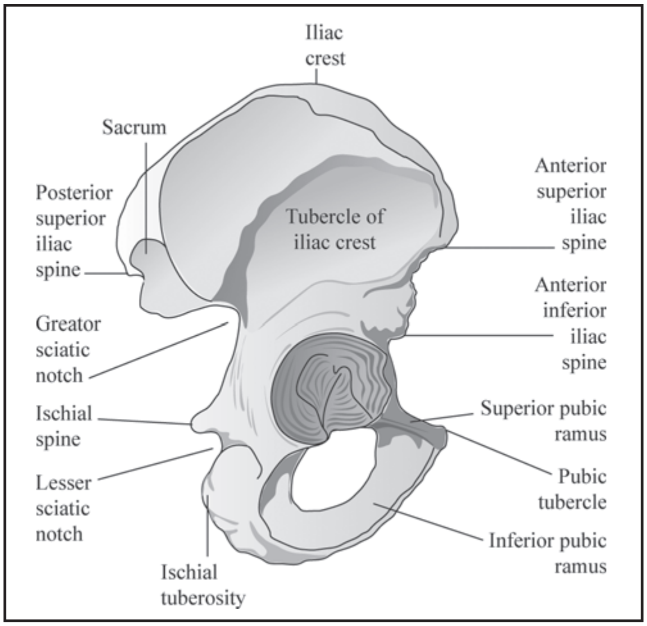

Figure 10-1. Bones of the pelvis.

Ilium

This is the fan-shaped, superior portion of hip bone.

The anterior superior iliac spines (ASIS) of ilia are located on the anterior and superior aspect of the ilium. These can be located by placing your hand on your hip with fingers in front and thumb in back (Biel, 2016).

The iliac crest is the long, superior portion of the ilium (Biel, 2016). There are two, one on each side. They are easily seen and palpated by placing the thumbs laterally. These two crests should be level in a standing position, and the highest point on the crest is at the level of the spinous process of the fourth lumbar vertebra. These can be seen in Figure 10-1.

The posterior superior iliac spines (PSIS) can be visually observed in some people as dimples in the skin above the PSIS. Facing the client posteriorly, place your hand with first finger resting on the iliac crest and palpate the PSIS with the thumbs about 1.5 inches from the midline. Below each PSIS is a depression that is a posterior landmark for the sacroiliac joint.

Ischium

The ischium is the inferolateral third of the innominate bone that forms over the posterior and lower portion of the hip.

The ischial tuberosity, also called the *sit bones*, are easy to locate when sitting on a hard chair or side-lying with hips and knees flexed. These are the large bony prominences at the midline of the buttocks just below the gluteal fold, and they can be palpated when the gluteus maximus and hamstrings are relaxed (Sine, Liss, Rousch, Holcomb, & Wilson, 2000).

Pubis

The pubis, the anterior part of the hip bone, is joined anteriorly in the midline at the pubic symphysis. The pubic crest can be palpated directly inferior to the navel and superior to the genitals (Biel, 2016).

Sacrum

This is the large, triangular, flat bone at the center of the back between the PSIS. It provides stability between the innominates and transmits body weight from the spine to the pelvis (Donatelli & Wooden, 2010). The posterior iliac portion of the innominate articulates with the sacrum at the sacroiliac joint. The sacral crest can be identified by placing a thumb and finger on the PSIS, locating the midline of the sacrum, and palpating superiorly to the PSIS (Biel, 2016).

Coccyx

The coccyx is a series of small, triangular bones located at the end of the spine that attaches to the sacrum. It is composed of three to five coccygeal vertebrae, which may be fused together to form a single bone. Palpating the coccyx can be challenging but possible, and the tip of the coccyx may not be accessible due to inward curve toward the body (Biel, 2016).

Structures of the Hip

The hip joint consists of an articulation between the head of the femur and the acetabulum of the pelvis.

Acetabulum

The acetabulum is a deep, cup-shaped depression, directed downward, laterally, and forward located on the lateral side of the hip bone. The pubis (above), ilium (lateral), and ischium (below) form this deep depression that serves for the attachment of muscles on both internal and external surfaces.

Femur

The only bone in the thigh is considered to be the strongest and longest bone in the body. Shaped to bear weight and transmit ground reaction forces, the head of the femur articulates with the acetabulum and distally articulates with the tibia and patella.

The greater trochanter of the femur is located distal to the iliac crest and is a large mass located on the side of the hip (Biel, 2016). With the thumb on the crest laterally, reach down on the thigh as far as possible with the middle finger or 4 to 5 inches inferior to the most lateral portion of the iliac crest. These large bony prominences can be felt if one stands on the opposite leg and rotates the femur in internal and external rotation. Also, this is marked by the depression that appears when the thigh is abducted (Biel, 2016).

Articulations of the Pelvis

The joints in the pelvic girdle include the right and left sacroiliac joints, symphysis pubic, and lumbosacral joint. While small amounts of movement are possible at the sacroiliac, symphysis pubis, and sacrococcygeal joints, the ability to have even these small amounts of movement is very important.

Symphysis Pubis and Lumbosacral Joints

The pelvic girdle is a closed osteoarticular ring. The two hip bones are joined by the pubic symphysis by a fibrous cartilage and interpubic disc creating this non-synovial amphiarthrodial joint, which lacks synovial tissue or fluid. The pubic symphysis is reinforced by the superior and inferior pubic ligaments, and the joint allows limited motion. The lumbosacral joint (an amphiarthrodial joint) joined by intervertebral fibrocartilage at L5 and S1, allows movement of the pelvis relative to the trunk. It is reinforced by strong iliolumbar and sacrolumbar ligaments and the continuation of spinal ligaments (anterior and posterior longitudinal ligaments, ligamenta flava, interspinal and supraspinal ligaments).

Sacroiliac Joints

The sacroiliac joints are the articulations of the two pelvic bones with the symphysis pubis.

The joint helps to transfer weight from the spine to the lower extremities and acts to decrease forces and provide shock absorption. The articulation of the sacrum and ilium anteriorly forms a synovial joint, while the posterior articulation between the sacral tuberosities and the ilium forms a syndesmosis joint, which provides elasticity to the pelvic ring (Magee, 2014). The close-packed position of the sacroiliac joint is where the top part of the sacrum moves down and forward relative to the fixed pelvis (nutation). Because of the varied articulation surfaces, the sacroiliac joint is actually part of three different kinematic chains: a lower extremity kinematic chain connecting the sacrum, innominate bones, and the lower extremity; L4-L5 to the sacrum; and innominate bone to sacrum to innominate bone (Donatelli & Wooden, 2010).

In childhood, the sacroiliac joint is a synovial joint but changes from a diarthrodial to a modified amphiarthrodial joint in adulthood. In childhood, the surfaces of the joint are smooth, allowing gliding motions. After puberty, the surfaces become rougher and, throughout life, fibrous plaques form, restricting motion and, at times, ankylosis results (Cohen, 2005; Magee, 2014). The joint is reinforced by the anterior sacroiliac, interosseous, and posterior sacroiliac ligaments, and the sacrotuberous and sacrospinous ligaments provide secondary joint stability (Neumann, 2002). The long posterior sacroiliac ligaments limit anterior pelvic rotation (counternutation), and the short posterior sacroiliac ligament limits all pelvic and sacral movement (Magee, 2014).

The kinematics of the sacroiliac joint are complex, and there is controversy regarding amount and type of motion that occurs and where the axes of motion are located. There is some motion that occurs here, but very little. Since this joint is in a closed kinetic chain with the pubic symphysis, any motion at the sacroiliac joint results in motion at the pubic symphysis (Levangie & Norkin, 2011).

Articulations of the Hip Acetabulofemoral or Coxofemoral Joint

The hip joint is a ball-and-socket synovial joint formed between the os coxa (hip bone) and proximal femur. The hip joint is the articulation of the pelvis with the femur, which connects the axial skeleton with the lower extremities. The function of the hip joint is to increase trunk stability, which is provided by bony congruency of joint surfaces, capsular reinforcement, and the neuromuscular system. The hip also provides support for transmission of forces between the torso and lower extremities (Donatelli & Wooden, 2010; Nordin & Frankel, 2012).

This joint is often compared to the glenohumeral joint. Both are ball-and-socket joints capable of a variety of movements. However, the hip acts more often as a closed-chain mechanism, which is opposite to the open kinetic chain of the shoulder. This demonstrates the different functions of these two ball-and-socket joints. The shoulder functions to enable the hands to be used to their most efficient capacity by means of significant mobility, whereas the hip provides stability, balance, and weightbearing to provide postural accommodations and locomotion.

The hip joint is made up of the convex acetabulum of the pelvic bone and the convex head of the femur. The acetabulum is formed by the fusion of part of the ilium, ischium, and pubis (innominate bone or the pelvis). The acetabulum is deepened by a ring of fibrocartilage—the acetabulum labrum, which is located in the lateral aspect of the pelvis. The labrum helps maintain the femoral head in the socket during extremes of motion, especially flexion. Together with the joint capsule, the labrum also acts as a load-bearing structure during flexion (Nordin & Frankel, 2012). The acetabulum faces laterally, anteriorly, and inferiorly (Kendall & McCreary, 1993). The synovial capsule encloses the entire joint, and it thickens and forms ligamentous bands (Gench, Hinson, & Harvey, 1995). This strong articular capsule is reinforced by iliofemoral, pubofemoral, and ischiofemoral ligaments (Kendall & McCreary, 1993). The capsule thickens anterosuperiorly where most forces occur to enhance joint stability.

The head of the femur fits deeply in the acetabulum. The femoral head is attached to the femoral neck, which projects anteriorly, medially, and superiorly at an angle of inclination of 125 degrees. This angle of inclination is between the axis of the femoral neck and the medial side of the shaft of the femur within the frontal plane. Angles greater than 125 degrees are called *coxa valga*, and angles less than 125 degrees are called *coxa vara*. Angles of inclination greater than or less than 125 degrees can cause inequities in the hip joint, leading to deformity and pain.

Osteokinematics

The resting position of the hip is 30 degrees flexion, 30 degrees abduction, with slight external rotation. The close-packed position is in extension, internal rotation, and abduction, and this is the position of greatest bony congruency. The capsular pattern is flexion, abduction, and internal rotation, and the order may vary.

Arthrokinematics

The head of the femur is convex, while the acetabulum is concave, so most motions of the femoral head will be in a direction opposite to the motion of the distal end of the femur (Table 10-1; Houglum & Bertoti, 2012; Kisner & Colby, 2012; Levangie & Norkin, 2011). The motions of flexion and extension are almost purely spin, with spinning occurring in

Table 10-1

ARTHROKINEMATICS OF THE FEMORAL HEAD IN HIP JOINT

MOTIONS OF FEMUR	**ROLL**	**SLIDE**
Flexion	Anterior	Posterior
Extension	Posterior	Anterior
Abduction	Lateral	Inferior
Adduction	Medial	Superior
Internal rotation	Medial	Posterior
External rotation	Lateral	Anterior

Reprinted with permission from Kisner, C., & Colby, L. A. (2012). *Therapeutic exercise: Foundations and techniques.* Philadelphia, PA: F. A. Davis.

a posterior direction for flexion and anteriorly for extension. Abduction and adduction are combined spin and glide, but again in a direction opposite to the motion of the distal end of the femur when the femur is the moving segment. However, when the hip is weightbearing, the femur is fixed. The motion of the hip is produced by the movement of the pelvis on the femur. While this motion is more common, the acetabulum now moves in the same direction as the opposite side of the pelvis (Kisner & Colby, 2012; Levangie & Norkin, 2011).

MOVEMENTS

There is a functional relationship between the hips, pelvis, and spine so that, with pelvic motion, the angle of the hip and the lumbar spine changes. This relationship is known as *lumbar-pelvic rhythm*, often seen as analogous to scapulohumeral motion in the shoulder. Due to this coordinated muscular activity, maximal forward flexion is possible, enabling us to pick up items from the floor and to touch our toes. Once the head and upper trunk initiate the flexion movement, the pelvis shifts posteriorly to maintain the center of gravity (COG) over the feet. At approximately 45 degrees of forward flexion, the ligaments become taut, the vertebrae become stabilized, and the muscles relax. Anterior pelvic tilt occurs once all vertebral segments have been stabilized. The posterior ligaments and the pelvis rotate forward. Forward movement continues until the full length of the muscles is reached (Kisner & Colby, 2012; Tafazzol, Arjmand, Shirazi-Adl, & Parnianpour, 2014). Full motion is influenced by muscle extensibility in the back and hips. Similar combined movements of hip abduction, lateral pelvic tilt, and flexion of the lumbar spine occur when one is side-lying and attempting maximal hip abduction. Full abduction would not be possible without the lateral tilting of the pelvis and the lumbar spine.

Innominate and Sacral Motion

Some motion of the innominate occurs relative to the sacrum through the interosseous ligament of the sacroiliac joint, brought about by hip or trunk motion (Donatelli & Wooden, 2010). With hip flexion, there is posterior rotation of the innominate while there is anterior rotation with hip extension. Hip and innominate motion for medial and lateral rotation are in the same direction and, with lateral hip rotation, there is lateral innominate motion. With abduction of the hip, the innominate glides superiorly, and with adduction, there is an inferior glide of the innominate (Donatelli & Wooden, 2010; Magee, 2014).

Sacroiliac Joint

Small amounts of translational and rotational movement are possible at this joint in the sagittal plane: 0.2 to 2 degrees of rotation and 1 to 2 mm for translation (Neumann, 2002). The sacrum can move anteriorly and inferiorly while the coccyx moves posteriorly relative to the ilium, which is called *nutation* (flexion). An example of this is when you bend over in standing to reach something on the floor; the sacrum nutates on the two innominate bones after flexion at the lumbosacral junction (Levangie & Norkin, 2011). Counternutation (extension) is the movement of the sacrum posteriorly and superiorly while the coccyx moves anteriorly relative to the ilium as seen in the movement of a backbend. The close-packed position is nutation, and the loose-packed position is counternutation. Asymmetrical motions in the sacral region occur during asymmetrical tasks, such as walking, and are described as pelvic torsion of innominates on the sacrum. Pelvic torsion motions are always accompanied by motion at the pubic symphysis (Levangie & Norkin, 2011).

The amount of movement varies from individual to individual and between genders. Men have stronger and thicker sacroiliac ligaments, so they have less mobile sacroiliac joints, and as many as 3 out of 10 men have fused joints. Men have a higher precedence of developing osteophytes and ankylosis in older age than do women. Women have more mobile sacroiliac joints due to greater ligamental laxity, which increases with monthly cycles of hormones and with pregnancy. The male sacroiliac joint is also more stable. In women, the COG is in the same plane as the sacrum, and in men, the COG is more anterior, so there is more of a load on the male sacroiliac joint than the female (Hamill, Knutzen, & Derrick, 2015).

Lumbosacral Joint

The relationship of movements at one joint affect the movement at other joints. With lumbar flexion, there is anterior rotation of the innominate bone and nutation then counternutation of the sacrum. With lumbar extension, there is anterior rotation of the innominate and nutation of the sacrum. Approximately 15 degrees of pelvic rotation occurs to the left or right at the lumbosacral joint, resulting in a pivotal movement of hips around the long axis (Gench et al., 1995). This movement generally occurs in a transverse plane around a vertical axis. When one leg is fixed on the ground, the other unsupported leg swings forward or backward. If the leg moves forward, there is forward rotation with the trunk rotating

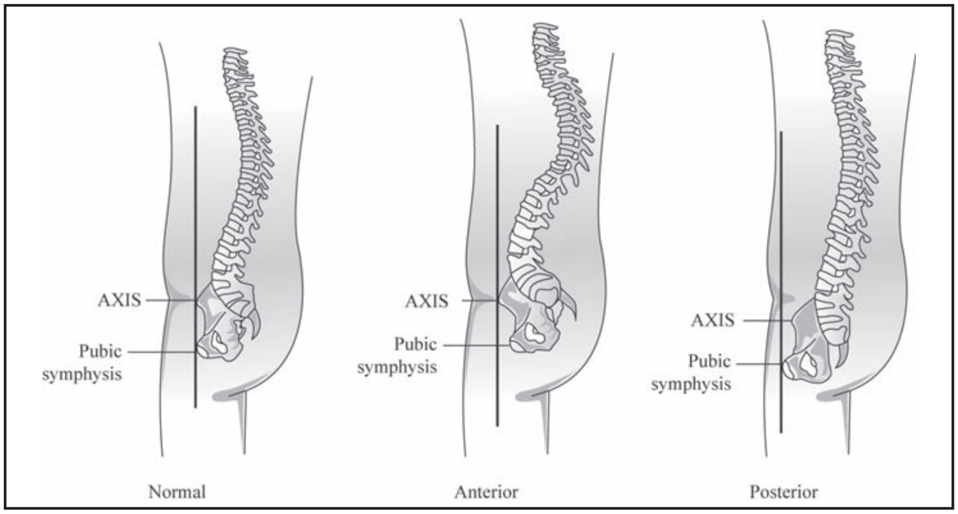

Figure 10-2. Pelvic tilt.

backward on the stabilized side and the femur on the stabilized side internally rotated. With backward rotation, there is posterior rotation, and the femur externally rotates with the trunk moving in the opposite direction. The motion of rotation of the right pelvis is the same movement as internal or medial rotation of the right thigh and to left trunk rotation at the lumbosacral joint (Muscolino, 2006).

Depression and elevation in the frontal plane around the anteroposterior axis also occurs. There is 30 degrees of elevation and depression. Elevation of the right pelvis is the same as right lateral flexion at the lumbosacral joint, and depression of the right pelvis at the hip is analogous to abduction of the right thigh at the hip (Kvitne & Jobe, 1993; Muscolino, 2006).

Hip Joint

Movements at the hip can occur in all three planes of motion and can occur with the hip motion in closed positions (femur is relatively fixed) or with open kinematic chains (nonweightbearing; femur free to move). For this reason, motions of the hip will be discussed relative to the movement of the pelvis on the femur and as movement of the femur on the pelvis. The muscles can act to move the proximal end (femur on pelvis as when one flexes the hip to go up a step) or to move the distal end (pelvis on femur as when one leans over to pick up an object from the floor; Houglum & Bertoti, 2012).

Pelvis Moves on Femur

The motions of the pelvis moving on the femur include anterior and posterior pelvic tilt, lateral tilt, forward rotation, and medial and lateral rotation.

Anterior and Posterior Pelvic Tilt

With anterior and posterior tilting, the entire pelvic ring moves in the sagittal plane around a coronal axis. With these motions, hip flexion and extension are produced. These symmetrical movements of the innominate bones where the anterior superior iliac spine and pubic symphysis move inferiorly produce anterior pelvic tilt. These movements can occur simultaneously or in a single limb around one axis.

Anterior pelvic tilt is the forward movement of the pelvis and is produced when the ASIS moves in an anterior and inferior direction. The ASIS is then in a position closer to the anterior portion of the femur as the pelvis rotates around the transverse axis of the hip joint (Kisner & Colby, 2012). The symphysis pubis is more inferior in location and, because of anterior pelvic tilt, hip flexion, lumbar spine extension (hyperextension), and thigh extension occur. The primary muscle involved in anterior pelvic tilt is the iliopsoas muscle. Anterior tilt of the pelvis is analogous to extension of the trunk at the lumbosacral joint. Pelvic tilt is shown in Figure 10-2.

Posterior pelvic tilt occurs when the PSIS moves posteriorly and inferiorly, bringing the pelvis closer to the posterior aspect of the femur as the pelvis rotates backward around the axis of the hip joints. The ASIS moves anteriorly and inferiorly as the pelvis rotates forward around the transverse axis of the hip joint. There is an upward and forward movement of the symphysis. This results in hip extension and lumbar spine flexion and thigh flexion. Posterior tilt at the lumbosacral joint is equivalent to flexion of the trunk at the lumbosacral joint. This means that the muscles that flex the trunk will also tilt the pelvis because this is the same action. A force couple occurs during posterior pelvic tilt as the abdominal muscles stabilize the pelvis and rotate upward and anteriorly, and the gluteus maximus rotates the pelvis posteriorly and into extension (Houglum & Bertoti, 2012; Kisner & Colby, 2012). Further joint motion is limited by the joint capsule and ligaments.

Lateral Tilt

Left and right lateral tilt accompany weightbearing on the right and left limbs. When one hip is moved into a position that is higher than the other side, this occurs due to lateral pelvic tilt. Lateral tilt occurs in a frontal plane of the pelvic around an anteroposterior axis. This results in opposite motions of each hip: one side will be elevated (hip hiking) and the other will be lowered (pelvic or hip drop). The movement is defined by what is occurring to the iliac crest that is opposite to the weightbearing extremity. The hip that is elevated is in adduction, and the active muscle is the quadratus lumborum. The lower hip is abducted with the gluteus medius activated, and the internal and external oblique muscles stabilize the pelvis (Kisner & Colby, 2012).

Forward Rotation (Protraction) and Backward Rotation (Retraction)

As with lateral tilt, with forward and backward rotation, the contralateral hip is the pivot point for the movement in a transverse plane around a vertical axis. As one side rotates anteriorly, the opposite side rotates posteriorly due to the closed reciprocal system. These rotational movements are vital for a smooth gait and in walking. Backward rotation (retraction) produces lateral rotation of the supporting hip joint, while forward rotation (protraction) produces medial rotation of the weightbearing hip (Houglum & Bertoti, 2012; Levangie & Norkin, 2011).

Femur Moves on Pelvis

Movements of the femur in the acetabulum at the hip joint include flexion, extension, abduction, adduction, internal and external rotation, and circumduction. Because the hip is a ball-and-socket or triaxial joint, it is capable of all movements in three planes and has 3 degrees of freedom.

Flexion and Extension

Flexion and extension occur in a sagittal plane around a medial-lateral axis. The axis is represented by a line from the axis of the femur through the femoral shaft and is vertical due to the angle of inclination. The range of motion (ROM) for unilateral hip flexion with the knee flexed is 0 to 120 degrees, and with the knee extended, the hamstrings limit full hip flexion, so the ROM is generally considered to be 0 to 90 degrees. With hip flexion, anterior pelvic tilt and increased lumbar extension will occur unless the pelvis is stabilized by the abdominal muscles. Flexion motion is limited due to the inferior fibers of the ischiofemoral ligament and the inferior capsule.

Hip extension average ROM is 0 to 20 degrees, and further extension is limited by the iliofemoral ligament, anterior capsule, and parts of the pubofemoral and ischiofemoral ligaments. Posterior pelvic tilt and decreased lumbar extension will also occur with extension.

Abduction and Adduction

Abduction and adduction occur in a frontal plane around a sagittal (anteroposterior) axis. The femur can be abducted 30 to 50 degrees and usually occurs with lateral tilt of the pelvis. Adduction, when the legs cross over the midline, can occur in a range from 10 to 30 degrees of motion and is accompanied by slight hip flexion. Abduction movement is limited by the pubofemoral ligament; inferior capsule; adductor and hamstring muscles; and adduction by the superior fibers of the ischiofemoral ligament, iliotibial band, and extensor fasciae latae.

Medial (Internal) and Lateral (External) Rotation

Rotation of the hip occurs in a transverse plane around a vertical axis that runs through the center of the femoral head and knee (Houglum & Bertoti, 2012). Average ROM is 0 to 45 degrees for lateral rotation and 0 to 35 degrees for medial rotation. Further internal rotation is limited by the ischiofemoral ligament and the piriformis muscle. External rotation is limited by the lateral fasciculus of the iliofemoral ligament, iliotibial band, gluteus minimus, and tensor fascia latae (Neumann, 2002).

Stability of the Pelvis and Hip

The stability of the hip and pelvis, as major weightbearing joints of the body, is vital to transitional movement, protection of viscera, and to positioning in all postures. At the sacroiliac joint, the stability of the joint is supported by the long posterior sacroiliac ligament that limits anterior pelvic rotation or sacral counternutation. Sacrotuberous and posterior sacrospinous ligaments limit nutation and posterior innominate rotation and provide vertical stability. The iliolumbar ligament stabilizes L5 on the ilium (Magee, 2014).

There are three main factors that determine the stability of the hip: bony anatomy, acetabular labrum, and the ligaments of the hip. Bony anatomy is the most important factor that contributes to the stability. The acetabulum, with its deep cup, encompasses nearly all of the femoral head. The acetabular labrum is a fibrocartilaginous band that increases the depth of the acetabulum, further decreasing the possibility of dislocation and improving the stability of the joint. It also provides a suction effect and negative pressure inside the joint. The joint capsule is surrounded by ligaments, which reinforce the capsule on all sides.

The iliofemoral, pubofemoral, and ischiofemoral ligaments are very strong and, along with the thickened joint capsule, provide a large degree of stability. The iliofemoral ligament, also known as the *Y ligament of Bigelow*, covers the hip anteriorly and is considered the strongest ligament of the body (Figure 10-3). In standing, the iliofemoral ligament (especially the inferior band) prevents posterior motion of the pelvis on the femur (hyperextension of hip). The pubofemoral ligament is anterior and inferior to the hip (Hamill et al., 2015), and this ligament assists in checking extreme abduction and some external rotation. The ischiofemoral ligament is in a posterior and inferior location and is considered a weak ligament. This ligament limits internal rotation and helps to stabilize the hip in extension (Magee, 2014). All of these ligaments are slack when the hip is flexed, and all ligaments become taut with hyperextension. Abduction is limited by the pubofemoral and ischiofemoral ligaments, and adduction is limited by the superior or iliotrochanteric portion of iliofemoral (Y) ligament. Under low loads, the joint surfaces of the hip are incongruous, but under heavy loads, there is maximum surface contact (Magee, 2014). In addition, the muscles and ligaments work in a reciprocal fashion at the hip joint. Anteriorly, the ligaments are the strongest, and the medial flexors are fewer and weaker. The strength of the ligaments anteriorly and superiorly gives maximum support for weightbearing functions. Posteriorly, the ligaments are weakest, but medial rotators are greater in number and stronger.

Internal Kinetics: Muscles

There are many factors that determine the function of a muscle, such as muscle architecture, size of the muscle, task requirements, or type of muscle contraction. Three kinesiological concepts are particularly relevant to the muscles of the hip and pelvis: the line of pull and leverage affecting muscle action, the number of joints a muscle crosses, and whether the motion is an open or closed kinematic chain. A change in

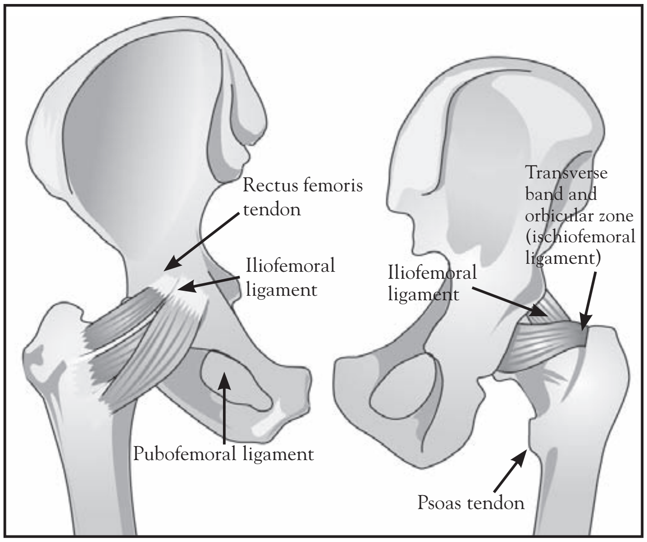

Figure 10-3. Ligaments of the hip.

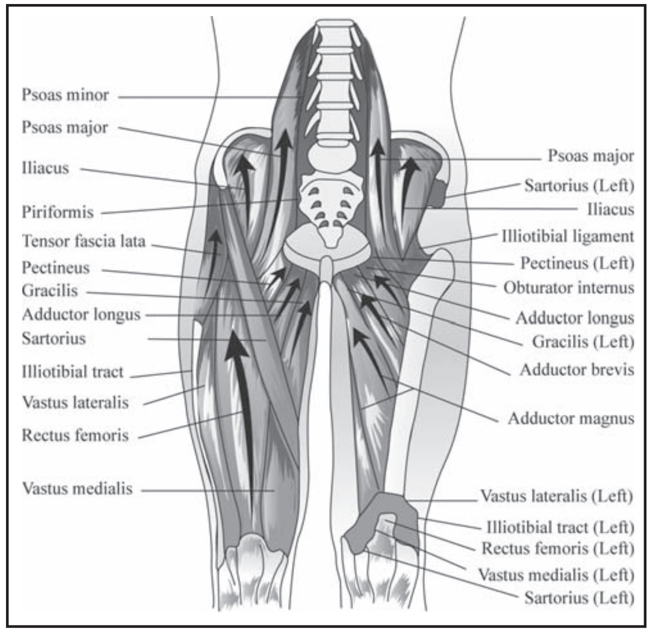

Figure 10-4. Anterior hip muscles.

the position of the hip will allow a muscle to have additional motion or to change the motion of the muscle. For example, sartorius and piriformis will assist with abduction when the hip is in flexion. Some muscles serve as their own force couple, such as with gluteus maximus, whose primary role is hip extension, but upper portions of the muscle will abduct while lower portions will adduct the joint. As is true in the shoulder, multijoint muscles acting on two joints can experience insufficiency. Two joint muscles include rectus femoris, sartorius, tensor fascia latae, gracilis, and hamstrings. An example of this is when rectus femoris becomes insufficient as a hip flexor with the knee extended (Houglum & Bertoti, 2012). Control and support of the weight of the head, arms, and trunk requires much more strength than moving the lower extremity, so very little weakness may result in an inability to perform a closed-chain activity (e.g., walking) as compared to an open-chain motion (Bertoti & Carcia, 2012).

Hip flexors are those muscles on the anterior or anteromedial surface of the hip region (Figure 10-4). Most of the muscles in the anterior area that cross the hip joint flex the hip and are innervated by the femoral nerve (iliopsoas, rectus femoris, sartorius, pectineus, tensor fascia latae). The rectus femoris and iliopsoas muscles both cross the hip anterior to the frontal axis and act as hip flexors. The iliopsoas muscle (sometimes referred to as two separate muscles, the *iliacus* and *psoas muscles*) is a powerful muscle that is especially useful in the initial part of hip flexion. As flexion progresses, the iliopsoas muscle becomes shorter and less effective. This mechanism has led to the development of the crunch to exercise the abdominal muscles as they flex the spine. By bending the knees while in a supine position, the iliopsoas is rendered ineffective so that the crunch involves the abdominals and not synergistic muscles (Gench et al., 1995). The rectus femoris exerts little power in flexion until other muscles have initiated the flexion action, and its action is complementary to the iliopsoas muscle. Pectineus, with a relatively long force arm and advantageous angle of insertion, is a powerful flexor as well as adductor muscle. Sartorius, the longest muscle in the body, is an effective hip flexor because its force arm is longest to the frontal axis, and tensor fascia latae also participates with this movement. Anterior fibers of the gluteus medius and gluteus minimus contribute to hip flexion, as do the adductor magnus, adductor longus, and adductor brevis. The gracilis muscle, depending on the location of the femur, can assist with flexion and extension, in addition to the adductor action at the hip (Gench et al., 1995).

The muscles that extend the thigh lie on the posterior aspect of the thigh and include muscles innervated by the sciatic nerve (gluteus maximus, biceps femoris, semitendinosis, semimembranosus, adductor magnus). The gluteus maximus, while a large muscle on the posterior buttocks, is a strong extensor. However, Gench and colleagues (1995) state that this muscle is "notoriously lazy during actions associated with daily living" (p. 197), which may account for the ease with which this muscle loses its firmness and attracts fat deposits. The posterior portions of the gluteus medius also contribute to hip extension, as do the lower portions of the adductor magnus muscle. Posterior hamstring muscles (semimembranosus, semitendinosus, and biceps femoris) lie posterior to the joint axis and can act as extensors. All three muscles have essentially the same mechanical advantage in moving the femur. Because the posterior hamstrings extend the thigh and flex the leg, they are not strong contributors to extension unless the knee is kept in extension. When the leg is kept extended and the thigh is flexed (e.g., touching one's toes or high-kicking activities), pain may be felt behind the knee due to the posterior hamstrings. The posterior hamstrings are active in any forward bending at the hips and act as antigravity postural muscles (see Figure 9-7; Jenkins, 1998).

The function of the muscles that abduct the thigh is to keep the pelvis in a horizontal placement when weight is put on the limb (see Figure 9-8; Jenkins, 1998). Most of the muscles in the lateral hip region abduct the hip (gluteus medius, gluteus minimus, tensor fascia latae). Two muscles are particularly strong in supporting the pelvis: gluteus medius and gluteus minimus. Both of these muscles pass the sagittal axis of the hip joint to the lateral side, so they are strong abductors, and both have

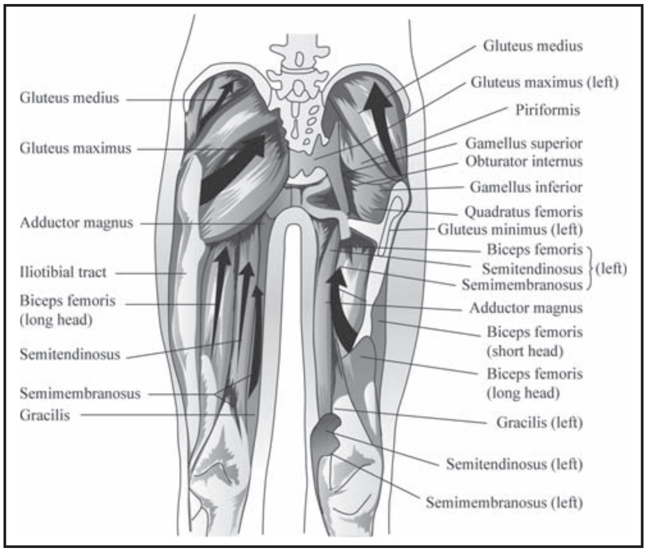

Figure 10-5. Posterior hip muscles.

similar angles of attachment, which give these muscles superior mechanical advantages at the hip (Gench et al., 1995). Because the gluteus minimus is a smaller muscle, it is less powerful than the medius. Tensor fascia latae also contribute to the movement of the limb in abduction, but only when the limb is weightbearing (Jenkins, 1998). Sartorius and, to a lesser degree, the piriformis, obturator internus, and upper fibers of the gluteus maximus, assist with abduction. When the thigh is flexed to 90 degrees, the gluteus maximus then becomes an abductor; in other positions, this muscle is an adductor (Jenkins, 1998).

Adductor muscles are medially placed on the thigh and include the adductor longus, adductor brevis, adductor magnus, gracilis, and pectineus and are innervated by the obturator nerve (Figure 10-5). The adductor magnus is well-placed to adduct but is recruited only when resistance is met (Gench et al., 1995). The adductor longus and brevis are active in all stages of adduction whether there is resistance or not (Gench et al., 1995), and the pectineus has both a long force arm and advantageous angle of insertion, so it is a strong adductor. Crossing the hip joint on the medial side of the sagittal axis, the gracilis is well-placed for adduction action. Muscles that also contribute to adduction include the gluteus maximus, quadratus femoris, obturator externus, hamstrings, gracilis, and iliopsoas (when the thigh is flexed), although not all sources indicate that these muscles function in adduction (Gench et al., 1995; Goss, 1973; Jacobs & Bettencourt, 1995; Sine et al., 2000).

The muscle actions of the medial and lateral rotation are often the secondary result of other movements, and there is some variability in the categorization of muscles that rotate the thigh. Muscles that laterally rotate the thigh are numerous. Gluteus maximus is a powerful lateral rotator. The piriformis, obturator internus, obturator externus, quadratus femoris, and superior and inferior gemelli are small muscles that lie deep in the pelvis with the primary action of external rotation. These six muscles are often grouped together and called the *outward rotators* (Gench et al., 1995). These six small rotator muscles hold the femur in acetabulum just like the rotator cuff muscles of the glenohumeral joint, and they either laterally rotate the femur or balance the pelvis and trunk. The biceps femoris, posterior fibers of the gluteus medius, and sartorius also produce weak lateral rotation. Medial rotation is produced by the gluteus minimus, tensor fascia latae, and anterior fibers of gluteus medius. The semimembranosus and semitendinosus are credited with weak internal rotation.

Due to the gluteals and hamstrings, the hip is very strong in extension. Perhaps extension of the hip is even more critical than hip flexion because extension is needed for an upright posture as well as sitting and standing. The hip extensors are active when gravity pulls the upper body into flexion, and they prevent this forward motion of the trunk (Hinkle, 1997). The hip extensors and flexors also maintain the lumbar curve, with the iliopsoas seen as a key postural muscle as it pulls anteriorly on the lumbar vertebrae and ilium to reinforce lumbar curve and anterior pelvic tilt (Hinkle, 1997), and the flexors help to maintain the anterior and posterior trunk balance.

The two-joint function of the rectus femoris and hamstrings (semitendinosus, semimembranosus, and biceps femoris) requires further discussion. When the hip is flexed, the rectus femoris acts as the agonist, and the hamstrings work antagonistically. In hip extension, the hamstrings are acting as agonists, while the rectus femoris is the antagonist. In knee flexion, the hamstrings have an agonist function, and the rectus is antagonist, but in knee extension, the muscle roles reverse. If hip and knee actions are performed simultaneously, the relationships are more complex. For example, a place kick in soccer requires hip flexion and knee extension, so the rectus femoris contracts to flex the hip and extend the knee, whereas the hamstrings must relax to allow the leg to move. The hamstrings are capable of generating more force than the rectus femoris at the hip due to a longer force arm, just as the rectus femoris is more forceful at the knee.

Simultaneous hip and knee flexion or hip and knee extension requires that both hamstrings and rectus femoris be agonists at one joint and antagonists at the other. This is contradictory to muscle action in the upper extremity, where a muscle will act as an agonist at all of the joints it crosses. For example, the extensor digitorum longus crosses five joints, causing extension at each; the flexor digitorum profundus crosses four joints, causing flexion at each joint. Due to this, these upper extremity muscles can be easily overstretched or overshortened.

In walking, the abductors control the pelvis, and the hamstrings control the amount of hip flexion and some propulsion. Abduction of the femur separates the feet, providing a wider base of support. Without adequate abductor strength, the hip of a swinging leg would drop (Trendelenburg sign), and ambulation would be more cumbersome and less energy-efficient (Hinkle, 1997). Lateral rotation accompanies abduction and extension of the hip and provides stability by allowing the feet and lower leg to be positioned before striking the ground or in balancing on one leg as we walk and run. When lateral rotation is diminished, the foot points toward the midline, which adds stress to the knees (Hinkle, 1997). Muscles controlling hip abduction and adduction are also important in the maintenance of dynamic sitting balance, as are the medial rotators, which control diagonal balance and weight shifts.

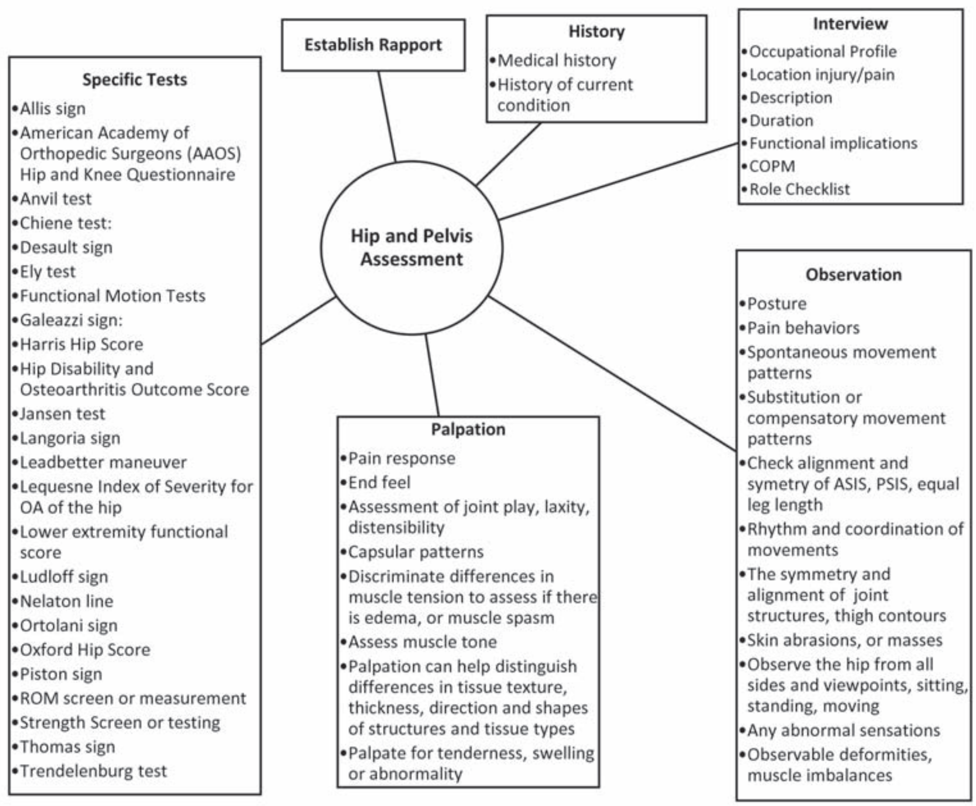

Figure 10-6. Evaluation of the hip. (Adapted from Cooper, C. [Ed.]. [2007]. *Fundamentals of hand therapy: Clinical reasoning and treatment guidelines for common diagnoses of the upper extremity* [p. 74]. St. Louis, MO: Mosby.)

Gench and colleagues (1995) state that "the muscles of spine and pelvic girdle are at the mercy of the demands of upright posture" (p. 184), which constantly needs to overcome the forces of gravity and sustain loads. If the muscles are unable to overcome these forces, the forces and movements tend to be transmitted to the spine rather than the pelvis, creating pain, decreased movement, and structural damage. Tight hip extensors can cause an increase in lumbar flexion when the thigh is flexed, and tight hip flexors can cause increased lumbar extension as the thigh extends. If the adductor muscles are tight, this can cause lateral pelvic tilt on the opposite side and side-bending of the trunk toward the side of tightness. The opposite result occurs with tight abductors (Gench et al., 1995; Hinkle, 1997).

Assessment of the Hip and Pelvis

Occupational Profile

The occupational therapist can obtain information about the client through formal interview and casual conversation as a means to understand the client's history and experiences, interests, values, and needs. This information is used to develop hypotheses about reasons for problems in meaningful occupational performance expressed by the client. This process facilitates the individualized, client-centered intervention and the establishment of the therapeutic relationship. Asking the client why he or she is seeking services and what outcomes he or she hopes will occur will lead to goals that are important to the client. Asking the client about the onset, type and duration of symptoms, and what aggravates or minimizes the symptoms is important in uncovering reasons for limitations. Figure 10-6 illustrates the hip evaluation process.

Ask the client if he or she has any pain and ask that the client describe the location and type of pain he or she is experiencing. Pain due to limitations of the sacroiliac joint may be reported by the client when turning in bed, getting in or out of bed, and with transitional movements (e.g., sit to stand). The client may point to the PSIS and may be unilateral and localized. Sacroiliac pain is usually worse with weightbearing and is more common in females (Donatelli & Wooden, 2010).

Symphysis pubis pain is localized and increases with movements that involve adductor or rectus abdominus muscles (Magee, 2014). If the client describes a dull, deep aching pain, this may be due to arthritis or Paget disease (which may also present with unremitting, long-duration pain, similar to the pain of metastatic carcinoma). Sharp, intense pain may be indicative of a fracture, and bursitis may cause pain in the trochanter or ischiogluteal region. Intra-articular pain (labral tears or anterior impingement) may be felt in the groin and along the anterior or medial side of the thigh to the knee. Pain in the buttocks (S1-S2) may be due to posterior labral tears or lumbar spine limitations. Pain in the hip region may be referred from other parts of the body representing a variety of different problems (e.g., aortic aneurysm, hernia, deep vein thrombosis).

Snapping may be due to external (e.g., posterior iliotibial band, anterior gluteus maximus, trochanteric bursitis), internal (e.g., iliopsoas tendon, iliofemoral ligament, hamstring syndrome, iliopsoas bursal/capsular thickening), or intra-articular (e.g., labral or ligamentum tears, loose bodies, synovial chondromatosis, displaced fractures, capsular instability) causes (Magee, 2014).

Observation and Palpation

As with observation of the spine, an observational assessment of the client begins with looking at the client's posture in sitting, standing, and walking. Look to see if the leg length is equal. Palpate the ASIS and PSIS and notice the alignment. The iliac crest should be level and without evidence of tenderness. Note any changes in skin color, scarring, and abnormalities of the hip and thigh contours. If there is anterior pelvic tilt, increased hip flexion, and compensatory hyperlordosis of the lumbar spine, this may be indicative of Unterkreuz syndrome (also known as *pelvic crossed syndrome*, *lower crossed syndrome*, or *distal crossed syndrome*). In this syndrome, there is weakness in the gluteal muscles (gluteus maximus, gluteus medius, gluteus minimus) and abdominal muscles and tightness in hip flexors (rectus femoris and iliopsoas) and lumbar erector spinae.

Movements

Assessment of the pelvic joints is difficult since these joints do not work in isolation. For this reason, the sacroiliac joint is not normally assessed until after the lumbar spine and hip evaluations are completed. Active motion of the sacroiliac joint is limited to very small amounts of rotation, and translation and palpation for pathology at this joint has limited clinical utility (Goode et al., 2008).

The passive movements of the pelvic joint involve stressing ligaments and joints and is comparable to provocative testing rather than passive range of motion (PROM) evaluation, thus reliability of the clinical examination of passive movements is questionable (Magee, 2014).

Watch the active movements of the pelvis movements of the femur and observe if there is an equal amount of weight on each foot. During active movement, look for unequal movement, loss or increase of movement (hypomobility or hypermobility), tissue contracture, tenderness, or inflammation. A simple active motion screen would be to ask the client to pick up an object from the floor from sitting and standing to assess hip flexion, requiring approximately 0 to 80 degrees of hip flexion, balance, and stability, and to cross one leg over the other as if to don socks (abduction and rotation). Observing a client sidestep over the bathtub would assess active hip abduction (approximately 0 to 30 degrees; Gutman & Schonfeld, 2009). Of common activities done requiring hip and pelvic motion, lacing the shoes and lying down were more demanding (requiring a minimum of 95 degrees of hip flexion; Charbonnier et al., 2015). Shoe tying requires about 120 degrees of hip flexion, and putting on trousers takes about 90 degrees of hip flexion (Magee, 2014).

PROM varies considerably with age and joint position and may diverge significantly from established norms. Clinician error occurred when measuring hip motion within a range of ±10 degrees, except for flexion and abduction, where the error was much higher. Clinicians overestimated the values of these two measurements by ignoring the subtle motion of the pelvis during flexion (posterior rotation of the pelvis) and during abduction (medial rotation of the pelvis). PROM of the hip is a precise method for determining hip motion if the pelvis is stabilized during hip flexion and abduction (Charbonnier et al., 2015). End feel for the hip is firm with the exception of hip flexion in knee flexion, which is limited by adipose tissue yielding a soft end feel (Houglum & Bertoti, 2012). Joint-play motions of traction, compression, and distraction can be assessed with the client in supine, and small differences between the two sides may be difficult to detect due to large muscle bulk (Magee, 2014).

While ROM values reflect norms for each motion, daily activities involving the lower extremities require much less ROM. For example, while the normal value for hip abduction is 30 to 50 degrees, tying a shoe with the foot on the floor requires only about 19 degrees of ROM in the frontal plane, 124 degrees in the sagittal plane, and 15 degrees in the transverse plane (Nordin & Frankel, 2012).This illustrates that, while a client may not have full or normal ROM, the client may be able to perform daily tasks successfully.

It is important to consider, too, that norms are culturally determined. Mulholland and Wyss (2001) and Hemmerich, Brown, Smith, Marthandam, and Wyss (2006) found that, in Asian and Middle Eastern cultures, many activities are performed while squatting, kneeling, or sitting cross-legged. Squatting requires 130 degrees to full hip flexion, and sitting cross-legged requires 90 to 100 degrees of hip flexion. Both positions require 111 to 165 degrees of knee flexion.

Strength Assessment

Resistance tests of the muscles of the lumbar spine and hip are performed with the client in supine per the recommended standardized methods. Resisted flexion and extension of the knee should also be done between the hamstrings and rectus femoris, which are two joint muscles that cross both the hip and the knee. A strength screen can be done for the motions of the hip by asking the client to raise the knee toward the ceiling, and resistance is applied to the anterior thigh toward the floor (Gutman & Schonfeld, 2009).

Normal (5/5) strength is not required for many activities of daily living (ADL). Fair plus strength is needed in hip flexors for stair climbing and in hip extensors to rise from a seated position. Sidestepping into the bathtub requires only fair strength in hip abductors.

There are many measures of hip function and special tests for the hip (see Figure 10-6). Outcome measures may include the Harris Hip Score, Hip Disability and Osteoarthritis Outcome Score, Oxford Hip Score, Lequesne Index of Severity for Osteoarthritis of the Hip, and American Academy of Orthopedic Surgeons Hip and Knee Questionnaire. The Harris Hip Score (Harris, 1969) was developed to assess the results following hip surgery and covers pain, function (ADL and gait), absence of deformity, and ROM. The Hip Disability and Osteoarthritis Outcome Score (Davis et al., 2008) was developed to be a cross-culturally valid short measure of function (including ADL, sports, and recreation). The Oxford Hip Score (Dawson, Fitzpatrick, & Carr, 1996; Murray et al., 2007), for use with clients after total hip replacement, measures the client's perception of pain and function. The Lequesne Index of Severity for Osteoarthritis of the Hip (Lequesne, Mery, Samson, & Gerard, 1987) was developed in France to evaluate the severity of hip osteoarthritis and covers osteoarthritis-specific symptoms and functional disability with several versions available (interview-based, self-administers, and modified versions; Lequesne, 1997; Stucki et al., 1998). Both the hip and knee are assessed in the American Academy of Orthopedic Surgeons Hip and Knee Questionnaire (Johanson, Liang, Daltroy, Rudicel, & Richmond, 2004), which covers stiffness, swelling, and pain in conjunction with walking, lying in bed, ability to get around, and donning/doffing socks (Nilsdotter & Bremander, 2011).

Summary

- The lower extremities absorb high forces and support the body weight as well as provide a mechanism for movement.
- The hip, a ball-and-socket joint, is capable of a wide variety of movement. The hip generally serves to provide stability, weightbearing, and balance.
- Movements of the pelvis include pelvic tilt, pelvic shift, rotation, and lumbar-pelvic rhythm. These movements enable flexion/extension, abduction/adduction, and internal/external rotation of the hip.
- The two-joint function of the rectus femoris and hamstrings (semitendinosus, semimembranosus, and biceps femoris) can act as an agonist at one joint and as an antagonist at another. This action is contradictory to the muscle action in the upper extremity, where a two-joint muscle acts as an agonist at all of the joints it crosses.

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11

The Knee, Ankle, and Foot

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The knee, ankle, and foot are a continuation of the lower extremity kinetic chain. The knee contributes to the functions of walking and running by adjusting the length of the leg to absorb shocks, conserve energy, and transmit forces. The foot is pliable enough to conform to a variety of surfaces and absorb shock as well as to impart thrust when ambulating. It is also rigid enough to withstand large propulsive and compressive forces (Magee, 2014; Neumann, 2002). While occupational therapists rarely remediate the knee, ankle, or foot by either stretch or strengthening, compensatory methods and adaptive devices are often recommended for limitations in these joints. An understanding of the contributions of these structures is essential for the performance of occupational tasks. In the following sections, the knee will be discussed, followed by information about the ankle/foot complex.

Knee

The knee, with the hip and ankle, supports the weight of the body. It functions to transmit loads and sustains high forces while maintaining the body's center of gravity. By lengthening and shortening the lower extremity, the knee enables lowering or raising the body during sitting, standing, climbing, and other movements of the body. Because the knee is positioned between the body's two longest lever arms (femur and tibia), it is often injured because of the large torques produced and, therefore, is susceptible to injury (Houglum & Bertoti, 2012; Nordin & Frankel, 2012).

Bones and Palpable Structures of the Knee

Of the two bones in the leg, the tibia is larger, more medially located, and articulates with both the knee and ankle. The fibula is smaller, more lateral in location, and articulates only with the ankle but not the knee. The proximal fibula is not considered part of the knee but does have a functional role in the movements of the ankle, so it will be discussed later in this chapter within the ankle/foot section. A proximal landmark that can be palpated on the fibula include the head of the fibula, which is distal and posterior to the lateral femoral condyle.

The knee includes three bones: the femur, tibia, and patella.

Femur

The palpable structures located on the distal femur include the medial and lateral epicondylesl condyles.

Medial and Lateral Condyles

With the knee flexed, the edges of the distal enlargements or rounded projections of the femur can be easily felt anteriorly on both sides of the patella and are easily palpated. The medial condyle is located on the proximal end of the tibia, medial aspect, and the lateral condyle is on the lateral aspect.

Medial and Lateral Epicondyles

These are two roughened prominences proximal to the condyles that can be palpated with the knee flexed. They are superficial with round surfaces and superior to the tibiofemoral joint. The lateral epicondyle of the femur is smaller and less prominent than the medial epicondyle, and this provides the

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attachment for the fibular collateral ligament. The medial epicondyle is the attachment site for the tibial collateral ligament.

Tibia

The tibia runs superficially from the knee to the ankle, and palpable structures include the tibial tuberosity, tibial spine, and tibial plateau.

Tibial Tuberosity

This superficial projection is about 1/2 inch in diameter and is located on the proximal end of the tibia, anteriorly, and distal to the patella and below the tibial condyles. This roughened area is easily palpated 2 inches below the inferior border of the patella with the knee flexed. The quadriceps insert into the tibial tuberosity, via the patellar tendon (Biel, 2016; Houglum & Bertoti, 2012).

Anterior Crest (Border or Shaft) of the Tibia

The anterior crest of the tibia is a vertical ridge that runs down the anterior aspect of the tibia (the shin bone) to the ankle. It provides an attachment point for the deep fascia of the leg. The crest begins above the tibial tuberosity and ends below the medial malleolus.

The tibia has three borders: the anterior, which is the most prominent; a medial border, spanning from the back part of the medial condyle to the posterior border of the medial malleolus; and the interosseous crest or lateral border, which is the attachment of the interosseous ligament connecting the tibia and fibula.

Tibial Plateaus

Medial and lateral tibial plateaus are located on the proximal end of the tibia, inside the knee joint so these cannot be palpated. The edges, located superficially on either side of the patellar ligament, are accessible. With the knee flexed, with thumbs on either side of the patella, move them inferiorly. As you compress the tissue, there is a softening as your thumbs feel the joint space between femur and tibia. Farther down, the edge of the tibial plateau can be felt (Biel, 2016).

Patella

The patella is a flat, triangular sesamoid bone. Sesamoid bones are small bones that develop in tendons (in this case, the tendon of the quadriceps femoris muscle). The function of a sesamoid bone is to protect the tendon, diminish friction, and alter the direction of the tendon's angle of pull. The patella functions to improve the efficiency of knee extensors by lengthening the lever arm of quadriceps muscle force around the center of rotation and by centralizing these forces into one concerted direction of pull (Houglum & Bertoti, 2012; Nordin & Frankel, 2012). The patella provides bony protection for the knee and contributes to overall stability of the joint.

The anterior surface of the patella is convex while the posterior surface is oval. There are three facets that are palpable on the posterior surface of the patella (lateral, medial, and odd facets). Other palpable features of the patella include the apex (inferior pole) and the base. The patella is covered by a thick layer of articular cartilage, which protects the patella from the stress of the quadriceps contraction. When the knee is extended, the patella is freely movable because the quadriceps are relaxed.

Articulations of the Knee

While the knee is often considered a simple hinge or ginglymus joint, it is actually a joint complex made up of three articulations. Two articulations are between each condyle of the femur and condyle of the tibia (tibiofemoral joints), and a third joint of the articulation is between the patella and femur (patellofemoral joint).

Tibiofemoral Joint

This biaxial, modified hinge joint (Kisner & Colby, 2012), which some consider to be a double condyloid (Levangie & Norkin, 2011) is made up of two large condyles on the distal femur and two asymmetrical concave tibial plateaus or condyles on the proximal tibia. The tibial plateaus are the main load-bearing structures of the knee. The medial condyle is longer than the lateral condyle and contributes to locking of the knee. The articular surfaces of the tibia and femur are not congruent, so they move different amounts. The tibia and femur approach congruency in full extension, which is the close-packed position of the joint.

There are two fibrocartilaginous joint discs called *menisci* that enhance joint stability by deepening the contact surface on the tibia. The menisci also aid in shock absorption, help to protect underlying articular cartilage and subchondral bone, prevent synovial impingement, serve to reduce the load per unit area on tibiofemoral contact sites, enhance lubrication, and limit the motion between the tibia and femur (Hamill, Knutzen, & Derrick, 2015; Houglum & Bertoti, 2012). The medial menisci are subject to injury if there is a lateral blow to the knee joint. The sloped menisci provide a tight articulation with the femoral condyles. The tibiofemoral joint is in the close-packed position in full extension and dorsal foot flexion with resting position in 25 degrees of flexion.

Patellofemoral Joint

The patellofemoral joint is embedded within the quadriceps muscle and is a partly arthrodial joint, formed by the articulation between the patella and femur. The tibia and fibula have been seen as corresponding to the ulna and radius of the upper extremity, while the anterior surface of the leg is seen to correspond to the extensor surface of the forearm.

The patella is a sesamoid bone in the quadriceps tendon that articulates with the anterior aspect of the distal femur. This is a modified plane joint and, during flexion and extension, different parts of the patella articulate with the femoral condyles. The patella is embedded in the anterior portion of the joint capsule and is connected to the tibia by the ligamentum patellae. Many bursae surround the patella.

Arthrokinematically, if the motion of the tibia is in an open chain, the concave tibial plateaus slide in the same direction as the bone motion (Kisner & Colby, 2012). However, if the motions of the femur occur on a fixed tibia (or closed kinetic chain), the convex condyles slide in the direction opposite to bone motion. The large articular surface of the femur and relatively small tibial condyle create problems as the femur initiates flexion on the tibia. If there was only rolling of the fibial condyle on the tibial condyle, the femur would roll off of the tibia. For this reason, there must be simultaneous rolling and sliding during flexion and extension.

Movements of the Knee

Movements that take place at the knee joint occur at both the tibiofemoral and at the patellofemoral joints, which permit hingelike movements as well as twisting and gliding motion. Motion occurs in three planes simultaneously, with the greatest amount of motion occurring in the sagittal plane. The knee joint is considered mobile because, during joint movement, the menisci move as the femur moves on the tibia. There are 6 degrees of motion at the knee: medial, lateral, proximal, distal, anterior, and posterior.

Tibiofemoral Joint

The primary motions of the tibiofemoral joints are flexion and extension with some rotation and some valgus (abduction) and varus (adduction) motion.

Flexion and Extension

The tibiofemoral joint moves in the sagittal plane to flex (angle between articulating bones decreases) and extend (angle of articulating bones increases back to anatomical position), with the axis running through the femoral condyles. The center of the axis is at the intersection of the collateral and cruciate ligaments. The axis motion is not a fixed but shifts anteriorly during extension and posteriorly during flexion due to incongruent joint surfaces and variations in ligamentous elasticity.

The axis for flexion is a few centimeters above the joint line transversely through femoral condyles. Clinically, the joint axis can be located approximately through the center of the lateral and medial condyles of the femur. The shifting of the joint axis creates problems when fitting for orthoses (e.g., long leg braces, below-the-knee prosthetic devices) or when using goniometers or isokinetic dynamometers. When one moves from extension to flexion, the anatomic axis moves 2 cm while the mechanical axis remains fixed.

In open kinematic chain motion, the tibia glides on the femur in the same direction as joint motion. In extension, the tibia rolls and glides forward on the femur into extension. Similarly, during flexion, the tibia rolls and glides posteriorly on the femur. In a closed kinematic chain, with the action of the femur on a fixed tibia (e.g., weightbearing), the convex femoral condyles slide on the concave tibia so movement is in a direction opposite to bone motion (Houglum & Bertoti, 2012; Kisner & Colby, 2012). When the tibia flexes on a fixed femur, the tibia rolls and glides posteriorly. Similarly, when the tibia extends on a fixed femur, there is anterior roll and glide.

As the knee moves into extension, there is about 20 degrees of lateral rotation of the tibia on the fixed femur. These rotary movements, associated with flexion and extension, are called the *screw-home mechanism*, and it is at this point that the medial and lateral condyles are locked and form the close-packed position (Hamill et al., 2015).

The knee osteokinematics and arthrokinematics are interdependent in how the femur moves on the tibia. Due to the different sizes of femoral condyles and meniscal action, gliding accompanies rolling. In an open kinematic chain, flexion is accompanied by posterior and medial rotation as the tibia glides posteriorly on the femur. During knee flexion, as the tibia rolls posteriorly, this elongates the anterior cruciate ligament (ACL), which pulls on the tibia and causes it to glide posteriorly. In a closed kinematic chain during flexion, the femur glides anteriorly on the tibia as the femur rotates externally.

Extension has similar patterns of rolling and gliding. In an open kinematic chain, the tibia glides anteriorly on the femur as the tibia rotates externally. The tibia moves anteriorly, which elongates the posterior cruciate ligament (PCL), pulling on the tibia and causing it to glide anteriorly.

Knee flexion range of motion (ROM) ranges from 0 to 120 degrees to 0 to 150 degrees, with an average of 0 to 135 degrees (Houglum & Bertoti, 2012) with a soft end feel due to contact with the posterior calf. The end feel for extension is firm.

Abduction and Adduction

Limited adduction and abduction occur in the frontal plane. ROM is 5 to 8 degrees in full extension and 13 degrees with slight knee flexion (Levangie & Norkin, 2011). With movement of the tibia on a fixed femur, there is anterior movement during abduction and posterior movement during adduction. These movements are opposite when the femur moves on a fixed tibia such that during abduction, there is posterior translation of bony surfaces and anterior movement during adduction (Houglum & Bertoti, 2012; Kisner & Colby, 2012).

Medial and Lateral Rotation

Medial and lateral rotation of the knee can occur if the knee is flexed. Motion of the tibial on the femur occurs in the transverse plane and longitudinal axis, which runs through the medial intercondylar tubercle of the tibia. The rotational movements are due to articular incongruence and ligamental laxity (Hamill et al., 2015) and occur with the knee flexed because, in this position, the joint capsule and ligaments are lax, the tibial tubercles are no longer in the intercondylar note, and the condyles are free to move. The medial condyle acts as a pivot point while the lateral condyles move through a greater arc of motion. As the tibia laterally rotates on the femur, the medial tibial condyle moves slightly on the fixed medial femoral condyle. During medial rotation, the medial condyle rotates slightly and the lateral condyle moves anteriorly (Houglum & Bertoti, 2012). Internal rotation is 0 to 30 degrees while external rotation is 0 to 45 degrees (Hamill et al., 2015). Normal end feel is firm due to capsule, collateral, cruciate and oblique popliteal ligaments, and retinaculum and iliotibial band (ITB; Houglum & Bertoti, 2012; Levangie & Norkin, 2011).

Patellofemoral Joint

Movements of the patella include patellar flexion and extension, lateral and medial patellar tilt, lateral and medial patella shifts, and medial and lateral rotation. Movements occur in two planes simultaneously (frontal and transverse) but is greater in the frontal plane. These movements enable the production of the functional movements of kneeling, sitting, squatting, and walking up or down a hill or stairs (Levangie & Norkin, 2011; Nordin & Frankel, 2012).

The patellofemoral joint slides superiorly when the knee extends and inferiorly when the knee flexes. In patellar flexion, there is rotation of the patella in the sagittal plane as it moves down the intercondylar groove of the femur. As flexion increases, the contact area of the patellofemoral joint moves proximally along the patella and posteriorly along the condyles. In patellar extension, the patella glides superiorly while rotating around the femoral condyles (Kisner & Colby, 2012;

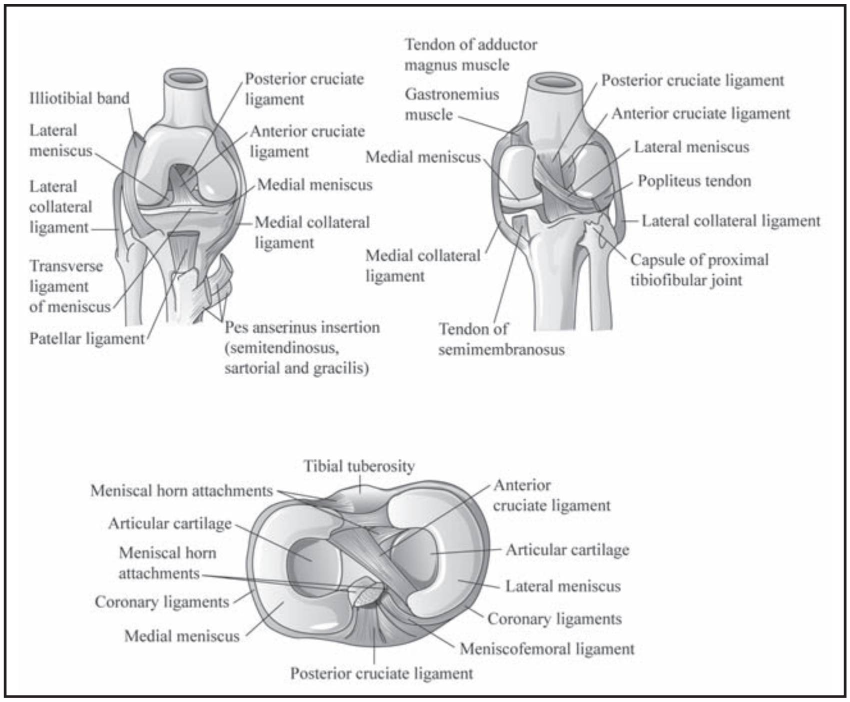

Figure 11-1. Ligaments of the knee. (Adapted from Muscolino, J. E. (2006). *Kinesiology: The skeletal system and muscle function.* St. Louis, MO: Mosby.)

Levangie & Norkin, 2011). The patella does not articulate with the trochlea at the end of extension ROM.

A slight amount of medial and lateral patellar tilt occurs around a longitudinal axis that shifts medially and laterally into the frontal axis and spins around the anteroposterior axis. Lateral patellar tilt occurs when the lateral edge of the patella comes into contact with the lateral femoral condyle, while medial patellar tilt occurs when the medial edge of the patella contacts the medial condyle (Levangie & Norkin, 2011). Patellar tilt can be evaluated by palpating the lateral patella facet and lateral edges of the patella, which can be lifted away from the lateral femoral condyle with the client in supine and the knee in full extension. In this position, the quadriceps muscle is relaxed and there should be no tenderness in this area.

Lateral and medial patella shifts are a gliding motion where the patella moves toward the femoral condyle in a medial or lateral direction in the frontal plane along the medial-lateral axis. Patella rotation around an anteroposterior axis (medial and lateral rotation) also occurs and refers to the motion of the apex of the patella: medial rotation when the apex points toward the medial femoral condyle and lateral rotation when the apex points to the lateral femoral condyle (Levangie & Norkin, 2011). In addition, the patella also translates superiorly and inferiorly with knee flexion and extension.

Stability of the Knee

Stability of the knee is provided by the ligaments, muscles, menisci, joint capsule, and cartilage, while the bones provide mobility (Figure 11-1; Houglum & Bertoti, 2012). The knee is stable in full extension where there is full bony congruence and taut ligaments in this close-packed position. In flexion, the passive structures are lax, and bony incongruence permits greater movement (Levangie & Norkin, 2011). Congruence between the patella and femur also changes throughout knee ROM.

Several soft tissues contribute to knee stability and provide cushioning within the joint. The joint capsule encloses the tibiofemoral and patellofemoral joints to increase stability. The lateral and medial menisci add depth to the joint surface and help distribute loads more evenly across the joint surfaces. The tibia and femur are lined with hyaline cartilage that also acts as a shock absorber for the joint.

Ligaments resist and control knee movements in nearly all knee motions. They prevent excessive knee extension, control varus and valgus stress, and prevent anterior/posterior displacement and medial/lateral rotation of the tibia beneath the femur (Levangie & Norkin, 2011). Ligaments are especially important since there are no bony restraints to movement at the knee.

Tibiofemoral Joint

There are two collateral and two cruciate ligaments that function as passive load-carrying structures and as a backup for the muscles at the tibiofemoral joint.

Tibial (or medial and lateral) collateral ligaments prevent passive movements of the knee in the frontal plane. These ligaments prevent abduction and adduction of the tibia on the femur, which would produce genu valgum (knock-knee) and genu varum (bowleg), respectively. The medial collateral ligament, or medial tibial ligament, attaches to the medial aspect of the medial femoral epicondyle, supports the knee against valgus forces in the frontal plane, and offers some resistance to lateral tibia rotational stresses and anterior displacement. This ligament is taut with knee extension.

The thinner lateral collateral ligament provides the main resistance to varus forces in the frontal plane and in lateral rotation and is also taut in knee extension. In full extension, the collateral ligaments are assisted by the tightening of the posteromedial and posterolateral joint capsules, making extension the most stable position of the knee joint. When the knee is flexed, the ligaments are lax so that the tibia can rotate around the long axis. When the knee is extended, the tight ligaments and bony structures are more congruent, which prevents tibial rotation. Because the knee often is in a flexed position (as in dressing, bathing, etc.), effort should be made to ensure that the muscles of the knee, which are the last line of defense against injury, be maintained at peak strength to avoid injurious twisting of the tibia (Gench, Hinson, & Harvey, 1995).

The ACL and PCL provide stability with anterior and posterior movements and with flexion and extension. They are important in controlling anterior-posterior and rotational movements. The ACL is the primary restraint for anterior movement of the tibia relative to the femur. Different parts of the ACL are tight in different positions; the anterior portions are tight in extension, the middle portions are tight in internal rotation, and the posterior portions are tight in flexion. Like the collateral ligaments, the ACL as a whole is taut in extension, which protects the joint against hyperextension. The ACL has secondary functions of limiting internal and external rotation. The PCL is the primary restraint to posterior movement of the tibia on the femur. The posterior fibers of the PCL are taut in extension, while the anterior portion is taut in midflexion and posterior in full flexion (Hamill et al., 2015). This ligament also protects against hyperflexion of the knee. Despite the numerous ligaments that support the knee, it is the most frequently injured joint in the body.

Additional passive mechanisms seem to contribute to rotational stabilization. The ITB is formed from the fascia from the tensor fascia latae, gluteus maximus, and gluteus medius muscles. It reinforces the anterolateral aspect of the knee joint and assists with preventing posterior displacement of the femur when the tibia is fixed and the knee is in extension (Levangie & Norkin, 2011). The ITB also helps to limit internal rotation of the tibia on the femur. The arcuate ligament protects the posterolateral capsule against hyperextension and rotational forces while the oblique popliteal ligament protects the posterior knee from hyperextension. The popliteofibular ligament resists posterolateral rotation, and the patellar ligament, a continuation of the quadriceps tendon, protects the anterior knee (Houglum & Bertoti, 2012). The meniscotibial ligament attaches the menisci to the joint capsule. The anterior meniscofemoral ligament (ligament of Humphrey) anchors the lateral meniscus, and the posterior meniscofemoral ligament (ligament of Wrisberg) stabilizes the lateral meniscus and provides anteroposterior stability, although the function of the meniscofemoral ligaments is controversial (Bintoudi, Natsis, & Tsitouridis, 2012). Rotational stability is also credited to the medial and lateral collateral ligaments, posteromedial and posterolateral capsule, and popliteus tendon. The menisci are important in medial-lateral stability (Norkin & Levangie, 1992).

Anteroposterior stabilization is achieved by the ACL, PCL, and ITB. The extensor retinaculum is composed of fibers from the quadriceps femoris and fuses with fibers from the joint capsule. This supports the anteromedial and anterolateral aspects of the knee. The medial and lateral head of the gastrocnemius reinforce medial and lateral aspects of the posterior capsule, with the popliteus being an important posterolateral stabilizer with the PCL. The ACL and hamstrings (especially semimembranosus) work together to resist anterior displacement of the tibia and shear forces on the femur posteriorly. The patella helps with posterior knee stability by preventing the femur from sliding forward and off the tibia (Levangie & Norkin, 2011).

Contributors to medial-lateral stabilization are the soft tissue, tibial tubercles, and menisci when the knee is extended. The knee is reinforced medially and laterally by the medial and lateral collateral ligaments and anteriorly and posteriorly by the anterior and posterior cruciate ligaments. The menisci are attached to the joint capsule via the coronary ligament. Laterally, the iliotibial tract, arcuate ligament, lateral collateral ligament, popliteus tendon, and biceps femoris tendon contribute to stability, and the posterolateral capsule is important for varus stability in extension. The pes anserinus muscles (sartorius, gracilis, semitendinosus), semimembranosus, and medial head of the gastrocnemius muscle also contribute to medial stability. Rotation is stabilized by the ACL and PCL, joint capsule, pes anserinus muscles, and medial and lateral collateral ligaments.

Patellofemoral Joint

The quadriceps tendon and patellar ligament provide support for the patellofemoral joint as well as the bony configuration, menisci, and joint capsule. Longitudinal patellar stability occurs inferiorly due to the patellar tendon and superiorly due to the quadriceps tendon, while the patellotibial ligament stabilizes the patella in the medial-lateral direction (Levangie & Norkin, 2011). The patellar ligament is a continuation of the quadriceps tendon and protects the anterior knee (Houglum & Bertoti, 2012). The menisci contribute when there is excess displacement or rotation in any direction (Frankel, Nordin, & Walker, 2012). Bony stability occurs when the patella enters the trochlea and provides some constraint for the joint during knee flexion.

The medial patellofemoral, patellomeniscal, and patellotibial ligaments provide stability to the medial side of the joint by constraining lateral patellar movement. The lateral side has both deep (patellofemoral ligament, patellotibial ligament, and deep transverse retinaculum) and superficial (vastus lateralis muscle and oblique retinaculum) stabilizers.

The quadriceps muscle is the main dynamic stabilizer of the patellofemoral joint. The patella acts as a pully for the quadriceps muscle and acts to magnify the force exerted by the quadriceps on knee extension. It also transmits the tension around the femur to the patellar tendon. Additional factors that influence patellofemoral stability are patellar height and the angle between the pull of the quadriceps muscle and the axis of the patella tendon. The angle formed between the femur in relation to the position of the patella is known as the *quadriceps (Q) angle*. The Q angle is greater in women due to wider pelvic girdles, and increases in this angle will increase the valgus stress on the knees.

Internal Kinetics: Muscles

The muscles that cross anterior to this axis are extensors, and those crossing posterior to the axis are flexors. Seven muscles cross posteriorly and flex the knee: semimembranosus, semitendinosus, biceps femoris, sartorius, gracilis, popliteus, and gastrocnemius (also plantaris, if present). All of these flexors, except the short head of the biceps femoris and popliteus, are two-joint muscles subject to insufficiency as they cross two joints (Levangie & Norkin, 2011). For example, the hamstrings are a two-joint muscle that is more efficient when simultaneously lengthened over the hip as it flexes the knee (Kisner & Colby, 2012).

Knee flexion occurs in a range from 120 to 145 degrees. The motion is due to the three hamstring muscles (biceps femoris, semimembranosus, and semitendinosus muscles) and is accompanied by internal rotation of the tibia, which is produced by the sartorius, popliteus, and gracilis (as well as the semimembranosus and semitendinosus). The semitendinosus and semimembranosus are particularly well-suited to flex and internally rotate the leg because they are located posteriorly to the frontal axis as it crosses the knee and medially to the long axis. For example, biceps femoris, while active in flexion, does not assist with internal rotation because its location lateral to the long axis makes this muscle responsible for external rotation of the tibia. It is an important muscle for knee stability because it will neutralize the internal rotation of the other knee flexors. The sartorius courses diagonally and medially in the front of the thigh and acts both as a flexor and internal rotator, although it should be noted that, in some individuals, the muscle crosses anterior to the knee joint rather than posteriorly, which would make this muscle an extensor of the knee. There are several calf muscles that extend across the knee and have a flexor action there, including gastrocnemius, plantaris, and popliteus. Internal and external rotation occur around the long axis, and muscles that insert medial to the axis will internally rotate the leg, whereas those inserting laterally will externally rotate the leg (Gench et al., 1995).

The quadriceps femoris group is the only muscle that crosses anterior to the axis of the knee and acts as an extensor. The quadriceps femoris group is made up of the vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris muscles, and these participate in extension of the leg. The vastus lateralis is considered the strongest of the group and produces a lateral pull on the patella (Hamill et al., 2015). The ITB, with its origins from the tensor fascia latae, gluteus maximus, and gluteus medius, has been reported to have an effect on the knee through this band (Jenkins, 1998). Some sources also cite gastrocnemius and soleus as contributors to knee extension (Arnold, Anderson, Pandy, & Delp, 2005; Jenkins, 1998; Kisner & Colby, 2012).

The medial rotators are essentially the same muscles indicated as flexors. The sartorius, gracilis, semimembranosus, and semitendinosus all cross the joint medial to the axis and act as internal rotators. The popliteus also crosses the knee joint distally and medially and acts as a medial rotator. Lateral rotation is achieved by the biceps femoris muscle, which passes on the lateral side of the joint axis.

Assessment of the Knee

As part of the occupational profile, you will talk with your client about any concerns he or she has about the ability to participate in daily activities due to limitations in normal knee function. In addition to gathering information about medical history and mode of injury, you will observe the client move and his or her willingness to move.

Notice the speed, cadence, patellar movement, and motion of the tibia as well as the movement of the pelvis, hip, and ankle. If viewed laterally, you may observe if there is hyperextension of the knee (genu recurvatum) and the position of patella: patella alta (higher) or patella baja or infera (patella lower; Magee, 2014). Notice if the patella points inward, which may represent a rotational malalignment of the hips (femoral anteversion).

Notice if there is swelling, such as swelling posteriorly caused by herniation of synovial tissue in the joint capsule (Baker's cyst) or discoloration. Ask the client about the onset of the swelling; rapid onset may suggest a rupture of the ACL or fracture; slower onset (24 to 36 hours) of mild to moderate effusion may accompany a meniscal injury or ligamental sprain. Observe if there are any noticeable deformities (e.g., genu varum [bowleg] or genu valgum [knock-knee]) or muscular asymmetry.

Alterations in the Q angle are often associated with patellofemoral disorders. Draw a line from the anterior superior iliac spine through the center of the patella and a second line from the center of the patella through the tibial tuberosity to see the Q angle. A Q angle greater than 15 degrees is a predisposing factor for patellar subluxation since forceful contraction of the quadriceps muscle can cause the patella to sublux laterally (Calmbach & Hutchens, 2003; Souza, Draper, Fredericson, & Powers, 2010).

You might notice unusual sounds, or the client may mention unusual sensations. For example, there may be a clicking sound or popping sensation, which may be indicative of an ACL tear, an osteochondral fracture, or, if on the lateral side, a popliteal tendon snap. If the knee seems to give way, this indicates instability in the knee, meniscus pathology or patellar subluxation, or osteochondritis (Magee, 2014). If the knee locks, this may suggest a meniscal tear.

Discuss with the client if he or she is having any pain and, if so, identify the location, duration, severity, and type of pain he or she is experiencing. If possible, have the client demonstrate in what positions or movements the pain occurs. What activities make the pain worse and under what conditions is the pain lessened are important questions to ask. If the pain is described as an aching pain, it may indicate a degenerative condition. If the pain is sharp and accompanied by a catching of the knee, this may indicate anterior patellofemoral or bursae problems, tendinosis, or Osgood-Schlatter disease (Magee, 2014). Posterior knee pain may be associated with popliteus tendinitis or fluid in the bursa while anterior knee pain is associated with overuse injuries to the knee. Because pain may be referred from the hip, an assessment of the hip may also be necessary.

Palpation of the knee can provide information about pain, joint integrity, and condition of the ligamental structures. Care should be taken since damaged structures are typically tender to pressure. Note any tenderness as this may indicate tendinitis, bursitis, muscle strain, or sprain. Palpate the medial and lateral joint lines; tenderness or pain may indicate a medial or lateral collateral ligamental injury. Tenderness on the posterior knee may indicate injury to the gastrocnemius or hamstrings muscles.

With the knee flexed, note any tenderness in the tibial plateau (a hard, transverse ridge just below the patella) and in the soft indentation just above (meniscus). Palpating in a circular motion, you can palpate the medial and lateral collateral ligaments. Again, take note of any diffuse tenderness.

With the knee extended, palpate around the patella. You can apply gentle valgus and varus stress for any excessive laxity or pain. Press down on the patella and see if there is any fluid shift, which would indicate effusion. Effusion with inflammation would point to an injury within the joint capsule (Hoffman, 2009). Passively move the patella in medial and lateral directions. If medial structures are too tight, the patella will lift up when pushed laterally; similarly, if the lateral structures are too tight, the patella will tilt up when pushed medially (Hoffman, 2009).

ROM of knee flexion and extension is easily done via goniometric measurement. Note any apprehension or pain on movement. End feel for flexion is tissue approximation (soft), tissue stretch (firm) for extension, and tissue stretch for internal/external rotation of the tibia on the femur. Patellar motion end feel is tissue stretch.

The amount of tibiofemoral ROM during common activities is less than the norms for joint movement. Normal gait requires 60 to 70 degrees of knee flexion, stairs 80 degrees, tying shoes 106 degrees, sitting 90 degrees, with norms for knee flexion at 0 to 135 degrees (Houglum & Bertoti, 2012; Nordin & Frankel, 2012; Rowe, Myles, Walker, & Nutton, 2000).

Resisted isometric muscle testing should be done to muscles involved in knee flexion and extension. In addition, resisted isometric tests may also be done for hip abduction and lateral rotators, which are found to be weak in patellofemoral pain syndrome. Testing of ankle muscles may also be necessary since the gastrocnemius crosses the posterior knee and both plantar- and dorsiflexion cause movement of the fibula (Magee, 2014).

Irrgang, Snyder-Mackler, Wainner, Fu, and Harner (1998) developed a client-reported measure of function of the knee that includes an activities of daily living scale with 14 items and a sports activity scale with 11 items. The activities of daily living scale is for those who do not participate in sports or have not yet progressed to the higher levels of function that are assessed with the sports activity scale. Function is reported in percentages, with higher percentages indicative of more knee function.

Additional client-reported knee function evaluations were reviewed by Collins, Misra, Felson, Crossley, and Roos (2011) and included the International Knee Documentation Committee Subjective Knee Evaluation Form (Irrgang et al., 2001), Knee Injury and Osteoarthritis Outcome Score (Roos & Lohmander, 2003), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (Perruccio et al., 2008), Knee Outcome Survey Activities of Daily Living Scale (Irrgang et al., 1998), Lysholm Knee Scoring Scale (Lysholm & Gillquist, 1982), Oxford Knee Score (Dawson, Fitzpatrick, Murray, & Carr, 1998), Western Ontario and McMaster Universities Osteoarthritis Index (Roos, Roos, Lohmander, Ekdahl, & Beynnon, 1998), Activity Rating Scale (Marx, Stump, Jones, Wickiewicz, & Warren, 2001), and Tegner Activity Score (Tegner & Lysholm, 1985). Additional tests specifically for the knee are found in Table 11-1.

Ankle

The foot and ankle together have 26 bones, 34 joints, 100 ligaments, and 30 muscles, so it is a very stable complex. Structurally, the ankle/foot complex is comparable to the wrist/hand, although the hand is more critical to daily life tasks. The ankle/foot complex needs to balance conflicting demands for stability and mobility. On one hand, the ankle and foot meet the stability demands of providing a stable base of support for the body without undue muscular or energy demands, and they act as a rigid lever for propulsive weightbearing. On the other hand, mobility demands of dampening the rotations imposed by the more proximal joints of the lower extremity, having the flexibility to absorb the shock of body weight, and permitting the foot to adjust to varied terrains are also met by this section of the lower extremity (Norkin & Levangie, 1992). The flexible-rigid characteristics of the ankle/foot complex provide these functions (Houglum & Bertoti, 2012):

- Support of superincumbent weight
- Control and stabilization of the leg on planted foot
- Adjustments to irregular surfaces
- Elevation of the body, as in standing on toes, climbing, or jumping
- Shock absorption
- Operation of machine tools
- Substitution for hand function in people with upper extremity amputations or muscle paralysis

Bones and Palpable Structures of the Ankle

The bones of the ankle region are the talus, tibia (discussed previously), and fibula.

Talus

The talus is located between the calcaneus and fibula and between the malleoli. The talus functions as a connection between the leg and foot to transfer weight from the ankle to the leg and facilitate movements of the foot. No muscles attach to the talus, so its position depends on the position of the neighboring bones. To palpate the talus, find both malleoli and move inferiorly until you find two depressions. You can feel the talus move as the foot everts/inverts.

Fibula

The fibula is the thinnest bone in the body in proportion to its length and bears only 10% of the body's weight (Biel, 2016, p. 347). The head of the fibula is irregular and flat in shape and is located on the posterior and lateral aspect of the lateral condyle of the tibia at the level of the tibial tuberosity. The head of the fibula is located proximally as you move distally and posteriorly from the lateral femoral head. A large protuberance on the lateral aspect of the ankle distally is the lateral malleolus, and the medial malleolus is a bony process extending distally off the medial tibia. The fibula plays a significant role in stabilizing the ankle and supporting the muscles of the lower leg. The joint axis of the ankle joint is estimated through palpation between the medial and lateral malleoli.

Table 11-1

SPECIAL TESTS FOR THE KNEE

TEST	**STRUCTURES INVOLVED**
Anterior drawer test	Ligamentous stability of the ACL
Apley compression/grinding test	Differentiate meniscal from ligamentous injury
Patellar apprehension sign	Patellofemoral instability or patellar subluxation
Bayonet sign	Lateral placement of the infrapatellar tendon with valgus knees produces a bayonet appearance in the quadriceps patellar tendon complex
Bounce home test	Torn meniscus, loose body, intracapsular swelling, or fluid in the knee joint
Camelback sign	Unusually prominent infrapatellar fat pad and hypertrophy of the vastus lateralis
Drawer sign	Ligamentous instability or ruptured cruciate ligaments
Lachman test	Ligamentous stability of the ACL
McMurray circumduction test	Joint menisci tears
Noble compression test	Test for iliotibial band friction syndrome
Patellar grind test	Test for patellofemoral pain syndrome, chondromalacia patellae, patellofemoral degenerative joint disease
Patellar retraction test	Test for synovitis
Pivot shift test	Ligamentous stability resulting in a sudden forward shift of the lateral side of knee
Posterior drawer test	Stability of the cruciate ligaments
Posterior tibial sag	Rotary ligamentous stability posteriorly or torn PCL
Varus stress test	Ligamentous stability of the lateral collateral ligament
Slocum's anterolateral rotary instability test	Rotary ligamentous stability
Thessaly test	Meniscal tear/lesion
Thumbnail test	Patellar fracture
Valgus stress test	Ligamentous stability of the medial collateral ligament or capsular or cruciate ligament laxity

Articulations of the Ankle

The ankle includes three joints: the ankle joint (talocrural joint), inferior tibiofibular joint, and subtalar joint. The joint surface of all bones in the ankle are covered with articular cartilage. The forces acting on the ankle can be as much as five times the body weight, and the talocrural joint transmits approximately 1/6 of the force exerted through the foot (Levangie & Norkin, 2011).

Talocrural Joint (Ankle)

The talocrural articulation is the articulation of the tibia and fibula (tibiofibular joint) with the talus of the foot (tibiotalar joint), and is designed for stability. It is a modified hinge synovial joint with 3 degrees of freedom. The close-packed position for the ankle joint is supination. The joint was designed for stability rather than mobility due to bony congruence and ligamentous support (Hamill et al., 2015; Levangie & Norkin, 2011; Magee, 2014). The resting position of the ankle is plantarflexion midway between inversion and eversion, with the close-packed position in maximum dorsiflexion.

Tibiofibular Joints

There are two tibiofibular joints: proximal tibiofibular and distal tibiofibular.

Proximal Tibiofibular Joint

The proximal tibiofibular joint is located close to the knee but has a separate joint capsule and is not related functionally to the knee. It is a plane synovial joint formed by the articulation of the head of the fibula and the posterolateral tibia. The function of the proximal tibiofibular joint is reduction of rotational stresses applied at the ankle, prevention of lateral tibial bending movements, and providing significant tensile (rather than compressive) weightbearing (Sarma, Borgohain, & Saikia, 2015).

Distal Tibiofibular Joint

The distal tibiofibular joint is a syndesmosis or fibrous joint between the medial side of the lateral malleolus of the fibula and the fibular notch of the distal tibia. The tibia and fibula do not actually come into contact because they are separated by fibroadipose tissue (Levangie & Norkin, 2011).

Between the two shafts of the tibia and fibula is what some consider the middle tibiofibular joint. This is a syndesmosis fibrous joint created by the interosseous membrane that holds the two bones together and allows the force of muscle attachments that pull on the fibula to be transferred to the tibia, moving the leg at the knee (Muscolino, 2006).

Subtalar Joint (Talocalcaneal)

The subtalar joint is the articulation between the inferior surface of the body of the talus and the facet on the middle of the upper surface of the calcaneus. It is a plane synovial joint that allows movements of inversion and eversion of the foot but has no role in dorsi- or plantarflexion. The articular surfaces are covered with hyaline cartilage and the joint has two joint capsules: one encloses the posterior facets of the talus and calcaneus and the other encloses the middle and anterior facets and the talonavicular joint (Houglum & Bertoti, 2012). The close-packed position is in supination. The subtalar joint can also be considered part of the talocalcaneonavicular joint.

Movements of the Ankle

The ankle/foot complex is capable of moving the foot up and down as well as in and out. Much variability exists in the literature about how to define these motions. The movement of the foot and ankle toward and away from the midline in the transverse plane around a vertical axis is referred to as *adduction* and *abduction*, and there is minimal ROM in these movements of adduction and abduction at the ankle/foot complex. Frontal plane motion of the foot turning inward (inversion) or outward (eversion) occurs in the anterior-posterior axis, although some authors use the terms *supination* (to turn up, or medial tilt or varus) and *pronation* (to turn down, or lateral tilt or valgus) to describe this motion.

Often, the terms *eversion-inversion* will be used to describe motion in open kinetic chains and *pronation-supination* to describe a closed-chain motion (Kendall & McCreary, 1983; Sine, Liss, Rousch, Holcomb, & Wilson, 2000). Other authors use the term *pronation* to describe a combination of dorsiflexion, eversion, and abduction, while *supination* is a combination of plantarflexion, inversion, and adduction. For simplicity, the terms *inversion* and *eversion* will be used in this text to describe the motion at the ankle, although the definition based on the combined movements more aptly describes the actual motion that occurs. Inversion and eversion occur primarily around the subtalar and transverse tarsal joints with very little movement at the talocrural joint. Due to these motions, the foot can be positioned to travel on uneven ground, and the ability to invert/evert one's foot is helpful in bathing and dressing the lower extremity.

Because the talocrural joint is a uniaxial modified hinge joint, there is 1 degree of freedom permitting flexion and extension of the foot, which is known as *plantarflexion* and *dorsiflexion*. These motions occur parallel to the sagittal plane around a mediolateral axis. Approximately 50 degrees of plantarflexion occurs and is due to the gastrocnemius, soleus, flexor digitorum longus, peroneus longus and brevis, flexor hallucis longus, and tibialis posterior. The large size of the gastrocnemius and the long force arm enable this muscle to be a strong plantarflexor of the ankle, but only when ankle motion is needed and not when standing at ease (Gench et al., 1995). Gastrocnemius and soleus (together known as the *triceps surae*) work powerfully on the calcaneus to push the foot down, and the soleus is more involved in static standing. The tendons of these two muscles form the large, easily palpated tendon on the posterior distal leg known as the *Achilles tendon*. Because the tibialis posterior, flexor digitorum longus, and flexor hallucis longus cross the joint posterior to the joint axis, these muscles act to plantarflex the ankle in addition to other actions. These three muscles are fondly referred to as *Tom, Dick,* and *Harry* with "Tom" for tibialis posterior, "Dick" for flexor digitorum longus, and "Harry" for flexor hallucis longus. The peroneus longus changes direction twice before insertion and is close but posterior to the axis, so it acts only as a weak plantarflexor, as does peroneus brevis. The plantarflexion action is the strongest movement of the foot and is important in propulsion force.

Dorsiflexion of the foot occurs in a range of 20 to 30 degrees, and the muscles producing the movement cross anterior to the joint axis. One of the most important muscles in this action is tibialis anterior; this is the muscle that gives our legs the roundness of the shank portion. The extensor digitorum longus crosses the joint anterior to the axis with a long force arm and is effective as a dorsiflexor. Peroneus tertius, which appears to be a part of the extensor digitorum longus (which, incidentally, is often missing in individuals), crosses the ankle in the same manner as the extensor digitorum longus and has similar action on the joint. Similarly, the extensor hallucis longus, with primary action involving the big toe, also crosses the joint anterior to the axis and is contributory to dorsiflexion. Generally, these muscles are weak and not capable of generating high forces (Hamill et al., 2015). With dorsi- and plantarflexion, the articulating surface of the talus slides in an opposite direction of the foot (Kisner & Colby, 2012).

Additional motion occurs in both the transverse plane around a vertical axis (talar abduction/adduction) and in the frontal plane around an anteroposterior axis (talar tilt or talar inversion/eversion), although these motions are relatively small (Levangie & Norkin, 2011).

The tibiofibular joints allow superior and inferior glide of the fibula in relation to the tibia. The tibiofibular joints are essential to dorsi- and plantarflexion due to the mortise-like arrangement of the bones that allows the tibia and fibula to grasp and hold onto the distal joint segments (Levangie & Norkin, 2011).

The subtalar joint has a triplanar axis that lies approximately 45 degrees in the sagittal plane and about 25 degrees in the transverse plane and produces rotational motion around this axis (Houglum & Bertoti, 2012). Inversion and eversion of the foot are two important movements occurring at the subtalar joint. Inversion is performed by the tibialis anterior, tibialis posterior, and gastrocnemius and soleus complex through 30 degrees of range. Eversion is identified as 18 degrees of range with movement produced by the peroneus longus, peroneus tertius, and peroneus brevis muscles.

Stability of the Ankle

The ankle joint is supported by strong ligaments. On the medial side, major ligaments are the deltoid (medial collateral) ligament with three separate ligaments, including the tibionavicular, tibiocalcaneal, and tibiotalar ligaments, which

Table 11-2

Special Tests for the Ankle

Test	Structures Involved
Anterior drawer test	Ligamentous laxity of the anterior talofibular ligament
Calf squeeze test	Rupture of Achilles tendon
External rotation test	Identify tibiofibular syndesmotic injury (ankle sprain)
Impingement sign	Impingement of the talocrural joint
Squeeze test	Identify tibiofibular syndesmotic injuries
Talar tilt test (dorsiflexion-eversion test)	Lateral ligaments of the ankle
Tarsal tunnel test	Test for presence of tarsal tunnel syndrome or compression of the posterior tibial nerve

serve to limit eversion across the talocrural, subtalar, and talonavicular joints. The tibiotalar ligament also resists translation and lateral rotation of the talus. On the lateral side, the anterior talofibular ligament resists excessive inversion of the talus, and this is the ligament that is most often injured by a lateral ankle sprain. The posterior talofibular ligament resists abduction during dorsiflexion (Houglum & Bertoti, 2012). The calcaneofibular ligament provides stability against maximum inversion at the ankle and subtalar joints (Magee, 2014). The calcaneofibular ligament restricts inversion of the talocrural and subtalar joints, and the talocalcaneal ligament assists in providing support to the subtalar joint (Houglum & Bertoti, 2012).

Assessment of the Ankle

Assessment of the ankle begins with the occupational profile. In conversations with the client, determine if limitations in ankle function are interfering with successful occupational performance.

As with assessment of other lower extremity joints, observation of all joints in the kinematic chain is essential since the lower extremity functions as a unit and not in isolation. Observing the alignment of the hip, knee, and ankle from the front, back, and side is an initial assessment. Gross deformities may indicate a fracture or dislocation. As the client enters the room, note any hesitancy in movement, avoidance of weightbearing, and abnormalities in gait. Compare the symmetry of both ankles and check the skin color (e.g., pale, flushed, cyanotic) and temperature of the area. If the entire joint appears wider on one side, this may suggest tibiofibular ligament damage. Clients who have ankle locking may have osteochondritis dissecans of the talar dome.

Assess swelling in the ankle. A rapid onset of swelling may indicate a more serious injury, and swelling may continue to develop for 6 to 24 hours after injury. Palpation may be limited by soft tissue swelling, which can result in diffuse pain.

Palpating areas of point tenderness is important in localizing areas of potential injury or disease. Palpate just below the knee and assess the gastrocnemius, tibia, and fibula, and feel for crepitus, instability, deformities, and tenderness. Distinguish between bone and soft tissue pain, and identify specifically where the pain is located.

Pain localized along the anterior or posterior ankle joint line may indicate a capsular or intra-articular pathology. Tenderness over the anterior talofibular ligament region may indicate a lateral sprain caused by inversion of the foot. Poor proprioceptive function frequently manifests as ankle instability and is a common cause of recurrent ankle sprains. If the client has pain or tenderness in the calcaneofibular ligament region, this may indicate a more severe ankle injury.

In the posterior region, the most common problems relate to the Achilles tendon. The Achilles tendon can often be palpated, approximately 2 to 3 cm proximal to the calcaneal insertion. If there is an acute Achilles tendon rupture, there is significant swelling and redness as well as weakness in plantarflexion. In Achilles tendonitis, palpation of the tendon will cause pain. With chronic Achilles tendonosis, a tender, boggy, soft-tissue mass often encases the distal 2 to 3 cm of the Achilles tendon sheath (Young, Niedfeldt, Morris, & Eerkes, 2005).

Anterior impingement symptoms may be reproduced by a quick, sharp, dorsiflexion movement. Posterior impingement symptoms may be reproduced by a quick, sharp, plantarflexion movement.

Active ROM of ankle dorsiflexion, plantarflexion, subtalar eversion, and subtalar inversion should be done. Methods to measure ankle ROM include goniometry, weightbearing, and torque-referenced techniques (Wilken, Rao, Estin, Saltzman, & Yack, 2011). ROM of the ankle measured with a goniometer, particularly dorsiflexion, has satisfactory reliability in the sagittal plane (Zhang, Davies, Zhang, & Xie, 2014), but problems in ankle measurement have been reported due to goniometric alignment, and recording angular displacement alone does not allow the calculation of stiffness (Wilken et al., 2011; Young et al., 2005). The reliability of plantarflexion was consistently lower than that of dorsiflexion (Martin, Davenport, Paulseth, Wukich, & Godges, 2013).

Passive ROM of dorsiflexion is done with the knee bent, and additional passive assessment would include ankle plantarflexion, subtalar eversion, and subtalar inversion. Strength would be tested by resisting the motions of ankle dorsiflexion, ankle plantarflexion, eversion, and inversion. Some studies have demonstrated the use of handheld dynamometers for the assessment of ankle strength (Bénard, Jaspers, Huijing, Becher, & Harlaar, 2010; Rose, Burns, Ouvrier, Ryan, & North, 2008; Spink, Fotoohabadi, & Menz, 2010), and isokinetic dynamometers have also been used to measure ankle strength (Zhang et al., 2014). Special tests for the ankle are listed in Table 11-2.

Foot

The foot is the final link in the lower extremity kinematic chain. The foot is flexible to adjust to uneven terrain and

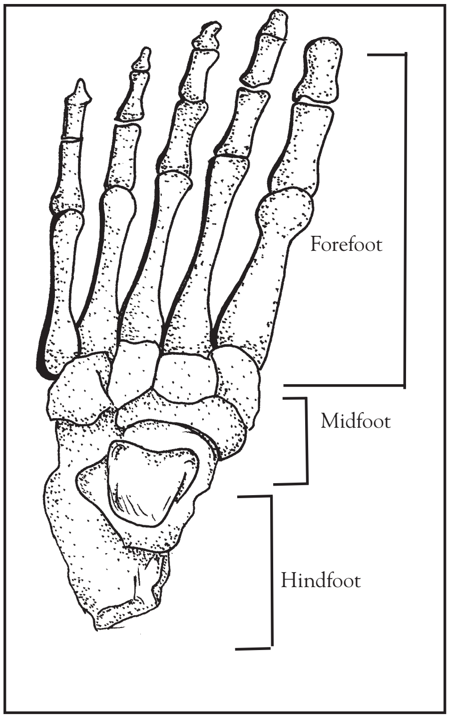

Figure 11-2. Parts of the foot.

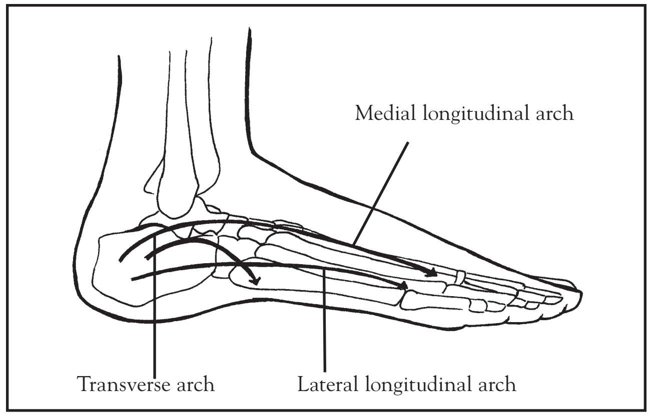

Figure 11-3. Arches of the foot.

absorb shocks and forces, yet is rigid to provide stability and propel the body forward (Magee, 2014; Nordin & Frankel, 2012). The foot includes all of the bones distal to the ankle joint with the talus considered a bone of both the foot and the ankle (Nordin & Frankel, 2012). The foot is divided into three regions: hindfoot, midfoot, and forefoot.

Bones and Palpable Structures of the Foot

Navicular

The navicular is a bean-shaped bone that lies anterior to the head of the talus and two finger-widths inferior to the medial malleoli. The anterior surface articulates with the three cuneiform bones, forming the cuneonavicular joint. It also articulates with the talus, forming the talocalcaneonavicular joint

Cuboid

This bone is surrounded by the fourth and fifth metatarsal posteriorly, lateral cuneiform and anterior to the calcaneus. It articulates with the calcaneus, forming the calcaneocuboid joint and, also with the lateral two metatarsals, forming the tarsometatarsal joint. The cuboid is about one-half inch from the tuberosity of the fifth metatarsal (Biel, 2016).

Cuneiforms

The three cuneiform bones (medial, lateral, and intermediate) lie in a row between the navicular and metatarsals. After locating the base of the first metatarsal, glide your fingers proximally into the indentation of the tarsometatarsal joint. As you continue in a proximal direction, you will feel the medial cuneiform. Move laterally to palpate the other two cuneiforms (Biel, 2016).

Metatarsals

The long tubular bones are located between the phalanges of the toes and tarsal bones. They arch upward (convex) and give the foot its arch. The first metatarsal is short and stocky.

Articulations of the Foot

The foot is divided into the forefoot, midfoot, and hindfoot (Figure 11-2). The anterior segment of the foot is made up of the 5 metatarsals and 14 phalanges, which make up the 5 toes. The midfoot is the middle section of the foot and is made up of five bones: the navicular, cuboid, and three cuneiforms. The most posterior segment, the hindfoot, is formed by the talus and calcaneus bones. Compression forces in the foot while standing are greatest at the hindfoot (60%), then the forefoot (28%), and least by the midfoot (8%; Neumann, 2002).

As with the hand, there are arches in the foot: two longitudinal and one transverse (Figure 11-3). These arches create an elastic shock-absorbing system, and the flexibility of these arches is critical in walking and running. The lateral longitudinal arch is a relatively flat arch that plays a support role in weightbearing and has limited function in mobility. The medial longitudinal arch is more flexible and mobile and plays a greater role in shock absorption. When one takes a step, the force is absorbed by a fat pad on the inferior surface of calcaneus. This force then causes an elongation of the medial arch that continues to maximum elongation at toe contact with the ground. This portion of the foot rarely touches the ground unless the person has flat feet. The medial longitudinal arch helps to diminish the impact by transmitting vertical loads through the deflection of the arch. The transverse arch supports a significant portion of weight during weightbearing (Hamill et al., 2015).

Hindfoot

The hindfoot includes the articulation between the calcaneus and talus at the subtalar (or talocalcaneal) joint. This is a synovial gliding joint, and the talus presents with three facets that correspond to three facets on the calcaneus. With the three articulations, the convex-concave facets limit mobility of the joint. When the talus moves on the posterior facet of the calcaneus, the articular surface of the talus should slide in the same direction as the bones move. However, at the middle and anterior joints, the talar surfaces should glide in a direction opposite to the movement of the bone. What actually occurs is a screwlike or twisting motion around a triplanar axis. When inversion (supination) occurs, the posterior articulation slides in a lateral direction, and with inversion (pronation), there is a medial slide of the posterior articulating surfaces (Kisner & Colby, 2012).

Midfoot

The midfoot is made up of the transverse tarsal joint and distal intertarsal joints. The transverse tarsal joint includes two articulations: talonavicular joint (talocalcaneonavicular), in which the head of the talus articulates with the proximal side of the navicular bone and the plantar calcaneonavicular ligament, and the calcaneocuboid joint, in which the transverse tarsal joint articulates with the proximal surface of the cuboid bone. Resting position for the midfoot is midway between the extremes of ROM, and close-packed position is in supination.

The transverse tarsal joint is a compound joint between the hindfoot and midfoot. This saddle-shaped joint has two axes that are longitudinal and oblique, permitting inversion/eversion and flexion/extension. Passive motions include abduction/adduction, inversion/eversion, and dorsal/plantar gliding (Kisner & Colby, 2012). The transverse tarsal joint forms an S-shaped joint line between the talonavicular and calcaneocuboid joints. The midtarsal joint participates in gliding and rotational movements of the forefoot on the hindfoot to lower the longitudinal arch in pronation and raise it in supination. The midtarsal joint also contributes to eversion (pronation) and inversion (supination) and in absorbing forces of contact.

Inversion occurs when the muscles pass around the medial border of the foot. This includes the tibialis posterior, flexor digitorum longus, flexor hallucis longus, tibialis anterior, and extensor hallucis longus. Of these, the tibialis anterior is the strongest inverter of the foot, while the extensor hallucis longus is the weakest. By pulling the feet inward (inversion or supination), the arches are maintained, and the body weight is distributed to the lateral sides of the feet.

Eversion of the foot is produced by the peroneus longus, brevis, and tertius and by the extensor digitorum longus. The extensor digitorum longus, while primarily involved in extension of the interphalangeal joints, does cross the joint anterior and lateral to the joint axis, so it has a long force arm for producing dorsiflexion and eversion of the ankle. By pulling the sole of the foot outward into eversion, body weight is distributed to the medial side of the foot.

The distal intertarsal joints include the intercuneiform and cuneocuboid joint complex, cuneonavicular joints, and cuboideonavicular joints. All of these joints except the cuboideonavicular joint are plane synovial joints, and all of the intertarsal joints are capable of gliding and rotational movement. The talus moves with the foot during dorsi- and plantarflexion, but during inversion and eversion, which occurs at the intertarsal joints, the talus moves very little.

Forefoot

The forefoot includes the metatarsals and phalanges. These make up the tarsometatarsal, intermetatarsal, metatarsophalangeal, and interphalangeal joints. Tarsometatarsal joints are where the three cuneiforms and cuboid articulate with the base of the five metatarsals. These joints are intrinsically stable and essentially immobile (Nordin & Frankel, 2012). The tarsometatarsal joints function to stabilize the second metatarsal, making it a rigid forefoot bone to carry most of the load while walking. Resting position is midway between the extremes of ROM, with the close-packed position in supination (Magee, 2014). The metatarsophalangeal joints are the articulations between the metatarsals with the phalanges. The interphalangeal joints are the articulations between the phalanges, which aid in keeping the toes in contact with the ground. Resting position is in 10 degrees extension, and the close-packed position is in full extension.

During weightbearing, pronation and supination of the foot permit the leg to rotate in all three directions relative to the calcaneus, due primarily to the interaction between the subtalar, transverse tarsal joints, and medial longitudinal arch. The distal intertarsal joints assist the transverse tarsal but have small joint movements, and the primary function of these joints is to provide stability across the midfoot (Neumann, 2002).

Essentially, the tarsals transmit the weight of the body to the heel and ball of the foot. Tarsals are seen to correspond structurally to the carpals of the hand. The metatarsals and phalanges thus correspond to the metacarpals of the hand, and these form the instep of the foot (Smith, Weiss, & Lehmkuhl, 1996).

Movements of the Foot

Abduction and adduction occur around a vertical rather than anteroposterior axis and mainly in the subtalar and midtarsal joints. Inversion and eversion occur in the coronal plane around an anteroposterior axis and mainly in the subtalar and midtarsal joints. Dorsi- and plantarflexion occur primarily at the talocrural joint (Levangie & Norkin, 2011). The motions of pronation and supination around oblique axes occur at the talocrural, subtalar, and midtarsal joints.

Stability of the Foot

The foot has bony congruency with the two malleoli and tibia forming a mortise joint with the talus as well as substantial ligamentous support (Nordin & Frankel, 2012).

The deltoid (medial collateral) ligament stabilizes the foot during eversion and protects the foot against valgus stresses in the talocrural, subtalar, and talonavicular joints. The anterior talofibular ligament limits anterior displacement, plantarflexion, and inversion of the foot. The transverse tarsal joint has support from the talonavicular ligament, which allows rotation and restricts the movement of the talus on the navicular, with the dorsal talonavicular limiting inversion. The long and short plantar ligaments limit depression and maintain the lateral longitudinal arch. Dorsal ligaments permit gliding between tarsals and metatarsals and support the arch. The tarsometatarsal joints have the interosseous cuneometatarsal ligament and plantar ligaments, which protect these joints and the arch while permitting gliding between tarsals and metatarsals. The intermetatarsal, metatarsophalangeal, and interphalangeal joints have interosseous, collateral, plantar, and deep transverse metatarsal ligaments to protect and support these joints and the joint capsule (Hamill et al., 2015; Houglum & Bertoti, 2012).

Assessment of the Foot

The occupational profile will be done first to determine what the client's goals are related to any limitations in occupational performance due to foot restrictions or pain. Observe the client standing while facing you and from behind. Have the client remove his or her shoes and socks. Looking at the shoes may reveal insoles or uneven wear, which may be helpful information in the dynamics of the client's gait, notably oversupination or overpronation. Observe any gross deformity, which may indicate a fracture or dislocation, and assess any swelling, changes in temperature, or color. An increased prominence of the posterior-superior lateral calcaneus may indicate Haglund's deformity, which may be accompanied by soft tissue thickening and tenderness. Observe the forefoot varus/valgus and rearfoot varus/valgus.

Foot shape may indicate predispositions to increased loads on proximal metatarsals and potential injury and arthritis. The majority of people have feet with the longest toe as the great toe (an Egyptian foot), followed by feet where the second toe is the longest (a Greek foot or Morton's foot), and fewer people have feet in which the great and second toe are the same length (Young et al., 2005).

The height of a normal medial longitudinal arch at the apex is approximately 1 cm when the client is weightbearing (Young et al., 2005). If the longitudinal arch is high (determined by the height of the navicular bone and known as *pes cavus* or *cavus foot*), the client may be more prone to overuse injuries as the higher arch is not as able to absorb shocks or provide support. The higher arch causes the plantar fascia to stretch away from the calcaneus and may cause plantar fasciitis.

If the longitudinal arch collapses, this can result in flat feet (pes planus). This can occur for a number of reasons, including heredity or congenital abnormality, stretched or torn tendons, inflammation of the posterior tibial tendon, broken/dislocated bones, obesity, diabetes, pregnancy, and aging. The foot may be painful or swollen, with back and leg pain also possible. A person with a flat arch will walk in a pronated position with the foot everted. Shin splints are also possible with both flat and high arches.

Assess all active and passive movements of the foot to include inversion, eversion, dorsiflexion, and plantarflexion. Compare the movement of both sides, and compare the ROM to known norms.

The American Academy of Orthopedic Surgeons (Riskowski, Hagedorn, & Hannan, 2011) conducted a systematic review of lower limb outcome assessments of patient-reported outcome measures, which included the Foot and Ankle Module (Johanson, Liang, Daltroy, Rudicel, & Richmond, 2004), Bristol Foot Score (Barnett, Campbell, & Harvey, 2005), Revised Foot Function Index (Budiman-Mak, Conrad, Mazza, & Stuck, 2013), Foot Health Status Questionnaire (Bennett & Patterson, 1998), Manchester Foot Pain and Disability Index (Menz, Tiedemann, Kwan, Plumb, & Lord, 2006), Podiatric Health Questionnaire (Macran et al., 2003), and Rowan Foot Pain Assessment (Rowan, 2001). Special tests of the foot are listed in Table 11-3.

Table 11-3

Special Tests for the Foot

Test	Structures Involved
Fracture screening tests	Test for metatarsal fracture
Navicular drop test	Assess height of the navicular bone
Test for interdigital neuroma	Presence of neuroma
Windlass mechanism test	Fascial and ligamentous impairments of the foot

Summary

- An overview of the structures of the knee, ankle, and foot is provided to understand the contribution these structures make to function.
- The knee, with the hip and ankle, supports the body and serves to help in foot placement in space.
- The ligaments of the knee are especially important because there are no bony restraints to knee movement.
- The ankle and foot are very stable due to the large number of bones, ligaments, and muscle that comprise these joints.
- These joints balance the conflicting demands of providing a stable base of support.

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Section III

Intervention

12

Biomechanical Intervention Approach

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The distinct value of occupational therapy is the provision of intervention that improves the health and quality of life for our clients by facilitating participation and engagement in occupations. Intervention is client centered, achieves positive outcomes, and is cost effective (American Occupational Therapy Association [AOTA], 2016). The types of occupational therapy interventions include occupational-based intervention, preparatory methods and tasks, education and training, advocacy, and group interventions. Intervention approaches are the strategies that direct the process of intervention, and these include create/promote, establish/restore, maintain, modify, and prevent disability (AOTA, 2014).

The biomechanical approach is a remediation or restoration approach, and the intervention is designed to restore or establish client-level factors of structural stability, tissue integrity, range of motion (ROM), strength, and endurance (Table 12-1). In particular, the focus is on performance skills, performance patterns, and client factors, with the underlying belief that by establishing or restoring these factors, resumption of valued roles and successful participation in areas of occupation will be possible. In cases where full restoration is not possible or in degenerative conditions, the maintenance approach is used within the biomechanical approach to enable preservation of the client's physical performance capabilities and slow declines in impairments and task abilities.

Conceptual Background

In selecting an intervention approach, remediation or restorative approaches are chosen when there is an expectation for significant reduction in the impairment that is limiting participation in valued occupations. It is assumed that resolution of physical impairments will reduce activity limitations and increase participation in areas of occupations. Intervention may involve learning new performance skills to maintain or improve the client's quality of life (McGinnis, 1999).

The biomechanical approach is used to explain function using anatomical and physiological concepts, with exercise physiology, kinetics, anatomy, and kinematics as the theoretical base (Radomski & Latham, 2014). Occupational therapists use their knowledge of activity analysis and apply it to understanding movement created by muscles, joints, and soft tissues and those circumstances that prevent or permit motion to occur (Pendleton, 2012). The biomechanical approach requires an understanding of the relationship between musculoskeletal function and how the body is designed and used in the performance of daily occupations. The effect, purpose, and meaning of engagement in these activities influence the client's compliance, effort, fatigue, and improvement in movement capacity (Kielhofner, 1992).

Rybski, M. F.
Kinesiology for Occupational Therapy, Third Edition (pp. 323-366).

Table 12-1

APPROACHES TO INTERVENTION

Occupational Therapy Framework

↓

Theory

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Intervention Approaches

Create/Promote	*Remediate*	*Maintain*	*Compensate*	*Prevent*
	Cognitive Behavioral		Cognitive Behavioral	Cognitive Behavioral
		Cognitive Disabilities	Cognitive Disabilities	
	Neurodevelopmental			
	Proprioceptive Neuromuscular Facilitation (PNF)			
	Biomechanical	Biomechanical		Biomechanical
	Sensory Integration			
	Psychodynamic		Psychodynamic	
		Rehabilitation	Rehabilitation	

Note: Lighter text indicates a secondary emphasis in intervention.

Assumptions

The biomechanical approach assumes that the client has the capacity for voluntary control of the body (muscle control) and mind (motivation). It is anatomy and physiology that determine normal function, and humans are biomechanical beings whose ROM, strength, and endurance have physiological and kinetic potential as well as role-relevant behaviors (Houglum & Bertoti, 2012). Humans are able to perform role-relevant behaviors most efficiently when they assume and maintain positions that are biomechanically advantageous.

The biomechanical approach involves the musculoskeletal system, peripheral nerves, and integumentary and/or cardiopulmonary systems and requires an intact brain and central nervous system to produce isolated, voluntary, coordinated movements. Intervention is aimed at improving strength, ROM, endurance, tissue integrity, structural stability, and coordination of these systems. This approach is most effective for clients with orthopedic disorders (e.g., fractures, rheumatoid arthritis) and lower motor neuron disorders resulting in weakness and flaccidity (e.g., peripheral nerve injuries and diseases, Guillain-Barré syndrome, polio, spinal cord injuries, and diseases) as well as clients with hand injuries, burns, cardiopulmonary disease, and amputations.

For the intervention techniques to be effective, the client must have motor pathways available with the potential for recovery in strength, ROM, endurance, and/or coordination. Some sensory feedback must be available to provide information about movement to the muscles and nervous system. Because the focus of intervention is on strength, endurance, and ROM, muscles and tendons must be free to move and relatively free of pain. In addition, the client must be able to understand the directions and purpose of the intervention and be interested and motivated to perform the activities and exercises. The biomechanical approach is not appropriate for clients with impairments in central nervous system function, which may result in spasticity and lack of voluntary control of isolated motion. Clients with inflamed joints or those just out of surgery are not appropriate for vigorous exercise regimens and activities.

The focus on musculoskeletal systems defines biomechanical intervention and includes physical fitness and health. While not the only frame of reference to accentuate the value of health promotion, many of the physical fitness goals are biomechanical in nature. In the *Guide to Occupational Therapy Practice*, health promotion and wellness often involves a "lifestyle redesign" (Moyers, 1999), underscoring the belief that occupation is an important component to staying healthy. Health involves the body, self, and environment and is intricately linked to sufficient cardiovascular function, age, fitness levels, hereditary factors, and level of physical health (Christiansen & Baum, 1997).

Function and Dysfunction

Function, according to the biomechanical approach, is the capacity for movement in bones, joints, muscles, tendons, peripheral nerves, heart, lungs, and skin as demonstrated by adequate ROM, strength, and endurance needed in role-relevant behavior. The functioning person can assume and maintain positions that are biomechanically advantageous and promote efficiency of motion. Performance depends on simultaneous actions of muscles across joints to produce the movement and the stability that is required of the task.

Dysfunction is characterized by the inability to demonstrate adequate ROM, strength, and endurance for physical subskills and independent life skills in role-relevant behaviors. The person is unable to assume and maintain positions that are biomechanically advantageous and promote efficiency of motion due to alterations or decreased capacity for movement in joints, bones, muscles, and tendons, resulting in impairments in strength, ROM, coordination, or endurance that interfere with occupational performance.

Assessment in this approach involves identification of ROM, strength, and endurance subskills needed to perform role-relevant behaviors. Activity analyses will reveal the most biomechanically advantageous and efficient positions to assume when participating in desired activities and will help determine discrepancies between the physical requirements of the activity and the client's baseline performance. Specific assessments usually include ROM testing and screens, strength testing (manual muscle testing and grasp/pinch via dynamometer and pinchmeter), and strength screens, as well as assessment of edema, tissue integrity, structural stability, and endurance.

Strengths and Limitations

Hall and Brady (2005) cite the following benefits of physical remediation:

- Increased client, caregiver, family, or significant other knowledge about condition, prognosis, and management
- Acquisition of behaviors that foster healthy habits, wellness, and prevention
- Improved levels of performance in activities of daily living (ADL) or instrumental activities of daily living (IADL) areas of occupation
- Improved physical function, health status, and sense of well-being
- Improved safety
- Reduced disability, secondary conditions, and recurrence
- Enhanced decision making about use of health care resources by the client and family
- Decreased service use and improved cost containment

Moyers (1999) identified two main techniques used in remediation approaches. The first is that of teaching new skills, behaviors, or habits where outdated or maladaptive skills, behaviors, or habits are replaced. This is done by modifying the existing performance skills and performance patterns. Client-related instruction also includes providing the client with information about the pathological process and impairments resulting in the experienced functional limitations. Clear explanations about the purpose, benefits, and complications are provided as part of the collaborative and ethical treatment planning process.

The second technique used in remediation approaches is to change the biological, physiological, psychological, or neurological processes. The focus is on decreasing the client's pain and reducing the impact of impairments on occupational performance. While sensorimotor techniques, graded exercise and activities, physical agent modalities, and manual techniques are used as intervention strategies in this approach, Moyers adds that:

> [S]imply expecting improvements in impairments to automatically produce changes in the level of disablement without addressing performance in occupations within the intervention plan is inappropriate. The relationship between the impairment and the level of disablement is complex and is affected by many factors in addition to changes in the impairment. (1999, p. 276)

This typifies a misinterpretation of this therapeutic approach where it is assumed that changes in impairments automatically lead to increased occupational performance. If the intervention goal is to increase ROM, strength, or endurance, this does not mean that the client will automatically or spontaneously use these new levels of physical performance in work, play, or self-care. The intervention goal is always focused on improved health and quality of life through facilitating participation and engagement in occupations. The methods to achieve this may include increasing strength or ROM to functional limits.

Another criticism of this approach is that, with the focus of the intervention on the client factors and performance skills, the approach is reductionistic. Some intervention methods, such as massage, wound care, or use of physical agent modalities, are considered preparatory methods (also referred to as *adjunctive* or *enabling methods*) used in preparation for occupational task performance. Preparatory tasks, such as strengthening exercises or conditioning programs, are chosen to target specific client factors that are impaired. These methods can be considered nonpurposeful and without an inherent goal of engaging both the physical and mental attributes of the individual. Often, the intervention is done "to" the client as a passive recipient. These adjunctive modalities are necessary to provide structural stability, position parts to prevent deformities, provide rest for a part, and increase function in components for use in occupations. It is important that the client understand how the preparatory tasks and methods will enable improved occupational task performance.

The use of enabling and adjunctive modalities seems inherently at odds with the core values of occupational therapy, and this would be true if the ultimate intervention goal is simply remediation of an impairment and not one of functional improvement in meaningful tasks. Occupational therapists see clients earlier in the recovery phase, clients who are more acutely ill, and clients who often have shorter lengths of stays that necessitate these preliminary interventions. Again, it must be reiterated that, without the ultimate focus of a functional outcome, using adjunctive or enabling activities should not be considered occupational therapy practice.

Another limitation of this approach is that it focuses only on the physical performance of occupations and does not include volition, context, roles, or environment, and little reference is made to motivation or to the psychological, emotional, or social aspects of recovery of physical function. The biomechanical intervention is usually part of a comprehensive occupational therapy program that develops goals in collaboration with the client to encompass all areas of the client's life.

Table 12-2

STRENGTHS AND LIMITATIONS TO THE BIOMECHANICAL APPROACH

STRENGTHS	LIMITATIONS

• Good use of media and equipment in a variety of creative and constructive activities
• Incorporates numerous knowledge bases:
  ◦ Activity analysis
  ◦ Anatomy/physiology
  ◦ Kinesiology—kinetics/kinematics
  ◦ Apparent direct cause-and-effect relationship between treatment and remediation or prevention
• Direct cause-and-effect relationship between techniques and goals
	• It cannot be assumed that increases in ROM, strength, and endurance will automatically be used by the client in functional activities
	• Requires continuous review and revision of treatment to ensure relevance to client needs
	• Client-centered focus can easily be lost if not attentive to the client's needs

Table 12-2 summarizes the strengths and limitations of the biomechanical approach.

Thoughtful clinical reasoning is used to determine what aspects of performance can be improved and which need compensatory strategies based on an in-depth understanding of the client as a person (interactive reasoning). Intervention occurs not only because there are impairments in biological, physiological, psychological, or neurological processes, but also because these impairments interfere with the successful living of this person's life. The remediation of strength or ROM is only one small part of the total intervention strategy used, and the biomechanical approach is often used with other approaches to address these other areas simultaneously. While the biomechanical approach relies heavily on procedural reasoning to incorporate disease and prognostic information into intervention planning, that is not to say that other aspects of reasoning are not also occurring concurrently as part of the total intervention process.

The biomechanical approach makes good use of media and equipment to promote physical function, and the techniques can be applied to a variety of creative and constructive activities. Knowledge of activity analysis is applied to understanding movements needed in specific activities. The utilization of anatomical, physiological, and mechanical knowledge has led to the development of specific techniques for measuring and treating movement, strength, and endurance limitations.

A direct cause-and-effect relationship can be clearly seen in the biomechanical treatment process. To ensure that the activities used in intervention will achieve goals that are of value to the client, these activities must correlate the physical demands of the graded activities to subskills and role-relevant behaviors. These activities should be motivating and have meaning to the client as a means of meeting individual needs and interests in relation to social roles. Short-term goals may relate to performance of subskills in the clinic while in the hospital, but long-term goals must relate to role-relevant behaviors and performance in the community environment in which they are ultimately expected to occur. The activities should be designed to prevent or reverse dysfunction and/or to develop new skills to enhance performance in life roles. Intervention should provide graded activities that simulate or duplicate the physical requirements of the tasks and demand increasing levels of ROM, strength, and endurance.

The techniques used in the biomechanical approach include:

- Teaching new skills, behaviors, or habits to reduce dysfunction and/or enhance performance
- Changing the biological, physiological, psychological, or neurological processes
- Use of procedural reasoning skills to incorporate disease and prognostic information into intervention planning
- Correlation of the physical demands of the graded activities to the subskills and role-relevant behaviors
- Provision of motivating and meaningful activities that meet the individual's needs and interests in relation to social roles
- Provision of graded activities that simulate the physical requirements of the task and demand increasing levels of ROM, strength, and endurance
- Establishment of collaboratively established goals that relate to role-relevant behaviors, relate to performance in the environment, and are occupation based

A summary of the focus, assumptions, definition of function, expected outcomes, and techniques used in the biomechanical approach are shown in Table 12-3. The components of the biomechanical approach are structural stability, tissue integrity, ROM, strength, and endurance.

STRUCTURAL STABILITY

Occupational therapists are involved in intervention programs for the entire spectrum of clients—from wellness programs to those who are critically ill. In hospital settings, occupational therapists previously would be consulted to work with clients who were medically stable. Now, our clients are more severely disabled and acutely ill, with greater complexity of comorbidities, so there is the need to balance early mobilization with rest. Clients do not always come to occupational therapy with stable cardiovascular and respiratory function. They may be referred to occupational therapy

Table 12-3

Biomechanical Approach Concepts

Focus	• Bottom-up approach • Restore or establish client-level factors, performance skills, performance patterns • Teach/train new performance skills and patterns • Musculoskeletal capacities, peripheral nerves, integumentary system, cardiopulmonary systems • Related fields: Exercise physiology, kinetics, anatomy, and kinematics
Assumptions	• Motor activity is based on physical mobility and strength • Purposeful activities remediate loss of ROM, strength, and endurance • Purposeful activity has meaning to client • Activities can be graded • Participation in activities maintains and improves function • Improvement in ROM, strength, and endurance will result in improved function • Rest/stress principles inherent
Function	• Capacity for movement • Adequate ROM, strength, and endurance to complete activities • Performance requires simultaneous actions of muscles and joints • Functional person uses positions that are biomechanically advantageous for efficiency • Reliant on the principles of rest and stress
Expected Outcomes	• Reduction in limitations • Learn new skills • Slow declines • Maintain or improve quality of life
Techniques	• Teach new skills, behaviors, or habits to reduce dysfunction and/or enhance performance • Change the biological or physiological processes • Use of procedural reasoning skills to incorporate disease and prognostic information into intervention planning • Correlation of the physical demands of the graded activities to the subskills and role-relevant behaviors • Motivation and meaningful activities meet individual needs and interests in relation to social roles • Provide graded activities that simulate physical requirements of task and demand increasing levels of ROM, strength, and endurance

because of shortness of breath, decreased endurance, or physical deconditioning. Shorter lengths of stay greatly influence intervention, which starts where the client currently is in the continuum of care and what further services are needed and expected.

Structural stability includes muscle balance, cardiovascular and respiratory stability, and integumentary system stability. When a muscle is in a state of equilibrium of opposing muscles acting on a joint, this is muscle balance where there is an ideal alignment of the joint for movement and for optimal stabilization. Muscle imbalance exists when there is a weak muscle and the antagonist muscle is strong, leading to faulty alignment, deceased joint stability, and inefficient movements. Faulty joint alignment results in undue stress in the joint, and structural instability may occur due to separation of the origin and insertion of the muscle. Structural stability also refers to core stability of the trunk, where balance and proximal stability is necessary for distal movement.

Structural stability is necessary to regain prior to implementation of other intervention goals. Splints or orthotic devices that are worn temporarily to enforce rest enable healing and facilitate changes in the biological, physiological, or neurological processes by temporarily immobilizing the part. Positioning devices can also serve to temporarily enforce rest to promote healing. By changing the damaged underlying structures, this is a remediation method of the biomechanical approach.

Devices and orthoses can be used to remediate, compensate, or prevent further disability. If the orthosis or device is used in joints too weak to resist the force of gravity to maintain functional alignment with the goal of preventing development of contractures and deformities, then this would be a method of prevention of disability rather than remediation. The use of a lapboard for a dependent hemiplegic arm, used to prevent further injury to the extremity, might also be an example of the intervention approach of prevention of disability. Neither of these devices is used to remediate or change the lack of function of that extremity. The use of a universal cuff with utensils inserted is a means of compensating for lost function, not to prevent disability or promote healing. However, if a foam wedge was used by a client with a hip replacement, this object will be used temporarily until the structures relative to the hip surgery are healed. The wedge does not serve to compensate for lost function (compensation/adaptation) nor to prevent disability; rather, the function of the wedge is to promote healing and enforce positioning. While the distinction between the use of these devices seems academic, why one is using a particular device or positioning technique has much to do with clinical reasoning, responsible use of adaptive equipment, and client outcomes.

Postural instability and misalignment may limit upper extremity reaching movements, and discrete movement is often not well-controlled (O'Sullivan & Schmitz, 1999). Stability enables controlled mobility, and many activities require both static and dynamic mobility for skilled and effective movement patterns. To progress the client to the level of effective, controlled mobility, static then dynamic stability is achieved first, then controlled mobility follows, including static-dynamic control involving the ability to shift weight onto one side and free the opposite side for nonweightbearing dynamic activities or to fix the distal segment to enable the proximal segment to move (O'Sullivan & Schmitz, 1999).

Joint stability can be seen in a loss of control of small arthrokinematic movements of roll, spin, slide, and translation (translational instability or pathological or mechanical instability); can be due to clinical or gross instability or due to pathological hypermobility (anatomic instability) resulting in excessive movement; or can result in the inability to control either arthrokinematic or osteokinematic movement in the available ROM (functional instability; Magee, 2014). When there is instability due to excessive flexibility due to stretched or loose ligaments, this increases the risk of sprain and subluxation.

Ligaments should be tight, and they provide the stability needed for controlled and safe movement. The fibers need to be flexible to enable movement yet tight to protect the joints. When ligaments are loose, too much movement at a joint can lead to ligamental, joint capsule, tendon, and muscle damage and can lead to joint instability.

Ligaments can become loose in three ways: through genetics, through trauma, or by the development of distended scar tissue. Genetically, tendons can be disproportionately long as they attach to the joint surfaces, allowing greater movement but less joint stability. Trauma or injury can stretch a ligament permanently. Adhesive scar tissue can stretch over time, leaving the joint hypermobile and unstable. Weak or lax ligaments allow pathologic forces to act upon structures, altering body mechanics and creating deformities, loss of function, and painful movement.

Intervention to improve joint stability would include strengthening weak structures, limiting excessive or abnormal joint mobility, and providing noncontractile joint stability (Pendleton & Schultz-Krohn, 2006). Kinesio taping has been used to prevent joint injury and provide stability while not restricting movement. It has been used with glenohumeral instability to enhance joint stability with dyskinetic dynamic scapulothoracic movement. The tape is anchored at either the origin or insertion and is gently stretched and taped over/around either shortened or lengthened muscles. This method of improving joint stability is believed to affect the peripheral somatosensory receptors in superficial skin, which influences the skin and lymphatic systems and joint and muscle function as it relates to pain, proprioception, and motor control (Cooper, 2007).

Documentation of intervention is an important part of the treatment process as a confirmation that the intervention actually occurred and clearly indicates that professional judgment and decision making was needed by a skilled practitioner. The occupational therapist's unique skills and knowledge need to be evident in the written record with evidence that the client would not improve naturally without the intervention provided. Documentation of intervention should provide evidence that significant improvement was made in a reasonable and predictable amount of time.

The goals are outcomes of intervention, not the process of intervention, and they are concrete, measurable, testable, achievable, relevant, and predictable. Because occupational therapy is a client-centered profession, substantiation of collaboration with the client in the development of the goals should also be seen in the documentation. Goals are relevant and meaningful to the individual, related to roles and the expected environment, time-limited, and related to length of stay. A short-term goal of driving would not be relevant or related to length of stay in an acute-care environment where clients stay only a few days until moving to the next level of care.

Intervention goals should have three essential parts: a statement of terminal behavior, a statement about conditions of treatment, and a criteria statement (Quinn & Gordon, 2003). A statement of terminal behavior is an indication of physical changes or changes in behavior that you expect. An example is, "The client will feed self." Further goal definition is needed, so a statement about the conditions of treatment will describe the circumstances that will facilitate achieving the terminal behavior. This can include how the environment will be set up to enhance performance; the use of any special devices; the degree of training, assistance, or supervision that is needed; and the types of cues that are required. An example is, "Given adaptive devices, the client will feed self." What is still not included in this goal is the acceptable level, degree of performance, or competence that is required to achieve this goal. The statement of criteria answers how much, how often, how well, how accurately, or how quickly the goal is to be accomplished. An example is, "Given assistive devices, the client will feed self independently in 30 minutes." The criteria state that the client will be independent (requiring no assistance, cues, or supervision) and will accomplish the task in a reasonable amount of time.

Borcherding (2005) uses the FEAST acronym, which covers similar essential parts of the goal. F = function, which is the functional gain to be achieved; E = expectation, which is a description of what the client will do as part of the goal; A = action or what will be done; S = specific conditions, essentially the same as the statement of conditions described previously; and T = timeline as an indication of how long the goal will take to be achieved.

While goal statements seem awkward and wordy, the focus of biomechanical intervention is actually the short-term improvement of the client's physical abilities that will result in the long-term outcomes of improvements in the areas of

Table 12-4

Structural Stability Intervention and Documentation

GOAL

Client will (be independent/modified independent) and (require maximal, moderate, or minimal assistance) in performance of (specify tasks) by regaining structural stability in damaged structures by using:

Method	**Principle/Rationale**	**Example**
Orthoses	That are worn/used to temporarily enforce rest until structures are healed	• Dorsal rubber band splint for flexor tendon repair • Body jacket or cast • Resting splints • Wrist braces for carpal tunnel syndrome
Positioning (static, dynamic, weight shift)	That is used to enforce rest until damaged structures are healed	• Stryker frame • Wedge for hip replacement • Pillow placement for cerebrovascular accident
Procedures	That gradually stress structures to new levels of adaptation	• Stump toughening and shaping • Lower extremity weightbearing for fracture

Adapted from Dutton, R. (1995). *Clinical reasoning in physical disabilities*. Baltimore, MD: Lippincott Williams & Wilkins and Marrelli, T. M., & Krulish, L. H. (1999). *Home care therapy: Quality, documentation and reimbursement*. Boca Grande, FL: Marrelli & Associates, Inc.

occupation of work, play, leisure, self-care/ADL, IADL, and social participation. The outcomes, or end result, of the occupational therapy intervention process may relate to engagement of occupation, while other outcomes are experienced by clients when they can return to participation in desired occupations (AOTA, 2014).

By writing one goal that includes the short-term objectives of intervention (e.g., increasing ROM, an aspect of motor skills, client factors) and the reason the goal is being attempted (e.g., the functional outcome of the ability to put on a shirt or area of occupation), the focus on function is clear. This answers the question "so what": so, what is so important about an increase of 50 degrees of additional ROM? It can mean the difference between being independent in dressing and being dependent on others. This needs to be clear in the goal statement. Table 12-4 provides a sample goal statement, method, principle or rationale for the goal, and examples of activities or methods to achieve the goal. Each component of the biomechanical approach (structural stability, tissue integrity, ROM, strength, and endurance) has similar tables to assist with writing functional, measurable, short-term biomechanical goals that are occupation based.

Tissue Integrity

Occupational therapists play an important part in both the restoration and prevention of wounds. Occupational therapists use their understanding of physiologic and anatomic wound healing, client factors, body structures, and functions as well as enhancing mental health in enabling participation in activities (Amini, 2013). Clients with wounds experience physical, social, economic, and emotional consequences, including anxiety and depression, independent of socioeconomic variables (Souza Nogueira, Rodrigues Zanin, Miyazaki, & Pereira de Godoy, 2009), all of which can adversely affect quality of life.

The maintenance of soft tissue integrity involves an understanding of tissue healing and pathology, remolding of scar tissue, as well as methods to reduce edema. Intervention can be viewed as both a biomechanical change in structures as well as prevention of further disability due to the damage that edema and scarring can do to adjacent structures and in resultant function.

Assessment of tissue integrity begins with observation of the skin. Look at the color of the skin and make note of any areas that are blue (cyanosis), red (erythematic), or white (pallor). A tissue that is red may be due to a superficial second-degree burn, acute fresh wound, surgical wound, or wound left open to heal by secondary intention (Cooper, 2007). Yellow skin may indicate that an exudate is present, and often pink or red granulation tissue can be seen at the wound edges. Yellow wounds may indicate a late inflammatory or early fibroplasia phase of tissue healing. Tissue that is black, brown, or grey may indicate necrosis or eschar. The wound may be in all stages of wound repair (Cooper, 2007). Wounds often have more than one color present at one time, and treatment would begin with the most serious wounds (i.e., progress from black to yellow to red; Cooper, 2007).

Notice if the skin is unusually moist or dry as well as the texture and temperature of the skin. If there is a wound, determine the length and width of the wound (using sterile tools to make the measurements). Cotton swabs may be used to determine the depth of the wound.

It is important to identify what tissues are involved, what causes movement restrictions, and how these restrictions limit occupational performance and to identify the stage of tissue healing.

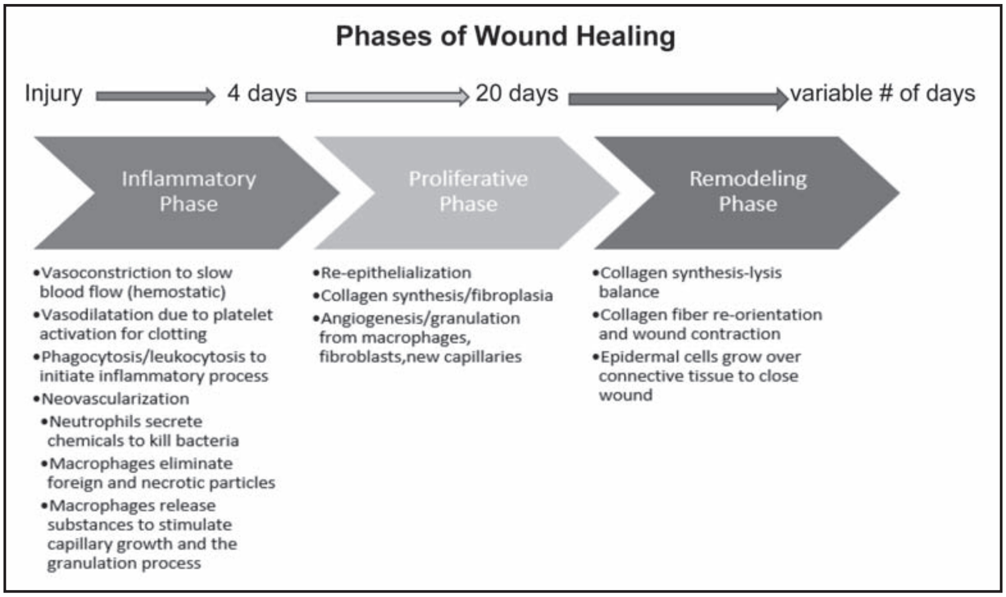


Figure 12-1. Phases of wound healing.

Tissue Healing

Soft tissue healing is a complex process of fibrous scar formation that begins at the moment of injury and can continue for months or even years. It is important to recognize the normal healing process of tissue. There are three phases of healing, with specific characteristics in each phase. The phases overlap, and parts of the healing tissue could be in one phase while other parts are in another (Figure 12-1).

Inflammatory Phase (Exudative Phase)

When a tissue is injured, inflammation begins almost immediately and lasts approximately 1 to 14 days. The wound is easily contaminated by bacteria and foreign substances, so the purpose of the inflammatory phase is to stabilize the wound, remove debris and bacteria, and arrange the substrate necessary for collagen synthesis. The inflammatory phase serves to protect structures from infection and to initiate healing by clearing tissue debris from the site of injury. The inflammatory phase can be acute (lasting 3 to 4 days) or chronic when there is persistent phagogenic microorganisms still present after the acute inflammation occurs (can continue for months and may have a gradual onset; Cooper, 2007; Prosser & Conolly, 2003).

When injured, initiated within hours, and lasting about 72 hours, there is a hemorrhagic reaction due to the disruption of blood flow. The wound is easily contaminated by bacteria and foreign substances. There is immediate but transient vasoconstriction, and platelet degranulation begins to initiate clotting. Activation of the platelets results in vasodilation, resulting in an increase in circulation and tissue edema. There is a migration of white blood cells to promote phagocytosis. Injured cells release chemicals that initiate the inflammatory response and eliminate bacteria and debris.

Fibroblasts are recruited, which then replace the phagocytes, and wound strength is provided as fibroblasts begin to lay down weak hydrogen bonds of collagen fibers (Cooper, 2007; Donatelli & Wooden, 2010; Hall & Brady, 2005; Konin, 1999). Due to the weak wound structure, immobilization is often advised (e.g., splints, casts). There may also be deficits in force production. The joint is characterized by pain, warmth, tenderness, swelling, and loss of function. Initially, cold modalities, compression, and elevation are used to decrease inflammation.

The goal of intervention at this stage is to decrease joint pain and tenderness, prevent the development of chronic inflammation, and rest the acutely injured parts while maintaining the mobility of adjacent joints (Cooper, 2007; Donatelli & Wooden, 2010; Kisner & Colby, 2012; Konin, 1999). Generally, there is no lifting, one-handed techniques are used, and good body mechanics are emphasized. During the first 24 to 48 hours, rest is provided (via splints, tape, casts) and cold modalities, compression, and elevation are used to decrease the inflammation (Kisner & Colby, 2012). This phase can subside and progress to phase II or can persist indefinitely, depending on the degree of bacterial contamination (Pendleton & Schultz-Krohn, 2001).

Fibroplasia Phase (Proliferation, Repair and Healing, or Subacute Phase)

The fibroplasia phase occurs when the body attempts to restore mechanical integrity to the injured tissue. Fibroblasts enter the wound and may last 2 to 4 weeks as they begin scar formation by laying down new collagen (Fess, Gettle, Philips, & Janson, 2005). In this phase, cell proliferation and granular tissue formation occurs. Fibroblasts, myofibroblasts, and endothelial cells proliferate, and temporary scaffolding called *granulation tissue* (type II collagen with little mechanical strength and is very fragile) is laid down. The fibers are thin and weak and have poor tensile strength. The tissue is vulnerable to breakdown, and because the vascular system is weak, the wound is subject to bleeding.

The wound begins to contract due to proliferation of epithelial cells, which have cells adjacent to the wound, and enlarge, flatten, and detach until cells touch each other (Prosser & Conolly, 2003). Fibroblasts begin scar formation by laying down new collagen, leading to a gradual increase in tensile strength. The collagen is primarily type III collagen, which is small, disorganized, and susceptible to disruption. Because the scar is not composed of organized tissues, the scar is red and swollen, easily damaged, and tender to stretch and pressure (Hall & Brady, 2005). A precaution is to avoid sun exposure when the scar is still immature (pink or red, thick, itchy, or sensitive; Cooper, 2007). The fibroblasts are replaced by the scar collagen fibers, making the wound stronger. The disappearance of fibroblasts marks the end of this phase. The joint may feel warm or have edema and tenderness, and pain is felt with resistance and stretch.

Active range of motion (AROM), typically used to promote balance in structures and splints, is used to protect healing structures (Cooper, 2007). Intervention at this point focuses on AROM and joint mobilization with gentle resistance (Fess et al., 2005). The client is experiencing less pain and may be tempted to resume normal activities that may be detrimental to the healing process. Active movement that does not result in inflammation or decreased ROM is encouraged to prevent new tissue adherence to surrounding structures that would limit joint mobility. As active motion and joint play improve, progress to isotonic activities and exercises develop neuromuscular control, strength, and endurance in the affected muscles (Kisner & Colby, 2012). Select activities that elongate tissue length, promote the use of the extremity as an assist, and are low-intensity for the boundaries of the healing tissue and pain. As healing progresses, initiate the development of neuromuscular control, muscle endurance, and strength in involved and related muscle by starting with multiangle isometric movement within tolerance and maintain the integrity and function of adjacent areas via progressive strengthening and stabilizing. Indications that too much movement or motion has been done at this stage are resting pain, fatigue, increased weakness, or spasms that last more than 24 hours (Kisner & Colby, 2012).

Remodeling Phase

The remodeling phase can start between weeks 3 and 6 and can continue for as long as 3 months to 2 years. The result of healing in all tissues is a scar (Fess et al., 2005). Factors related to scar maturation are the rate of collagen turnover, increased number of stronger collagen cross-links, and the linear alignment of collagen fibers (Cooper, 2007). The tissue changes as new collagen replaces the old tissue, the collagen fibers become more organized, and there is an increase in the tensile strength of the scar.

Scar tissue reorganization is better if therapy is started as soon as the tissue can tolerate, with gentle resistive activities and exercises and both dynamic and static splinting (Cooper, 2007). Scar formation occurs due to simultaneous collagen breakdown and production. If the rate of breakdown exceeds the rate of collagen production, then the scar is softer and less bulky. If the rate of production is greater than the rate of breakdown, a hypertrophic, bulky (keloid) scar may result (Fess et al., 2005). The rate and extent of scar organization varies among individuals, and the wound may remain metabolically reactive for long periods of time, possibly necessitating long-term splinting to avoid contracture development (Fess et al., 2005).

The remodeling and maturation of the collagen and scar results in more dense tissue, but the tensile strength of the scar never reaches the pre-injury state (Prosser & Conolly, 2003). By about 6 weeks after the injury, the vascularity of the scar matches adjacent skin, and there is decreased sensitivity.

Intervention is directed toward providing controlled tension on the scar by means of stretching, active movement, resistance, or electrical stimulation to remodel the collagen fibers (Cooper, 2007) and make the scar more pliable. Light compression (Coban [3M], Tubigrip [Molnlycke], pressure garments) facilitates scar maturation (Cooper, 2007). The focus of intervention is to remodel the scar tissue, increase strength and neuromuscular control, and return to engagement in occupations (Cooper, 2007). Cooper (2007) advises early mobilization within a pain-free ROM to promote faster healing of connective tissue, stronger collagen bonds, reduced scar tissue adhesions, and improved collagen fiber orientation.

Increasing scar flexibility can be done by deep friction massage, tendon gliding exercises, and pressure garments that help to separate deep structures (tendons, nerves, blood vessels) that are stuck by the collagen bundles so that these deep structures can move separately (Demeter & Andersson, 2002). Once the structures move separately, slow stretch forces and massage can be applied. Rapid stretching causes scar tissue to tear, while slow stretching produces small gains and is more effective than aggressive, rapid overstretching (Demeter & Andersson, 2002).

Scar tissue adhesions occur when scar tissue adheres to healthy tissue and limits motion. Factors that contribute to adhesion formation include location of the injury, extent of the trauma, reduced blood flow, and prolonged immobilization. Contractures due to scar tissue adhesions can occur in muscles, tendons, joint capsules, or skin. Ligamental tautness can decrease due to adhesive scar tissue because it will stretch and distend over time, which can lead to further injury. Internal adhesive scar tissue forms within a structure (e.g., within a tendon or a ligament) following injury as part of the normal healing process. When an external adhesion forms, it is between two different structures (e.g., between a ligament and the bone), interfering with the normal function of smooth, friction-free gliding of cartilaginous articular surfaces and the excursion of tendons unimpeded by restrictive scars and adhesions (Cooper, 2007; Fess et al., 2005).

If the part is immobilized, the scar tissue may form in unusual places and the pattern of collagen is irregular, but when the part is allowed to move, external adhesive scar tissue is minimized. Movement can help minimize restrictive scar tissue formation, adherent tendons, shortened ligaments, and muscle contracture (Magee, 2014). Knowledge of the healing process and subsequent intervention can prevent scar tissue adhesions, and exercise is helpful once scar tissue develops. There is strong evidence that treatments combining the use of a pressure garment, silicone gel sheeting or spray, and lanolin cream massage were effective for scar management (Schwartz, 2016).

When performing scar management and passive range of motion (PROM) with clients who are recovering from burns, there is strong evidence to support including virtual reality techniques into treatments to decrease pain and anxiety (Schwartz, 2016).

In addition to scar management, neuromuscular control, strength, and muscle endurance can progress from submaximal to maximal resistance, single plane to multiplanar movement, and low to high repetitions. Once ROM is functional, use of supportive or assistive devices can be discontinued. If activities result in joint swelling or pain lasting more than 4 hours, pain that requires medication, a decrease in strength, or the part fatigues more easily, this is indicative of overstressing the healing tissues.

Bones heal by regeneration. Bone is remodeled in response to mechanical demands in accordance with Wolff's law, which states that the remodeling of bone is influenced and modulated by mechanical stress (Levangie & Norkin, 2011; Nordin & Frankel, 2012). Uncomplicated bone remodeling can occur in approximately 10 weeks and occurs in four phases. Initially, there is hematoma formation with swollen, painful, and inflamed tissue at the fracture site. This is followed by fibrocartilaginous callous formation, in which fibroblasts and osteoblasts begin to reconstruct bone and cartilage. Phagocytes clean the debris and old dead bone. A bony callous forms and capillaries grow, creating a spongy bone with increasing tensile strength. By 6 weeks, the collagen matrix is about 70% of normal strength, and by 10 weeks, there is mature bone (Donatelli & Wooden, 2010).

Articular cartilage has a limited capacity for repair and regeneration, and low-frequency compressive loading increases cartilage formation while high magnitude will induce fibrocartilage formation (Levangie & Norkin, 2011). Tendon and ligament repair occurs in the same three phases as soft tissue but at a slower rate due to limited vascularity (Nordin & Frankel, 2012). Tensile loading encourages tissue formation in both tendons and ligaments.

Edema

Edema is a barrier to function because ROM is limited, and there is decreased coordination and pain. Edema often reduces sensation, and coordination is often diminished. Untreated edema may result in permanent losses of ROM if fluids become fibrotic. Loss of active movement combined with compromised nutrition of distal parts can ultimately lead to amputation (Dutton, 1995). Maintenance and remediation of the anatomical and physiological condition of interstitial tissue and skin are important aspects of intervention.

Swelling is a normal consequence of trauma, resulting from vasodilation, which leads to an increase in white blood cells. The inflammatory response is an attempt to decrease the bacteria in the injured part (Pendleton & Schultz-Krohn, 2006). Edema is a condition characterized by excessive swelling of a tissue due to an abnormal accumulation of interstitial fluid in the subcutaneous tissue. Edema may be the result of bone or synovial thickening or fluid accumulation in or around a joint (Magee, 2014). Edema may be localized as in a cyst, swollen bursae, or intra-articular swelling.

Swelling that occurs in 2 to 4 hours after insult is usually accompanied by blood leaking into the tissues (ecchymosis) or joint. Blood swelling feels firmer, thick, and gel-like. There may be elevated skin temperature when swelling is due to blood or pus. Within 8 to 24 hours, there is inflammation and synovial swelling. Swelling that feels hard may be due to osteophytes or myositis ossificans, while soft tissue swelling may feel boggy or spongy.

Long-standing soft tissue swelling feels leathery and thick. Pitting edema is fluid that is thick and slow moving, leaving an indentation when pressure is applied, often caused by circulatory stasis (Magee, 2014). Take note of the skin color, temperature, and sensory changes as these may be signs of serious problems (e.g., purple color may mean pooling of venous blood, which might mean that arterial blood flow is impaired; Pendleton & Schultz-Krohn, 2006).

Types of Edema

Acute

Acute (transudate) edema occurs in the inflammatory phase of tissue healing. The edema pits deeply, rebounds quickly, and can be easily moved (Pendleton & Schultz-Krohn, 2006). The edema is composed primarily of water and electrolytes and decreases after 2 to 5 days because intact venous capillaries can absorb the edema and the lymphatic system absorbs the large plasma proteins not removed by macrophages (Artzberger, 2007).

Subacute and Chronic

The edema in this stage continues to pit but is slower to rebound with a viscous quality due to high plasma protein content. Chronic edema (edema lasting longer than 3 months) pits very little and has a hard feeling. Severe edema is characterized by no elasticity, and the skin is shiny and taut and cannot be lifted (Pendleton & Schultz-Krohn, 2006). Chronic edema is due to the protracted presence of plasma proteins in the interstitum, causing the tissue to become fibrotic.

Complex or Combined

Edema that initially begins as transudate edema may develop into an exudate edema and is often found in clients who have experienced a stroke. Overexercising a flaccid extremity can cause microscopic rupture of tissues, resulting in inflammation and increased edema. If there is no motor return in the flaccid extremity and no motor pump to remove the fluids, the edema can become fibrotic (Pendleton & Schultz-Krohn, 2006).

Other Types

When the heart is unable to pump blood effectively, fluids can accumulate in the extremities. This may be noted in the ankles, along with a slight pink color. Many edema reduction techniques are contraindicated for cardiac edema because of the additional stress placed on an already impaired cardiac system (Pendleton & Schultz-Krohn, 2006).

Low protein edema is swelling due to liver disease, malnutrition, or kidney failure. In contrast to chronic edema, in low protein edema, there are too few plasma proteins in the interstitum. As with cardiac edema, many edema reduction methods are not safe for this type of edema because of the additional burden placed on the liver and kidney (Pendleton & Schultz-Krohn, 2006).

Types of Lymphedema

Lymphedema is chronic swelling that occurs when protein-rich lymph fluid accumulates in the interstitial tissue. The International Society of Lymphology defines lymphedema as an abnormal collection of excessive tissue proteins, edema, chronic inflammation, and fibrosis (International Society of Lymphology, 2013). This occurs when there is permanent mechanical obstruction or disruption of the lymphatic system as a result of cancer, surgery, and/or radiation; bancroftian filariasis (parasitic infection); or a congenital deficit. The lymphatic system provides an accessory route for excess fluids with larger molecules than removed by the venous system. Upper extremity lymphedema most often occurs after breast cancer; lower extremity lymphedema most often occurs with uterine cancer, prostate cancer, lymphoma, or melanoma (Bicego et al., 2006; National Cancer Institute, 2015). The increased lymphatic pressure with accumulation of edema in the subcutaneous tissue can result over time in fibrosis of the tissues, chronic infection, or loss of limb function.

Lymphedema is initially difficult to diagnose because the symptoms may not be seen. The International Society of Lymphology (2013) and National Cancer Institute (2015) generally classify lymphedema according to four stages. Stage 0 is the subclinical or latent stage where there are no visible changes in the limb or body, but the client mentions feeling mild tingling, is unusually tired, or feels the arm or leg is heavy. Mild lymphedema is experienced in Stage 1. The body part appears mildly swollen as the protein-rich fluid starts to accumulate. This stage is spontaneously reversible since skin and tissues have no permanent damage. Stage 1 is typically marked by pitting edema, which may resolve when the part is elevated. Stage 2 is moderate lymphedema characterized by greater swelling, non-pitting edema. There is inflammation and stiffening of blood vessels and tissues. Stage 3 is the most advanced stage, reflected by severe lymphedema. The body part becomes very large and misshapen and the skin looks leathery and wrinkled, feels scaly and dry, or may seep fluid (Bicego et al., 2006).

Another classification system for lymphedema is the *Common Terminology Criteria for Adverse Events v3.0*, which was developed for grading adverse events in the context of clinical trials (Cheville et al., 2003). The lymphedema is graded according to the severity of signs and symptoms as follows (National Cancer Institute, 2015):

- Grade 1: 5% to 10% interlimb discrepancy in volume or circumference; swelling or obscuration of anatomic architecture on close examination; pitting edema
- Grade 2: More than 10% to 30% interlimb discrepancy in volume or circumference; readily apparent obscuration of anatomic architecture; obliteration of skin folds; readily apparent deviation from normal anatomic contour
- Grade 3: More than 30% interlimb discrepancy in volume; lymphorrhea; gross deviation from normal anatomic contour; interfering with ADL
- Grade 4: Progression to malignancy (e.g., lymphangiosarcoma); amputation indicated; disabling lymphedema

Evaluation of Edema and Lymphedema

Evaluation of edema begins with observing and palpating the skin. Is the skin taut or shiny and is there a loss of normal wrinkles and joint creases? Find out how the injury occurred and how long it has been since the injury happened. Describe in detail how the skin feels, looks, and responds to pressure. Is the edema displaced by pressure, leaving a pit that fills back slowly when the pressure is removed (pitting edema), or is it more gel-like and firmer (brawny)?

Edema and lymphedema are measured in essentially three different ways: volumetric measurements, electrical techniques, and optical methods. Clinical assessment methods of edema rebound, and pit depth and pressure assessments are also performed. The edema rebound test measures the amount of time required for the skin to return to its original shape after pressure is applied to an edematous structure. The boggier the edema, the slower the skin is to rebound. A tonometer can be used to measure changes in resistance to tissue pressure, but this not widely used (Cooper, 2007). Edema can be measured and graded by palpating and applying firm pressure for 5 seconds. The degree of edema is based on the depth of indentation in centimeters as follows (Jacobs & Jacobs, 2009):

- 1 cm or less = 1 + edema
- 2 cm = 2 + edema
- 3 cm = 3 + edema
- 4 cm = 4 + edema
- 5 cm or more = 5 + edema

Measurements of Volume

Volumetric measurements can be taken using a volumeter, which measures the amount of water displaced from a container when the hand is inserted. Volumetry is considered the "gold standard" and is a reliable and valid method for edema measurement (Brodovicz et al., 2009; Maihafe et al., 2003). By using a new protocol with an adjustable height table, external trunk support, and 1-mL micropipette, Dodds et al. (2004) confirmed test-retest reliability of a commercial volumeter and reduced the standard error of measurement to 3 mL, compared with the standard of 10 mL. However, one criticism of this measure is that the time it takes to administer the test makes it clinically impractical (Brodovicz et al., 2009; Maihafe et al., 2003). Additionally, immersing the hand in water is sometimes contraindicated (skin infection, open wounds, fixator devices) and may be inappropriate during periods of intense pain (Whalen, 2014).

Use of a tape measure is another method of measuring the volume of edema. It is estimated that this test takes only 1 minute to perform as compared with nearly 6 minutes needed for water volumetry (Maihafe et al., 2003). Circumferential measurements do not provide data about the normal limb but are useful to document progress. Comparing limbs, a comparative circumferential measurement method is easy to perform and uses the contralateral limb as a control (Hayter, 2004).

Many studies have found that the figure-of-eight circumferential volume measurement is reliable and valid (Leard et al., 2004; Maihafe et al., 2003; Pellecchia, 2004). A disadvantage to the use of tape measures is that they are not considered true volume measurements and have not been standardized (Rincon, Shah, Ramella-Roman, & Bhansali, 2016). Use of circumferential hand measurements may also not permit assessment of areas of the hand that are critical in the evaluation of pathology or injury (Maihafe et al., 2003).

The disc model method divides the limb into 10 discs, each given a size of 5 cm. Volume is then calculated by calculating the volume of each disc and adding them. This method, while inexpensive, easy, and reliable, is difficult due to the hand's asymmetrical shape (Rincon et al., 2016). Similarly, the Frustrum (or Sitzia) Method takes circumference measurements at 4 or 8 cm intervals and the volume is derived via a mathematical formula. A final volume measurement can be made with a Limb Volume Measurement System (Bednarczyk, Hershler, & Cooper, 1992), although the use of this method is uncommon.

Electrical Techniques

Electrical techniques are used to measure the water content in tissues by sending a small electrical current through the body and measuring the resistance to the current flow. This method, bioelectrical impedance, provides an estimate of the amount of water in the body. One disadvantage of using bioelectrical impedance with lymphedematous parts is that it cannot detect change in the nonfluid component of fibrous tissue (Rincon et al., 2016).

Optical Techniques

Optical techniques are used to measure either tissue absorbance or limb volume. The computer-aided measurement laser technique is based on computer-aided design methods and requires an infrared laser scanner (Trombetta et al., 2012). A perometer uses an optical electronic scanner to measure limb volume, percentage difference between selected measurements, contour, and cross-sectional areas. It is difficult to measure the most proximal part of the arm or thigh, and the perometer is not able to measure the hand or foot accurately. The measurement of the limb via the perometer requires consistent body placement, a calibrated system, and specialized personnel, and the device is large and expensive. A three-dimensional (3D) LED scanner system has also been developed and, even though volume is calculated from a very large number of measurements, it is not necessarily more accurate than the earlier version (Rincon et al., 2016). Infrared optoelectronic volumetry (Tierney, Aslam, Rennie, & Grace, 1996) use is uncommon (Maihafe et al., 2003). Use of a 3D scanner has the advantage over circumferential measurements of detecting uneven limb shapes (as in lymphedema), which can be overlooked with other volumetric methods (Cau et al., 2006). Lee, Kim, and Chung (2014) used Microsoft Kinect to create 3D depth images.

Imaging via computed tomography (CT) scans, magnetic resonance imaging, or ultrasound with CT scan are highly sensitive and useful in identifying lymphedema, but they are not convenient for continuous monitoring of edema (Rincon et al., 2016). CT scans provide a cross-sectional area of the limb and density measurements, and ultrasound is used to assess skin thickness (Uzkeser, Karatay, Erdemci, Koc, & Senel, 2015). Use of x-rays in the detection of lymphedema (lymphangiography) is not recommended because of the concern that it may contribute to the spread of malignancy in clients with cancer (Bicego et al., 2006; Mondry, Riffenburgh, & Johnstone, 2004).

Treatment of Edema and Lymphedema

Edema

The treatment goals for edema depend on the stage and type of edema. Often, pain reduction is noticed before ROM shows improvement and is an indication of improvement.

Acute Edema. In acute edema, the goal is to prevent excessive swelling, accumulation of blood, and additional tissue damage and to control pain. Minimizing further irritation, inflammation, and infection is important in the treatment of acute edema, so be careful to disinfect any open wounds, provide protection to healing structures, and balance rest with activities.

Reduction of swelling is done by vasoconstriction, compression, and elevation. One way to do this is with bulky dressings (Artzberger, 2005). Bulky dressings can be used to reduce excessive fluid outflow and help to prevent stress on fragile tissues (Cooper, 2007). Caution needs to be taken not to wrap the dressings too tight, which can cause vascular and temperature changes, resulting in increased edema and painful compression.

Retrograde massage is an effective method of applying compression. Teaching self-massage to the client is helpful in desensitizing painful parts and in giving the client a sense of control and responsibility in the management of the edema. Light retrograde massage with elevation facilitates diffusion of small molecules into the venous system. If the compression is too tight, this will restrict fluid flow, which increases edema.

Compression can be applied by pressure garments, gloves, elastic wraps, or even string. The sequence of dressings may start with elastic bandages initially, followed by tubular/Coban next, and then pressure garments. Pressure garments are worn nearly all day for as long as 6 months to 2 years. Elastomer molds may also be worn for the chest, palms of the hands, and face. Pressure garments and elastomer molds use compression to decrease blood flow, which may slow collagen synthesis (Dutton, 1995). These garments may also produce friction and shear forces, putting the part at risk for ischemia, so wear schedules and skin should be monitored periodically. Because scar management can take such an extended period, client compliance is an important issue in intervention. While pressure garments are smooth and would leave few marks on the skin, they are also expensive and take time to receive from vendors. Use of a fitted pressure garment may be more applicable to maintaining edema reduction than for reducing edema.

When performing massage or wrapping parts for compression, it is important that the application of the compressive force be distal to proximal. The idea is to push the fluid from the part toward the heart. For example, if the dorsum of the hand is swollen, begin at the fingertips and massage toward the wrist, from the wrist to the elbow, etc. In addition, the choice of material for application of compression needs to be considered with regard to the skin surface to which it will be applied. Coban would be contraindicated for open wounds and skin grafts as it leaves a ribbed, uncosmetic imprint.

Elevation is also used to reduce outflow, which reduces capillary filtration pressure and increases the gradient pressure of the lymphatic vessels (Artzberger, 2005). Optimally, the part should be elevated above the level of the heart to enhance the flow of fluid. Caution should be taken with extreme elevation in stroke clients with right-sided weakness because this might cause the fluid to flow too quickly into the right side of the heart (Cooper, 2007).

Adaptive equipment is also used to decrease edema by means of elevation, such as an arm trough placed on the wheelchair of a client with hemiplegia. The arm trough positions the arm safely and elevates it to facilitate circulation of the fluid from the hand toward the heart. Continuous passive motion (CPM) devices are also used to prevent and decrease edema. The use of elevation is practical when the client is at rest or is not able to use the extremity. However, once the extremity can be used in activities, some adaptive equipment can actually prevent active use of the arm and should be discontinued. For example, a sling may enable a dependent extremity to be placed in an elevated position but may prevent active motion. In this case, other positioning devices would be better for the extremity that is capable of active motion, such as using a trough or pillow for optimal positioning (Dutton, 1995).

Therapeutic use of cold modalities for the treatment of pain and edema produce quick vasoconstriction and also desensitize pain receptors and decrease muscle spasms. If cold packs are used to cause vasoconstriction and reduce outflow, the temperature of the pack should not be colder than 59°F (15°C) because, below these temperatures, proteins leak into the interstitum from the lymphatic structures, causing more edema. Cold packs are recommended within the first 24 to 48 hours, and a dry towel should be placed between the skin and the cold pack to prevent tissue damage.

Other forms of cryotherapy may include ice massage, ice dips, vasocoolant sprays, or use of contrast baths. Ice baths or ice dips are used by having the client immerse an edematous hand in water for 3 seconds. The client would then squeeze the hand or wiggle it while in the water, and this would be repeated two to three times. Contrast baths are used if the client cannot tolerate ice or is experiencing hypersensitivity. Contrast baths alternate cold (66°F/18.9°C) and warm (96°F/35.6°C) water each minute for 20 minutes, which provides vasodilation/vasoconstriction acting as a pumping action.

Other modalities that are used for the treatment of edema include iontophoresis, phonophoresis, and mild, pulsed, alternating current ultrasound. Iontophoresis promotes healing and decreases pain and edema by using electrical currents to deliver medications.

Active motion can be used, if not painful, to minimize reduced mobility of joints, ligaments and tendons, tissue atrophy, and impaired gliding of structures. Active proximal trunk and shoulder motions are helpful during the acute wound stage to decongest the lymphatic vessels, remove tissue waste, and better oxygenate the healing tissues (Artzberger, 2005; Pendleton & Schultz-Krohn, 2006). Edema reduction should not begin where the edema is visible but instead should start in normal, uninvolved areas proximal to the visible edema. Diaphragmatic breathing, trunk stretching, and muscle contraction exercises and activities help to reduce edema and decongest the lymphatic system. Diaphragmatic breathing helps to decongest the lymphatic system by changing the thoracic pressure, creating a vacuum that draws the lymphatic fluid from more distal vessels (Cooper, 2007). Exercise of abdominal muscles increases the pumping of blood, which stimulates the lymph nodes, moving lymph through more rapidly (Artzberger, 2007).

Normal muscle contraction serves to increase circulation, so active movement and use of weightbearing positions stimulate these normal muscle actions and can be useful in decreasing edema. However, active motion that is too forceful in early stages of recovery may aggravate edema instead of reducing it, so parameters of movement need to be controlled.

Subacute and Chronic Edema. Treatment for subacute edema includes diaphragmatic breathing, trunk exercise, lymphatic massage of the uninvolved axilla, manual edema mobilization (MEM), kinesio taping, gentle myofascial release, fluidotherapy at body temperature, passive motion (via CPM machine), fluidotherapy with the temperatures no higher than 98°F (36.7°C), and active and passive exercise and activities (Cooper, 2007).

Kinesio taping was used after a total knee replacement in a randomized clinical trial, and postoperative edema was less intense and subsided more quickly than in clients who did not have this intervention (Donec & Krisciunas, 2014). Kinesio taping was also used following anterior cruciate ligament reconstruction and was attributed to faster recovery of knee ROM, reduction of edema, and less pain (Boguszewski, Tomaszewska, Adamczyk, & Bialoszewski, 2013). Decreased pain and swelling after use of kinesio taping in pes anserinus tendinobursitis and De Quervain's disease has also been reported (Homayouni, Foruzi, & Kalhori, 2016; Homayouni, Zeynali, & Mianehsaz, 2013).

Treatment for chronic edema is similar to subacute and also includes softening of fibrotic tissue before the tissues can be decongested. Methods to soften the fibrotic tissue include neutral warmth, elastomer, or silicone gel sheets that provide light compression and retain body heat; kinesio taping to reduce inflammation and stimulate the lymphatic system; low-stretch bandages; foam-lined splints; and gentle myofascial release (Artzberger, 2005; Cooper, 2007). For low-stretch bandaging to work, proximal MEM needs to be done first to decongest the lymphatic system (Cooper, 2007).

MEM is used to activate only the lymphatic system to absorb the large plasma protein molecules and other molecules from the interstitum that are not permeable to the venous system (Artzberger, 2005). The lymphatic system does not have a continuous pump system, so large molecules that cannot permeate the venous system are absorbed into the lymphatic system. It works on a negative pressure gradient so that when the lymph vessel fills, high pressure is created to move fluid to an area of lower pressure. Excessive swelling distal to the lymph nodes does not increase their rate of filtration but causes further congestion distally (Artzberger, 2005; Cooper, 2007). Given this, proximal uninvolved structures have to be stimulated first to decongest or draw the distal edema out of the involved area, creating lower negative pressure (Artzberger, 2005). Congestion exists proximal to the visible edema. MEM decongests the more proximal edema and moves the edema proximally, thereby creating a space into which the more distal edema can flow. Absorption of the protein into the lymphatics occurs because of changes in interstitial pressure due to movement, stretching of filaments from lymphatic to connective tissue, respiration, pulsation of nearby arteries, and light massage (Artzberger, 2005).

MEM is considered an advanced skill requiring specialized training but includes a light, stroking massage starting proximal to distal to the edematous area. The massage is done following the flow of lymphatic pathways. Exercise or engagement in functional activities follows the massage of each segment (Pendleton & Schultz-Krohn, 2006). Contraindications and precautions of MEM are that this method may spread infection and should not be used in areas of inflammation or in the inflammatory phase of wound healing. Do not perform MEM if there are hematomas or blood clots as this may cause the clot to move. MEM is contraindicated in clients with cancer, renal disease, kidney disease, or lymphedema (either primary or from a mastectomy). If the client has congestive heart failure or cardiac or pulmonary problems, MEM may cause problems because these systems are already overloaded or impaired (Artzberger, 2007; Cooper, 2007; Pendleton & Schultz-Krohn,

Table 12-5

Tissue Integrity Intervention and Documentation

GOAL

Client will (be independent/modified independent) and (require maximal, moderate, or minimal assistance) in performance of (specify tasks) in reducing peripheral edema as measured by (volumeter/circumferential measurement, etc.) by using:

Method	Principle/Rationale	Example
Elevation	That reduces outflow, reduces capillary filtration pressure, increases the gradient pressure of the lymphatic vessels, and reduces pain	• Arm trough on wheelchair • CPM machines • Elevation on pillow or lapboard • Sling • Cold modalities
Compression	That permits filtration of fluids from capillaries into interstitial tissues, decreases blood flow, and controls pain	• Retrograde massage • ACE wraps (3M) • Coban wraps • Elastomer molds • Pressure garments
Temperature control	That stimulates localized vascular responses	• Thermal modalities
AROM and/or diaphragmatic breathing	That pumps fluids out of interstitial tissues and joint structures and increases circulation	• Gentle AROM • Active assistive range of motion (AAROM)
MEM	That activates the lymphatic system and decreases proximal congestion	• MEM techniques

Adapted from Dutton, R. (1995). *Clinical reasoning in physical disabilities*. Baltimore, MD: Lippincott Williams & Wilkins and Marrelli, T. M., & Krulish, L. H. (1999). *Home care therapy: Quality, documentation and reimbursement.* Boca Grande, FL: Marrelli & Associates, Inc.

2006). In a study comparing MEM with traditional edema techniques in clients with subacute edema following a distal radius fracture, neither the traditional nor the modified MEM treatment program was superior in terms of edema reduction. However, the MEM program resulted in fewer sessions to decrease edema compared with the traditional edema-reduction techniques (Knygsand-Roenhoej & Maribo, 2011).

Lymphedema

Treatment for lymphedema usually consists of compression stockings and garments, wound and skin care, adaptation of ADL, and specialized gentle massage to reroute excess fluid. MEM is not appropriate for clients with lymphedema because MEM requires an intact lymphatic system (Cooper, 2007). Other methods for lymphedema reduction are surgery and lasers.

Table 12-5 provides goal statements, methods, and principles of intervention for the remediation of tissue integrity and examples.

Range of Motion Interventions

ROM may be limited for a variety of reasons, including disease, injury, edema, pain, skin tightness, muscle spasticity, muscle and tendon shortening (tightness or contractures), and prolonged immobilization.

The effect of immobilization on muscle is that there is a loss of muscle mass due to decreased numbers of muscle fibers, which may begin as early as 48 hours after immobilization. There is a decrease in muscle force not only because of lost muscle mass, but also due to metabolic, vascular, and neurologic factors. There are changes in the length and number of sarcomeres; filaments lose the ability to slide; and there is a loss of fibers, thickening of tissue, and potential atrophy (Fabrizio & Rafols, 2014). There is disruption of synovial fluid, membranes, and articular cartilage (Nyland, 2006). Due to these changes, muscle fatigue increases and there is decreased functional movement. Movement of the surrounding joints and muscles helps to prevent atrophy and scar tissue that may limit motion.

Immobilized connective tissue results in reduced tensile forces applied to tendons and ligaments due to reduced structural stiffness and decreases in the number of collagen fibers. There is an increase in collagen synthesis and degradation, and the collagen becomes disorganized (Fess et al., 2005). Tendons atrophy, and the space between the tendon and tendon sheath is decreased because of adhesions, which restricts the gliding action of the tendon (Cooper, 2007). When the articular cartilage breaks down and synovial fluid is no longer providing nutrients and enabling smooth joint movement, there is further loss of function due to pain, inflammation, and edema (Kisner & Colby, 2012; Levangie & Norkin, 2011).

Even if immobilized, isometric contractions of the immobilized muscles load the immobilized tendons (which is essential for connective tissue nutrition and repair), encourage normal collagen production, and align the collagen along lines of stress (Cooper, 2007). Low-load prolonged stretch (LLPS) are preferable to high-load, short-stretch movements for these weakened tissues. When remobilizing tissues, avoid excessive force, poor force direction, and undesirable or abnormal patterns of mobility.

Flexibility is the amount of ROM of a joint and is determined by the elasticity of soft tissues, specific conditions within the joint, excessive body fat or muscle mass, and pain (Hamill, Knutzen, & Derrick, 2015). Muscle stiffness is the ability to resist stress and is a measure of the rate of increase of passive tension as a muscle is stretched (Nyland, 2006). Flexibility training is designed to decrease the stiffness of the musculotendinous unit. Flexibility can be static or dynamic. Static flexibility is measured with a goniometer, whereas dynamic flexibility is seen to be the ease of movement, amount of resistance to joint movement, or amount of resistance to passive motion of a joint or tone. Kisner and Colby (2012) define flexibility as "the ability of muscle to relax and yield to a stretch force" (p. 985).

In interpreting ROM values made via goniometric measurements, it is important to remember that the available range varies with age, occupation, gender, specific joint, and activity levels. Earlier discussions described problems with reliability and validity, especially because normative values rarely describe how the measurement was made, from what population the values were taken, and the standard deviation for the mean values.

Limitations in ROM are the focus of intervention if the limitation prevents successful engagement in areas of occupation that are of value to the client or would present structural imbalances that might lead to deformity. Full ROM is not needed to achieve many tasks, and functional range is sufficient for many occupations. This illustrates that the clinical collaboration between the therapist and the client is vital, and use of this approach must go beyond the procedural reasoning about the knowledge of musculoskeletal function and prognosis. It is only by assessing contextual variables, knowing the client, and using interactive reasoning that meaningful interventions take place. For example, if a client lacks 90 degrees of shoulder flexion but is still able to dress him- or herself and this is of value to the client, then increasing ROM is not indicated. If the client lacks 120 degrees of shoulder flexion and is unable to put on a shirt but the spouse will dress the client, then increasing ROM for the shoulder may not be indicated. Intervention directed at remediation of ROM itself is not a valid long-term intervention goal because it is not directed toward a functional outcome related to work, play, or self-care.

Generally, if the limitations in movement are due to shortened tissues, the goal is to stretch the tissues to new, greater, permanent lengths to enable function. If the limitation is due to edema, pain, or spasticity, preventing the loss of ROM is the secondary goal. If the limitation is due to permanent shortening (contracture) or chronic shortening of the tissues, the goal is to compensate or adapt to the limitations because remediation efforts would not be successful (Radomski & Latham, 2014).

Passive Range of Motion

Limitations in PROM are due to problems within the joint. This might include stiffness due to capsule, ligament, muscle, or tendon tightness; decreased joint space; or osteophytes (Cooper, 2007). If PROM and AROM are equal, the first step of treatment is to focus on regaining PROM. If PROM is normal and AROM is limited, the focus is on AAROM. This progression from passive to active assistive to active to resistive is a treatment pattern for ROM and strength.

PROM (also known as *passive mobility* or *passive flexibility*) would be appropriate for clients who are unable to move through full ROM actively due to weak or denervated muscles, are unconscious or in a coma, have paralysis, have a neurological disease, or are on enforced rest (Trew & Everett, 2005). In regions where there is acute, inflamed tissue, AROM would interfere with the healing process (Kisner & Colby, 2012).

The purpose of performing PROM or maintaining the current length of the tissues is to prevent adhesions and contractures from developing to maintain joint and connective tissue mobility and elasticity of muscle fibers (Sidebar 12-1). If no movement is done, the actin and myosin proteins would be reabsorbed, the area of cross-bridge formation would be decreased, and the result would be muscle weakness and shortening. The noncontractile elements will change the collagen turnover rate so that more collagen will be produced, increasing the stiffness of the muscle and decreasing its elasticity. PROM helps to maintain the integrity of soft tissue and muscle elasticity. By moving the part, even passively, venous circulation is increased, synovial fluid production is enhanced, and the joint receives needed nutrition. Movement may reduce pain and maintain functional movement patterns and can be used to increase kinesthetic awareness (Trew & Everett, 2005).

Sidebar 12-1 Maintaining Range of Motion

Maintenance of ROM occurs when movement occurs through the full ROM.

The main principle regarding ROM is that there must be movement through full ROM. There are many different ways to ensure that the movement produced is through the complete range. Exercise and activities can occur in anatomical planes of motion. For example, PROM for flexion of the shoulder would need to occur in a sagittal plane and in a frontal axis. By grasping the client's arm under the elbow and grasping the wrist with the other hand, the client's arm would be lifted straight up and parallel to the trunk. Similarly, abduction would occur in a frontal plane and a sagittal axis, and the arm would be moved in a direction perpendicular to the trunk. The therapist could perform this motion, or the client or caregiver could be instructed in the procedure through the available ROM.

Codman pendulum exercises can also be done, in which the client bends forward at the waist (or while seated, as in Figure 12-2) and allows the affected arm to hang down toward the floor. The body is moved so that the arm moves in a straight

Figure 12-2. Pendulum exercises.

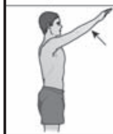
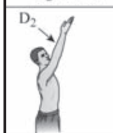
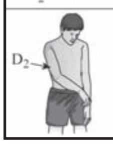
	Scapula	Glenohumeral	Elbow	Wrist and fingers
D_1 flexion				
	Elevation Abduction Upward rotation	Flexion Adduction External rotation	Flexion or extension	Flexion Radial deviation
D_1 extension				
	Depression Adduction Downward rotation	Extension Abduction Internal rotation	Flexion or extension	Extension Ulnar deviation
D_2 flexion				
	Elevation Adduction Upward rotation	Flexion Abduction External rotation	Flexion or extension	Flexion Radial deviation
D_2 extension				
	Depression Abduction Downward rotation	Extension Adduction Internal rotation	Flexion or extension	Extension Ulnar deviation

Figure 12-3. PNF patterns of movement.

line in forward/backward, side-to-side, and clockwise/counterclockwise direction.

Another method of providing PROM would be to move the part in the direction of the muscle range of elongation. Knowledge of muscle fiber composition and line of pull would be necessary because the ROM exercise would be antagonistic to the line of pull of the muscle (Kisner & Colby, 2012).

Combined patterns of movement (as in PNF patterns; as seen in Figure 12-3) are a functional way of incorporating ROM actions with movement in several planes of motion. Patterns of movement are multijoint, multiplanar, diagonal, and rotational movements (Kisner & Colby, 2012). An example might be to have the client start with the arm in shoulder flexion, adduction, and internal rotation, and then the client moves to a position of shoulder extension, abduction, and internal rotation. This D1 flexion pattern may be used when combing the hair on the opposite side, and the D1 extension pattern may be functionally used in pushing a car door open (Pendleton & Schultz-Krohn, 2006). Several motions and planes are combined in one smooth movement. The disadvantage with these patterned movements is the complexity of the movement, planning involved, and ability to follow multistep directions. Again, these combined patterns can be performed actively by the client as exercise or as part of an activity and can also be taught to caregivers.

Functional patterns of movement associated with functional tasks can also be encouraged. This would be an appropriate screening strategy or could be considered an aspect of the top-down approach, where occupational performance areas of work, play, and ADL are assessed rather than an initial focus on client factors and body structure and function. Observation of functional patterns of movement is actually a constant, ongoing assessment that occupational therapists make and is part of what comprises conditional clinical reasoning.

A CPM device is often used to provide constant movement through specified ranges for a predetermined duration for clients following orthopedic surgery. Muscle fatigue is not a factor because the motion is passive. Use of CPM devices prevents the development of adhesions, contractures, and joint stiffness; stimulates healing of tendons and ligaments; increases synovial fluid joint lubrication; increases the rate of intra-articular cartilage healing; prevents negative effects of immobilization; provides quicker return of ROM; and decreases postoperative pain (Kisner & Colby, 2012, p. 69). CPM devices can be used immediately after surgery with a low arc of movement (20 to 30 degrees) initially and increased by 10 to 15 degrees per day as tolerated. Use of CPM is usually less than 1 week or when functional ROM is accomplished (Kisner & Colby, 2012)

If a client experiences unilateral deficits in ROM (e.g., stroke), then self-ROM exercises can be taught for independence in the maintenance of ROM. These can be exercises that use the unaffected hand and arm to move the affected side or can use a variety of tools such as those used in wand, cane, or dowel exercises (Figure 12-4).

Other tools and devices used in ROM exercises include the following:

- Finger ladder
- Shoulder wheel
- Overhead pulleys
- Suspension (e.g., Swedish suspension sling)
- Skate or powder board
- Tai chi
- Games
- Aquatics

The total end range time (TERT) theory states that the amount of increase in ROM of a stiff joint is proportional to the amount of time the joint is held at its end range, and it is seen as a valid means to increase the elongation of tissue and the importance of sustained stretch (Flowers & LaStayo, 1994).

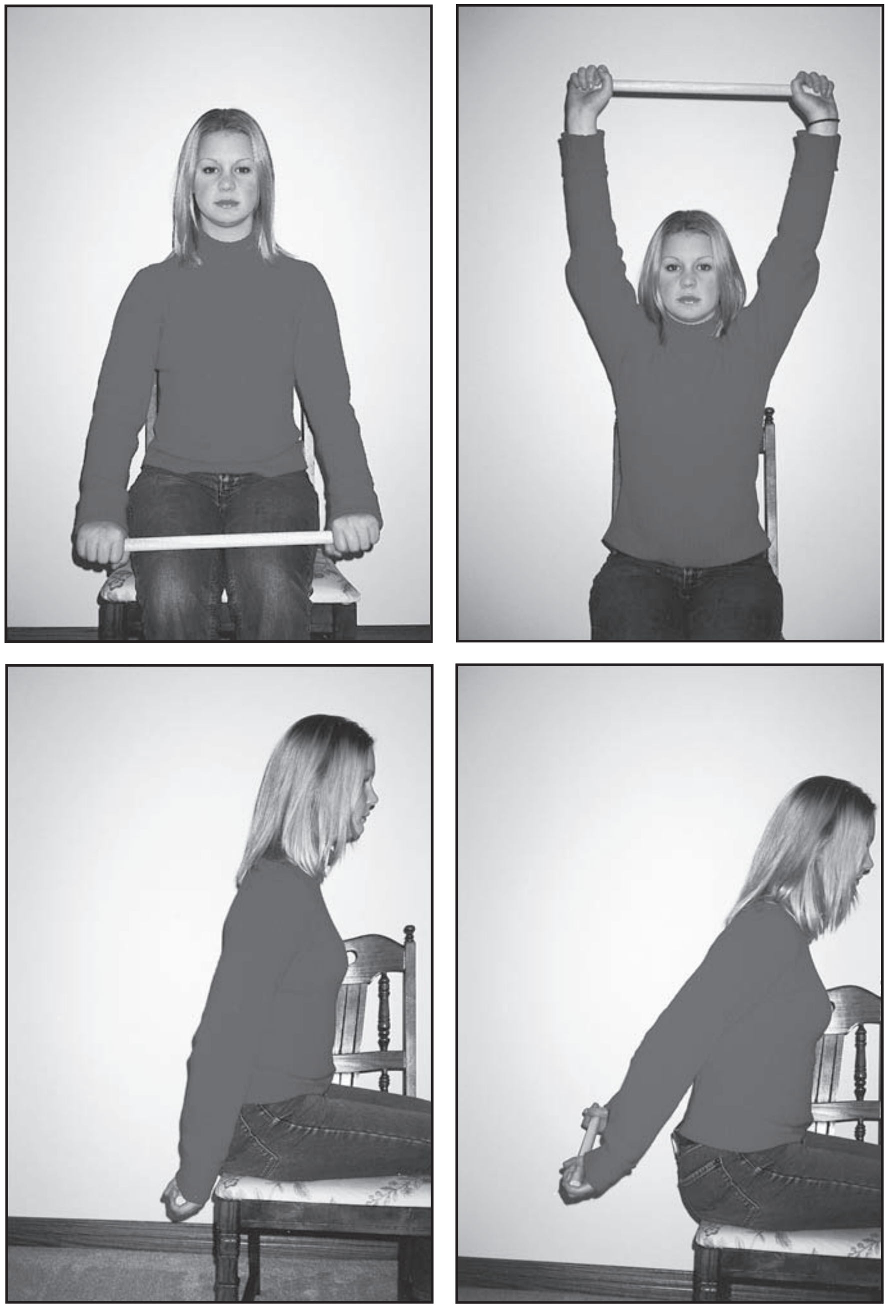


Figure 12-4. Cane/dowel exercises to maintain ROM. Top left: shoulder flexion (start). Top right: shoulder flexion (end). Bottom left: shoulder extension (start). Bottom right: shoulder hyperextension (end).

TERT is based on a formula of intensity × duration × frequency. If the client could tolerate maximum stretch (intensity) for 20 minutes (duration) and frequency is three times per day, then optimal TERT is 60 minutes per day (Davies & Ellenbecker, 1999). The plastic deformation that occurs lasts no more than 4 weeks, and PROM in a joint is not functional. To achieve permanent increases in ROM, the tissues in their newly elongated state need to be integrated into functional activities.

Contraindications to Passive Range of Motion

There are a few contraindications to performing PROM. PROM can injure swollen and inflamed joints and tissues (Cooper, 2007; Kisner & Colby, 2012). It is contraindicated immediately following surgery, acute tissue tears, and fractures. Other contraindications include excessive pain, incomplete muscle or ligament tears, or areas where circulation is compromised (Cooper, 2007). An inflammatory response can be triggered, causing additional scar production, pain, and stiffness, and can lead to complex regional pain syndrome if done inappropriately or too aggressively.

Active Range of Motion

Indications for use of AROM (also known as *dynamic flexibility* or *active mobility*) and AAROM is if the client can contract the muscles actively. When the client is able to contract muscles actively and move a segment with and without assistance, AROM is used; when the client has weak musculature and is unable to move through desired ROM, AAROM is indicated. If a part is immobilized, AROM is used above and below the immobilized segment to maintain areas as much as possible to maintain joint and muscle integrity. AAROM and AROM help to maintain the physiological elasticity and contractility of the participating muscles, provide sensory feedback from contracting muscles, deliver a stimulus for bone and joint tissue integrity, and increase circulation and prevent thrombus formation (Kisner & Colby, 2012).

When soft tissues around a joint are shortened and there is a loss of ROM, elongating these soft tissues will result in increased range. The shortening of soft issues may be due to prolonged immobilization, restricted mobility, connective tissue or neuromuscular disease, tissue pathology secondary to trauma, or congenital and acquired bony deformities (Kisner & Colby, 2012). The use of stretching is indicated when ROM is limited due to loss of soft tissue extensibility in connective tissue and/or muscle weakness and stiffness and muscle imbalance, which can lead to preventable structural deformities. Increasing ROM exercises and activities is supported for clients with many shoulder impairments, including rotator cuff tears, shoulder instability, proximal humerus fractures, subacromial impingement syndrome, trapezius myalgia, chronic neck or shoulder pain, frozen shoulder, and thoracic outlet syndrome (von der Heyde, 2011). The most relevant benefit to stretching is the enhanced performance to enable greater participation in occupational tasks.

Shortening of muscle or other tissues that cross a joint can produce a contracture. Note that this is not synonymous with contraction, which is the process by which tension develops in a muscle during shortening or lengthening. Contractures can be defined and classified by the soft tissues affected. A myostatic contracture has no specific tissue pathology, yet there is loss of range that is usually mild and transient. Myostatic contractures often are resolved quickly with gentle stretching. *Tightness* is a term often used to describe loss of ROM at the outer limits of ROM that occurs in otherwise healthy tissues (Jacobs & Bettencourt, 1995).

Chronic inflammation and fibrotic changes in soft tissues can lead to fibrotic adhesions that are difficult to reduce. Irreversible contractures are those in which there is a permanent loss of extensibility of soft tissues. Irreversible contractures often are released surgically and occur when normal tissue is replaced by bone or fibrotic tissue. Hypertonicity can also cause a limitation of joint ROM because of central nervous system lesions. The muscle is in a state of high tone and constant contraction, resulting in a pseudomyostatic contracture (Kisner & Colby, 2012).

To elongate the tissues, a stretch force is applied (Sidebar 12-2). The force, velocity, speed, and extent of the stretch force must be controlled, and the joint movement needs to exceed the currently available range. The effects of stretching are an increase in ROM, flexibility, and soft tissue length; relief of muscle spasm; and increase in tissue compliance (Trew & Everett, 2005). Allowing quicker recovery from workouts, reducing soreness, facilitating relaxation, maintaining balanced musculotendinous lengths between agonist/antagonist muscles, and improving motor performance are benefits of stretching (Nyland, 2006).

Sidebar 12-2 Increasing Range of Motion

To increase ROM, a stretch force must be applied to the tissue that is beyond the current ROM to elongate the collagen fibers in soft tissues.

Some general concepts related to stretch are that static stretching is preferable to ballistic stretch techniques. Stretching will increase flexibility and ROM, but the motion should not exceed the normal muscle length by more than 10%. Stretching is recommended before and after strengthening activities, although results vary regarding whether stretching before exercise decreases the risk of injury (Gleim & McHugh, 1997; Shrier, 1999).

Stretching is enhanced if the tissue is warmed prior to elongation of tissues, which increases collagen extensibility and decreases muscle-tendon stiffness. The stretch should not be painful, but rather an overstretch of current tissue length. Stretching and warm-up are not the same, as a warm-up done prior to exercise raises the total body and muscle temperature. Raising the tissue temperature between 104°F to 113°F (40°C to 45°C) can lead to greater connective tissue elongation and less tissue damage.

The process of stretching causes a connective tissue deformation. During stretching, collagen bonds are broken and fibers are realigned, and microfailure of muscle fibrils and fibers is needed for permanent changes in fiber length. This follows a predictable pattern known as the *stress-strain relationship*.

Stress-Strain Relationship

When a tissue is stretched, this causes stress inside of the tissue. Stress is an invisible force per unit area and is an internal reaction force within the material. When stress is applied to a tissue, as when a muscle is elongated beyond the current range, the size and shape of the tissue changes or deforms. The amount of deformation depends on the amount of the load and the ability of the material to resist the load. The percentage of deformation that occurs is known as *strain*. These two ideas, stress and strain, are reflected in Hooke's law, which states, "deformation increases proportionally to the applied force or strain increases proportionally to the stress of resisting the applied load" (Irion, 2000, p. 228).

Both the contractile and noncontractile elements of muscle fibers influence stretching of soft tissues, and both contribute to the temporary (elasticity) and permanent (plastic) changes in tissue length. Noncontractile tissue, composed of collagen, elastin, reticulin fibers, and ground substance (mostly gel containing water), can develop tightness and contractures and limit joint motion and function. Because collagen is the element that absorbs most of the tensile stresses, tissues with a greater proportion of collagen fibers will provide greater stability, while soft tissue with a greater proportion of elastin fibers will have greater extensibility and flexibility.

When stress is applied to a muscle, the reaction of the muscle follows a predictable pattern, shown in the stress-strain curve in Figure 12-5. When a muscle is passively stretched, there is an initial lengthening of the series elastic components due to a mechanical disruption of the cross-bridges as the actin and myosin proteins slide apart. This causes the sarcomere to lengthen until the stretch force is released. This is the toe region where most functional activity normally occurs (Kisner & Colby, 2012). Different connective tissues have different toe regions (e.g., ligaments have longer toe regions than tendons). Once the force is stopped, the muscle returns to its original resting length, illustrating the elastic nature of the short-term stretch and the muscle characteristic of elasticity.

If, however, the muscle is immobilized or held in a lengthened position for a prolonged period, the changes in the muscle will be more permanent, and a plastic change has occurred. This is due to the greater number of sarcomeres in series, allowing the greatest functional overlap of actin and myosin proteins (Kisner & Colby, 2012). This more permanent change is the result of sequential failure of the collagen bonds, which responds to forces by remodeling and rebonding over time in line with the application of the stress. For tissue to return to normal length after plastic changes, it must exhibit inflammation and undergo repair (Donatelli & Wooden, 2010).

The muscle may also be immobilized for prolonged periods of time in a shortened position. In this case, the muscle produces increased amounts of connective tissue to protect the muscle against stretch. There are fewer sarcomeres due to sarcomere absorption. The changes in sarcomere length are transient, and they will resume the original position if the muscle returns to normal length after immobilization.

If stress continues to be applied to a muscle in the plastic range, plastic changes can only continue up to a point, known as *necking*. This is the point of ultimate strength of the muscle. Past this point, there may be increased strain without an increase in stress so that even with less loads applied, the tissue is under increased strain. After this point, the tissue fails rapidly either due to a single maximal force applied or repeated submaximal stresses. Stretching effectiveness is time-dependent: use of much force for a short duration results in elastic changes; low-force application for a long duration produces plastic deformation. Permanent change in the tissue length is the goal of increasing ROM.

It is important for the therapist to be aware of the way that the tissue feels when stretching because, when the strain is increased but the resistance felt in the muscle decreases and when less force is needed for deformation to occur, necking may be occurring, and tissue failure may be imminent even with smaller loads (Fisher, 1998).

Creeping is the application of "low magnitude loads over prolonged periods of time [that] increases the plastic deformation of noncontractile tissue, which allows a gradual rearrangement of collagen fibers" (Kisner & Colby, 1990, p. 119), and it is the gradual increase in tissue length necessary to maintain a constant stress (Nyland, 2006). The remodeling and rebonding of the collagen fibers require time for healing. Intensive stretching is usually done every other day to allow this time for healing. This is especially true in tissues of elderly clients because a normal age-related change is a reduction in collagen, and there is decreased capillary supply that reduces the healing abilities in the elderly. In addition, there is a decrease in tensile strength and rate of adaptation to stress in the elderly (Bonder & Bello-Haas, 2009; Kisner & Colby, 2012).

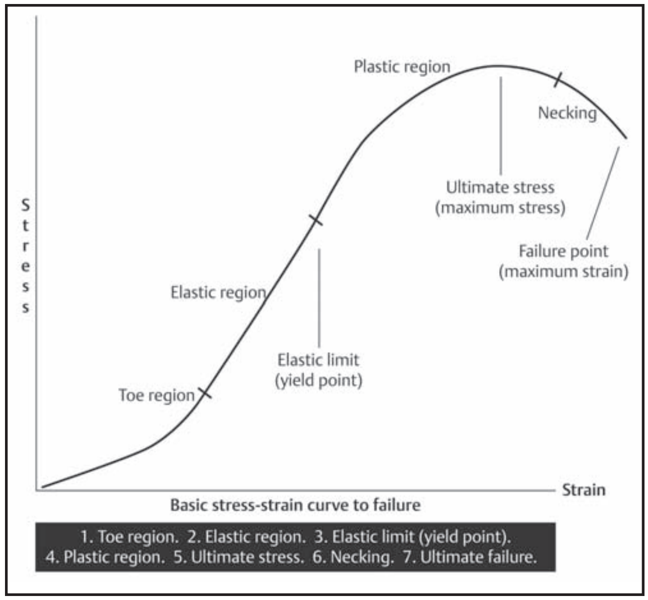


Figure 12-5. Stress-strain curve.

Heat increases creep and, therefore, the elasticity of collagen fibers, making tissues more amenable to stretch (Demeter & Andersson, 2002; Kisner & Colby, 2012) and making the stretching of tissues more comfortable for the client. Heating muscle tissue to 104°F (40°C) affects the bonding between the collagen molecules and decreases viscosity and resistance to external force, thereby increasing the rate of creep and relaxation (Houglum & Bertoti, 2012; Oatis, 2004). For this reason, both superficial and deep heat modalities increase the extensibility of tissue and are often used prior to stretch. Both muscle and connective tissue are viscoelastic tissues with properties of viscosity and elasticity and are able to withstand changing shape when force is applied until the force is sufficient to cause a change and is unable to return to the original length and shape (Houglum & Bertoti, 2012).

Cognitive relaxation techniques, such as dissociative visualization (pleasant memory or image); autogenic relaxation (similar to self-hypnosis); Pilates; deep breathing; or use of videotapes, audiotapes, music, or meditation, also serve to relax the client prior to stretch. Several nontraditional techniques, such as the Feldenkrais method, Alexander technique, or hatha yoga, can also be used. Other techniques used to relax the tissues prior to stretch force application may include active inhibition techniques, local relaxation, progressive relaxation techniques (e.g., controlled breathing techniques, progressive muscle relaxation), and biofeedback. Low-intensity exercise or activity can also be used to warm the tissues prior to stretch. Massage done before stretching serves to increase circulation and decrease muscle spasms and stiffness. Taylor and Dalton (1990) found that the muscle-tendon units respond viscoelastically to stretch. They also found that only a minimum number of stretches (as few as four) will lead to tissue elongation and that slow stretching (rather than an actual technique) may decrease the risk of injury.

Neurological Factors Related to Stretch

A limiting factor related to stretching a muscle is resistance secondary to reflex activity. In increasing ROM, you want to inhibit reflex activity of the muscle. Two sensory receptors are directly involved in muscle function and to the application of stretch forces. The muscle spindle is a major sensory organ of the muscle and consists of microscopic intrafusal fibers that lie parallel to the extrafusal (skeletal) muscle fibers. These fibers are sensitive to the length and velocity of the lengthening of extrafusal muscle fibers, and the muscle spindle initiates muscle contraction. Type Ia primary afferent sensory neurons are responsive to the rate of stretch, and type II secondary afferent sensory neurons are facilitated by changes in muscle length. Once a muscle shortens, the type Ia primary sensory neurons are no longer activated because they are no longer stretched. Because the muscle spindle lies parallel to the extrafusal muscle fibers, when the muscle is lengthened, the muscle spindle is also lengthened and responds by initiating a muscle contraction (Oatis, 2004).

The muscle spindle has been called a *comparator* because the spindle compares the length of the spindle with the length of the skeletal muscle fiber. If the length of the extrafusal muscle fiber is less than the spindle, the spindle is less active. Conversely, when the spindle is stretched, more nerve impulses are sent to activate the extrafusal fibers (Pendleton, 2012). For example, when the patella is tapped by a small hammer, this illustrates the activation of the muscle spindle in a brief contraction called the *stretch reflex*, *muscle spindle reflex*, *myostatic or monosynaptic stretch reflex*, or *deep tendon reflex*.

The second sensory receptor, the Golgi tendon organ (GTO), wraps around the extrafusal fibers of the muscle in neuromuscular junctions between the muscles and tendons. This sensory receptor is sensitive to the tension in muscles, either due to passive stretch or active muscle contraction. It serves a protective function to inhibit the contraction of a muscle in which it lies and has a low threshold (fires easily) after active muscle contraction. The GTO has a high threshold (fires less easily) to passive stretch. Due to the GTO, the force that can be developed in a muscle is limited.

The implications of the actions of these two receptors on the stretching of extrafusal skeletal muscles is that, if a muscle is stretched too quickly (too great a velocity) or too far (too great an increase in length), the muscle spindle will be stretched. This, in turn, will produce increased tension in the skeletal muscle, and this is counterproductive to efforts to lengthen this muscle. Slow, static stretching is recommended because it slowly decreases the response of type Ia input, which provides interference to joint movement. When a muscle is stretched, the type II fibers respond with an inhibitory response to relax the muscle.

Stretching done at too high a velocity may actually increase the tension in a muscle that you are trying to lengthen. This relates to the viscoelastic tissue of the parallel elastic components of the epimysium, perimysium, and endomysium, which respond with greater resistance to a quick stretch (Nyland, 2006). When a muscle is stretched slowly, the GTO fires, which inhibits increased tension development in that muscle and allows lengthening to occur by permitting the sarcomeres to lengthen. The decreased reflex activity from the slow stretch results in reduced resistance to stretch, enabling gains in ROM (Nyland, 2006).

Determinants of Stretch Force Application

In considering using stretching in intervention, there are several determinants to consider when developing the program. There are different types of stretching that can be done (active, passive, static dynamic) that will involve the manner of force application and the degree of client participation. Proper alignment will ensure that the stretch force is directed toward the appropriate muscle, and stabilization of one side of the muscle is important as force is applied to the other bony attachment. Both intensity and duration need to be considered for effective, permanent change that is comfortable for the client (Kisner & Colby, 2012).

Types of Stretch

Stretch can be applied statically, dynamically, passively, and actively. The evidence is not clear about the most effective method to increase flexibility due to differences in studies in experimental design, measurement instrumentation, lack of control group or inadequate control groups, and inconsistent application of stretching techniques (Cooper, 2007).

Static Stretching

Static stretching is the most common method of force application. This is a sustained, controlled stretch that is done slowly. Static stretching does not require another person, there is less danger of excessive lengthening, less energy is used, and it may help to decrease muscle soreness. Static stretching is more tolerable for the client and is seen as less painful or uncomfortable (Cooper, 2007; Oatis, 2004).

Dynamic Stretching

In dynamic stretching, a muscle is stretched by muscular contraction, usually as a warm-up to prepare the muscle for movements specifically required by a particular sport or activity.

Passive Stretching

Situations for passive stretching would be in cases when the client is unable to stretch the part actively due to muscle weakness, when the client cannot learn how to prevent substitution movements, or when the goal is to increase ROM at the end of the range. Passive stretching can be applied by means of joint mobilization, which involves passive rocking and oscillatory movements aimed at increasing joint play. Joint play is not under the client's voluntary control and is used when there is joint stiffness, pain, or reversible joint hypomobility (Radomski & Latham, 2014). Strong evidence was found that ROM, strengthening exercises, and joint mobilizations can improve function and decrease pain for shoulder disorders (Marik & Roll, 2017) and are supported for clients with subacromial impingement syndrome and adhesive capsulitis (von der Heyde, 2011).

The distraction and gliding of joint surfaces improve synovial fluid movement to improve joint nutrition. Stretching the joint capsule causes permanent changes in collagen fibers to improve motion (Houglum & Bertoti, 2012). Capsular tightness has its own capsular pattern, and if this is present then joint mobilization is indicated as an intervention option. The benefits of joint mobilization are that there is better joint lubrication, impingement can be prevented, soft tissue length can be maintained, and it may reduce spasticity (Gillen & Burkhardt, 2004). Joint mobilization is believed to stimulate mechanoreceptors and inhibit nociceptive stimulation and can cause muscle relaxation.

Soft tissue mobilization is referred to as *friction massage*, *myofascial release*, *acupressure*, or *trigger point therapy*, and the similarities in these methods is that pressure is used to change underlying structures. The location of the pressure points, intensity and duration of the pressure application, and purported results vary from one method to the other. Myofascial release is the passive stretching and breaking up of adhesions of the fascia, capsule, and ligaments, intended to decrease muscle immobility and pain, improve blood and lymphatic circulation, and stimulate the stretch reflex in muscles via gentle sustained pressure (Nyland, 2006). Friction massage is a deep pressure massage often used for tendinitis, to realign collagen fibers, as a means to decrease adhesions, and as a mechanoreceptor stimulator that produces a temporary analgesic effect. The Cyriax method of deep friction massage and joint manipulations was found to be beneficial in terms of motion, pain, and treatment time for clients with adhesive capsulitis (von der Heyde, 2011). Both acupressure and trigger point techniques apply pressure in very specific points and for a variety of conditions. Tissue mobilization is a deep massage to increase the mobility of adherent connective tissue (fascia, tendons, and ligaments).

Joint manipulation is the skilled passive movement of the joint following joint arthrokinematics (Donatelli & Wooden, 2010) and is done to break up massive adhesions, often under anesthesia. These techniques require extensive training beyond entry-level competence and are beyond the scope of this text.

Manual Passive Stretching

Manual passive stretching is most appropriate in the early stages of the rehabilitation program and is useful in determining the intensity, duration, and amount of stabilization needed. It can be applied passively, with assistance from the client, or independently by the client (Kisner & Colby, 2012).

Manual passive stretching is a short-duration stretch (15 to 60 seconds) where the tissue is elongated beyond resting length against an external force. The therapist (or client) controls the direction, speed, intensity, and duration of the stretch. It is important to point out that manual passive stretching is not the same as PROM. PROM moves the part through unrestricted, available range, while manual passive stretching is done to the point of maximal stretch or a few degrees past the point of discomfort (Kisner & Colby, 2012; Thompson & Floyd, 1994).

Excessive overstretching occurs when the movement overcomes the natural supportive function of the joint and tissues, resulting in hypermobility, joint instability, and increased risk of strain and injury. Signs of excessive overstretching are pain, redness, and swelling that persist for several hours. Nonverbal danger signals that may be observed may include a sudden increase in sweating, visual signs of stretching on the skin, gradual loss of slack, the client looks away suddenly, or there is a sudden constriction of the pupils.

The procedure for manual passive stretching is to stabilize the proximal segment and move the distal part. Move the part slowly, with low intensity, through unrestricted ROM to the point of resistance. Maintain the stretched position for 30 seconds or longer, during which time the tension in the tissues should slowly decrease. When it does, progress the elongation a bit further. The client should not feel pain, but instead experiences a pulling sensation. Gradually release the stretch force, rest, and repeat (Kisner & Colby, 2012). Use of cold after stretching may minimize post-stretch soreness, and having the client use the part in active movements or activities immediately after stretching is suggested. Gains in muscle elongation due to manual passive stretching are transient and attributed to temporary sarcomere give (Kisner & Colby, 2012). The stretch force applied is dependent on the client's tolerance and the therapist's strength and endurance.

Prolonged Mechanical Stretching

Prolonged mechanical stretching is a low-intensity external load (5 to 15 pounds) that is applied to a part for a prolonged period of time by means of positioning, traction, braces, splints (static), or serial casting. The force is applied from 20 to 30 minutes to several hours. The longer duration of low-intensity force application permits the sarcomeres to be added and for remodeling and rebonding of collagen fibers to occur so more plastic changes occur. Prolonged mechanical passive stretching is seen to be more effective and more comfortable for the client than manual passive stretching. This static stretching technique is seen as less labor-intensive because the body part or object is providing the stretch force.

Active Stretching

Active stretching involves the series elastic and parallel elastic components of the muscle as well as the contractile elements. Active stretching is done in cases where the client is afraid of passive stretching due to loss of control, fear of reinjury, or low tolerance for discomfort. When passive stretching is harmful (e.g., in newly sutured tendons or grafted skin), active stretching can be done. Because the client is providing or controlling the stretch force, there is less chance of overstretching. This can mean that injury and discomfort will be minimized, or it could also prevent sufficient lengthening of the soft tissues and, for a long enough duration, enable permanent elongation. In active stretching, the resistance force is minimal. Active stretching can be done by self-stretching one's own muscles, by means of the shoulder wheel or finger boards, or by using PNF diagonal patterns of movement (see Figure 12-3). Self-stretching (also known as *flexibility exercise*) is done by the client using the weight of a body part or gravity as the stretch force.

PNF techniques are used to improve neuromuscular movement by applying proprioceptive stimulation. The client's own volitional isometric muscle contractions are used to increase ROM by minimizing the resistance attributed to spinal reflexes. This is accomplished when the isometric contraction of the antagonist muscle group results in reflex inhibition of the muscle being stretched (reciprocal inhibition). At the same time the agonist muscle is facilitated, the antagonist muscle is relaxed (Nyland, 2006).

Active inhibition techniques are used in collaboration with the client to actively stretch shortened tissues. The client must have normally innervated muscles capable of volitional control, and the stretch affects contractile elements by stretching the elastic tissues. Kisner and Colby (2012) indicate that the assumption is that the sarcomere will give more easily when the muscle is relaxed, and there is less active resistance in the muscle as it is elongated. While active inhibition is generally

Table 12-6

CONTRAINDICATIONS AND PRECAUTIONS RELATED TO TISSUE ELONGATION

Contraindications	Precautions
Hypermobility	Hematomas
Joint effusion	Infectious disease
Inflammation	Neurologic dysfunction
Bony blocks	Arthritis (post-inflammatory phase)
Sharp pain	Tendon repair or tendon transfer
Arthritis (acute exacerbation)	Prolonged bed rest
Dislocation	Prolonged immobilized tissue
Recent trauma or surgery	
Osteoporosis or bone weakness	
Spinal cord injury when trying to develop tenodesis	
Unhealed fractures	

more comfortable for the client than other types of stretches, the gains are usually temporary.

Several PNF methods are used to elongate tissue. In the contract-relax method, there is a voluntary contraction of the antagonist muscle against maximal resistance provided by the therapist. The client then relaxes the muscle as the therapist moves the limb to the end of the ROM until a stretch is felt. The client contracts against resistance for 5 to 10 seconds and is then passively moved to the new muscle length, where it is held in place for 10 seconds. The contract-relax with agonist contraction is similar to the contract-relax method except that the limb is taken to the point of stretch and the therapist applies resistance to the muscle being stretched for 5 seconds. Again, the client relaxes the muscle while the agonist concentrically contracts, is pushed to the new length, and is held. The hold-relax method is also similar to the contract-relax method, but an isometric rather than dynamic contraction against resistance is applied prior to relaxation (Nyland, 2006; Smith, 2005). Whether contract-relax, hold-relax, contract-relax-contract (hold-relax-contract), or agonist-contraction methods are used, the client is asked to first relax and then elongate tight muscles. These relaxation and inhibition techniques have been used to relieve pain, muscle tension, tension headaches, high blood pressure, and respiratory distress (Kisner & Colby, 2012). The use of autogenic inhibition is especially useful when the client is anxious about movement due to pain (Houglum & Bertoti, 2012).

Active stretch done during occupational activities and tasks that are meaningful to the client serves to distract the client who has pain, can be a motivational factor, and can reduce psychological dependence on the therapist (Dutton, 1995). Whether passive or active stretching is done, it is vital to incorporate tasks and activities that the client actually needs to be able to successfully perform as a major focus of intervention. The goal of occupational therapy is to enable clients to return to the daily activities that are important to them, and it cannot be assumed that increases in ROM will automatically be assimilated into these meaningful tasks.

Studies to determine the optimal type of load and duration of force application have used a variety of stretch mechanisms and methods. LLPS is used to reduce contractures, often by means of an orthotic device. High-load brief stretch and exercise in PNF diagonal patterns were compared with LLPS. In this case, LLPS was found to be superior in the results, while a study comparing the use of a Dynasplint (Dynasplint Systems, Inc.) with PROM and manual stretching found no difference between this regimen and LLPS (provided by the Dynasplint). Serial casting often is used as a means of providing a LLPS, and this has been found to result in significant increases in PROM as compared with other methods (Nuismer, Ekes, & Holm, 1997).

Another type of stretching, ballistic stretching, involves a jerking or bouncing motion and is the least desirable and most controversial method to stretch tissues. It is a short-duration, intermittently forceful stretch performed at a high speed and high intensity. This type of stretch is not recommended for the sedentary, elderly, or clients with musculoskeletal pathology since this type of stretch puts the tissue at risk for rupture and actually stimulates the muscle spindles, thus putting the muscle in a state of resistance to further stretch that does not yield easily and tears more readily (Kisner & Colby, 2012; Nyland, 2006).

Contraindications to Stretch

An obvious contraindication to stretching tissues is not to force the tissue beyond the normal limits of the ROM. It is also true that vigorous stretching should be avoided in tissues that have been immobilized due to the changes in muscle, tendon, and ligamental tensile strength and joint integrity. Allowing time for the collagen to remodel requires rest after stretching, so this does not need to be done every day. If soreness or pain occurs 24 hours after stretching, too much force was used.

Avoid stretching edematous tissues because they are more susceptible to injury, and stretching may cause further pain and edema. In post-inflammatory phases of rheumatoid arthritis, gentle, prolonged stretching can help prevent the shortening of tissues into fixed deformities, but when the joints are in acute, inflammatory phases, stretching should be avoided.

In cases where shortened tissues are providing greater joint stability in lieu of normal stabilization or strength, stretching is contraindicated. This may occur in special cases, such as cervical spinal cord injuries, where intervention is aimed at the development of tenodesis action of the fingers and wrist. The development of slight finger flexion tightness enables a better passive grasp of objects when the wrist is extended. To encourage this, the fingers are flexed while the wrist is extended, or the fingers are extended while the wrist is flexed to avoid overstretching across all joints crossed. Table 12-6 summarizes the contraindications and precautions related to active tissue elongation.

Table 12-7 provides sample goal statements, methods, and principles guiding treatment that can be used in documentation and examples of activities to increase ROM.

Table 12-7

INCREASING RANGE OF MOTION INTERVENTION AND DOCUMENTATION

GOAL

Joint ROM will be increased in (specify joint, right/left/bilateral, and motion) by using:

METHOD	**PRINCIPLE/RATIONALE**	**EXAMPLE**
Heat	That increases the elasticity of collagen fibers in soft tissue and decreases muscle-tendon stiffness	• Neutral warmth • Warm water • Paraffin • Fluidotherapy • Light activities or exercise
Relaxation	Of soft tissues prior to stretch, which decreases tension	• Active inhibition techniques • Progressive muscle relaxation • Controlled breathing • Low-intensity activities or exercise • Massage • Cognitive relaxation strategies • Videotape/audiotapes/music • Feldenkrais method • Alexander technique • Hatha yoga
Passive stretch	Beyond current range, which elongates collagen fibers in soft tissues	• Manual passive stretch • Prolonged mechanical stretch • Joint mobilization • Joint manipulation • Myofascial release
Active stretch	Beyond current range, which elongates collagen fibers in soft tissues	• Active activities and exercise • Active inhibition techniques • Finger boards • Shoulder wheels • PNF diagonal • Self-stretch • Codman exercises
Prolonged stretch via orthoses and positioning	That maintains gains from stretching between treatment sessions Or That provides gradually increasing amounts of prolonged static stretch	• Splints • Serial casting
Role-related activities	That will ensure gains will be generalized to daily routines	• Simulated activities • Engagement in occupations

(continued)

STRENGTHENING INTERVENTIONS

Muscle strength may be limited due to many different factors, including injury, disease, disuse, immobilization, and overwork. Lower motor neuron diseases (e.g., polio, amyotrophic lateral sclerosis), spinal cord injuries or disease, peripheral nerve damage, muscle diseases (e.g., muscular dystrophy), and stroke all can result in loss of muscle strength.

Weakness occurs in 80% to 90% of clients with stroke (Kane & Buckley, 2004). If muscle weakness is a primary contributing factor to the inability to achieve participation

Table 12-7 (continued)

INCREASING RANGE OF MOTION INTERVENTION AND DOCUMENTATION

GOAL

Joint ROM will be increased in (specify joint, right/left/bilateral, and motion) by using scar remodeling procedures of:

METHOD	**PRINCIPLE/RATIONALE**	**EXAMPLE**
Temperature	That stimulates localized vascular responses and increases tissue elasticity	• Neutral warmth
Compression	That reduces inflammation and stimulates lymphatic system	• Elastomer molds • Silicone gel sheets • Kinesio taping • Low-stretch bandages • Foam-lined splints • Gentle myofascial release • Pressure garments
Deep friction massage	That reduces dense external adhesive scar tissue and separates deeper structures	• Deep friction massage techniques

Adapted from Dutton, R. (1995). *Clinical reasoning in physical disabilities*. Baltimore, MD: Lippincott Williams & Wilkins and Marrelli, T. M., & Krulish, L. H. (1999). *Home care therapy: Quality, documentation and reimbursement.* Boca Grande, FL: Marrelli & Associates, Inc.

in occupations of choice, then increasing strength would be a valid treatment objective. Many clients who have had a stroke have muscle tone problems ranging from flaccidity to spasticity. The generally accepted practice is to normalize tone first and strengthen only those muscles that can be controlled voluntarily by the individual. Volitional control of muscles is required for strengthening programs and activities. In a systematic review of strengthening interventions to increase strength and improve activity after stroke, Ada, Dorsch, and Canning (2006) found that, across all stroke participants, strengthening interventions had a small positive effect on both strength (standardized mean difference [SMD] 0.33, 95% confidence interval [CI] 0.13 to 0.54) and activity (SMD 0.32, 95% CI 0.11 to 0.53) and very little effect on spasticity, suggesting strengthening can be a part of rehabilitation after stroke (Ada et al., 2006).

Similarly, in clients with Parkinson's disease, tone (specifically rigidity), is the limiting factor, not strength. Rigidity represents a problem in muscle tone that is more aptly treated using sensorimotor/neurodevelopmental/motor control approaches. Instead of focusing on increasing strength, activities and exercises should emphasize increasing mobility and rapid, rhythmical movements.

In rheumatoid arthritis, strengthening may be done if the client is in remission and not in an acute, inflammatory phase. Isometric exercises and activities are preferred because no joint movement occurs. For clients with multiple sclerosis (MS), be aware that the client with MS will more likely be fatigued in the afternoon and more energetic early in the morning and in the evening, although this may vary based on the individual. In addition, the environment is important when working with the client with MS because heat is fatiguing to these individuals. It is very important to avoid overfatiguing the recovering muscles of clients with Guillian-Barré syndrome. Clients with cardiopulmonary diseases fatigue more quickly due to decreased oxygen availability and require a longer amount of time to recover from exercise or strenuous activities.

Muscle disuse may be due to muscle imbalance, pain, denervation of motor units, spasm, habit, psychological factors, or immobilization. Muscle disuse can lead to decreased force production and strength as actin and myosin develop diminished ability to form cross-bridges. The eventual reabsorption of small blood and lymph vessels leads to decreased endurance (Trew & Everett, 2005).

In the elderly, the loss of strength is multifactorial. There may be normal age-related changes, such as a decline in total muscle fibers, atrophy of muscle fibers, loss of muscle mass, changes in connective tissue and bone, decreased hydration of the joint, decreased elasticity of the joint capsule, and increased joint stiffness (Bonder & Bello-Haas, 2009). Preexisting conditions make interventions more complex. It is important to ensure that there is postural and structural stability and that all comorbidities are known prior to intervention implementation. Limitations in strength may be permanent or temporary, and an understanding of the cause of the deficit will influence intervention strategies. Remediation intervention will be focused on those muscles in which improvement is possible.

Maintenance of Strength

Maintenance of strength might be an intervention focus if a client has been on bed rest for 6 to 10 days or more or a specific body part has been restricted (Dutton, 1995). Active movement and participation in grooming and hygiene activities can maintain muscle grades of fair plus to good. In muscle

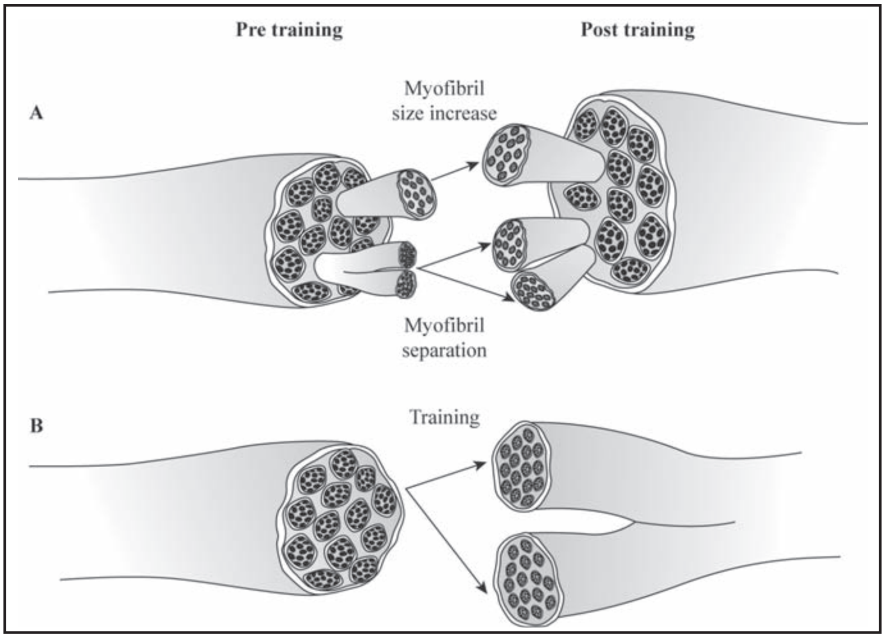


Figure 12-6. Effects of strengthening on muscle fibers.

grades of fair or greater, active movement is beneficial not only in maintaining strength, but also in maintaining range. Isometric activities and exercise without resistance can be used to maintain muscle strength when active motion is not possible or is contraindicated with muscle grades above trace. This type of activity is especially good for those in casts, after surgery, and with arthritis or burns (Pendleton, 2012). Because strength is maintained and not increased or changed, maintenance of strength may more aptly be viewed as a rehabilitation goal or as one to prevent further structural limitations (disability prevention).

Increasing Strength

Increasing muscle strength would be the focus of intervention when muscle weakness interferes with performance in occupations. Muscle weakness is potentially deforming due to muscle imbalances, and strengthening weak muscles will balance the forces of agonist and antagonist muscles. If muscle imbalance is present, the tight muscle must first be elongated to a normal length before strengthening programs and activities are initiated (Sidebar 12-3; Magee, 2014).

Sidebar 12-3 Increasing Strength

To increase strength, the muscle must be overloaded to the point of fatigue, which recruits more motor units and causes hypertrophy and hyperplasia of glycolic type II (fast-twitch) muscle fibers.

When a muscle is stressed, this message is sent to the central nervous system, which then stimulates ribosomes to replicate more actin and myosin. As a result, the myofibrils thicken and increase in length. The number and size of the sarcomeres increases so there is an increase of strength in the muscle. Changes in the mitochondria and increased vascularization also occur. Increasing strength occurs when more motor units are recruited due to the stress applied to a muscle to the point of fatigue. The stress to the muscle needs to be great enough to require a maximal motor unit response. A training effect occurs, which reflects the increased number and type of motor units involved in muscle contractions. The muscle fibers become larger (increase in cross-sectional area of the muscle or hypertrophy), and the fibers may split (hyperplasia) as they adapt to increased stress (Figure 12-6; Donatelli & Wooden, 2010; Nyland, 2006). The greatest hypertrophy occurs in type IIb fibers and remodeling of type IIb to type Ia muscle fibers may occur. Early resistance training increases in the cross-sectional area may not be purely hypertrophy since there is concomitant muscle edema, which may account for the increased cross-sectional area (Damas et al., 2016; Donatelli & Wooden, 2010). Increases in tensile strength include increases in tendons, ligaments, and connective tissue in muscle (Kisner & Colby, 2012).

Strengthening programs are based on Hellebrandt's overload principle (Hellebrandt, 1958; Tan, 1998), which states that an increase in strength occurs only if the load is greater than that to which the tissue is accustomed and that the load is applied to the point of fatigue. The application of the appropriate stress will overload the metabolic capacity of the muscle and cause adaptation. Without overload, there is no adaptation and no improvement in strength. Overload can be accomplished by increasing the resistance, increasing the number of repetitions, increasing the numbers of sets done, and decreasing the rest between sets or exercises (Nyland, 2006). In strength training, the amount of resistance is increased; in endurance training, the time a muscle contraction is sustained, or the number of repetitions is increased.

Adaptation is defined as a persistent (Hamill et al., 2015) change in the structure or function following repeated bouts of activity. Adaptation is based on Wolff's law, which states that body systems adapt over time to stresses placed on them

(Kisner & Colby, 2012). Examples of adaptation include hypertrophy and increased strength, increased maximal oxygen consumption, or a change in body composition (Hamill et al., 2015). Overload is achieved by varying the parameters of intensity, duration, and frequency of the stress, with intensity being the most potent factor in yielding adaptation to stress.

Activities and exercises should be directed to increasing strength in specific muscle groups, the amount of energy used, and the type of muscle contraction required for specific tasks. This reflects the SAID (specific adaptation to the imposed demand) principle, which indicates that the choice of activity or exercise should be related to the activity in which you want a functional outcome. There is training specificity, so an analysis of the motions required in daily tasks in terms of type, method, velocity, limb position, and movement pattern needs to be done to strengthen those muscles needed in those specific activities. Functional training and conditioning involves compound movements that works many large muscle groups together in movements similar to everyday tasks.

Duration, velocity, type of muscle contraction, frequency, intensity, pain, muscle strength, and fiber type all influence a strengthening program. This is consistent with how the magnitude of active tension develops in a muscle. Tension development is affected by the size of motor units, number and size of muscle fibers in cross-section, number of motor units firing, frequency of motor unit firing, sarcomere length, fiber arrangement, type of muscle contraction, and speed of contraction. Designing the program is based on the client's physical needs and interests in returning to roles and occupations. At times, engagement in desired tasks is sufficient stress to muscles to increase strength and is more desirable and motivating to the client. Other times, a home exercise program can lead to gains in strength more quickly. Consideration of the client's unique needs and interests in addition to the parameters related to strengthening are all considered when establishing a strengthening program. Overall, there is strong evidence that strengthening programs should include unilateral and bilateral exercises and single and multiple joint resistance.

Determinants of Strengthening Activities and Exercise

Duration

Duration of exercise refers to the length or total time the client participates in the activity or exercise. When the duration increases, this causes fatigue, which leads to the recruitment of additional motor units. In addition, weak muscles activate more motor units than do strong muscles. If the client is engaged in activities that are of high intensity and low duration, increases in strength are the objective. Usually, programs that are of low intensity but high duration are aimed at increasing endurance. Activities that are of interest to the client will likely be done for longer periods of time, which increases the duration as well.

Velocity

The rate or velocity is the speed of the activity or exercise. The velocity of muscle contraction is affected by the recruitment order of the motor units, with slow conduction velocities recruited first. Strong evidence supports slow and moderate velocities for untrained individuals (American College of Sports Medicine, 2009). The type of muscle fibers in the motor unit is also a factor in velocity since muscle tension develops more quickly in type I muscle fibers. A final factor is the length of the muscle fiber, with longer fibers having higher shortening velocity than shorter fibers (Levangie & Norkin, 2011).

Generally, it has been found that by using slower speeds, muscle strength can be increased more quickly, and slower, more constant rates tend to decrease the effects of momentum. Galley and Forster (1987) state that low-speed, high-load exercise produces greater increases in muscular force only at slow speed, whereas high-power (high-speed, low-load) exercise produces increases in muscular force at all speeds, as well as increases in endurance. The high-speed, low-load exercises need to be done for a longer duration because rapid movements have little strengthening capability as muscle forces are so low (Lieber, 2002).

The velocity of the contraction should be based on the client's physical capacity at the time the exercise or activity is initiated. Activity analysis is a helpful skill in determining in advance the rate of the activity for which the strengthening is directed.

Muscle Contraction

The type of muscle contraction is also important to consider. The force-velocity curve (see Chapter 4, Figure 4-8) demonstrates that, in concentric muscle contractions, as the velocity of muscle shortening increases, the force that the muscle can generate decreases because the muscle does not have time to reach peak tension. Slow, concentric contractions produce more torque than fast, concentric contractions. However, as Dutton (1995) points out, it is ironic that clients often prefer fast, concentric activities and exercises because the speed recruits assistive, synergist muscles. If using concentric contractions, the velocity should be slow.

In eccentric muscle contraction, as the velocity of muscle lengthening increases against resistance, force production increases to a point but levels off, and this serves as a protective measure when excessively loaded (Baxter, 2003; Berne & Levy, 1998; Galley & Forster, 1987; Houglum & Bertoti, 2012; Kisner & Colby, 2012; Levangie & Norkin, 2011; Neumann, 2010). Fast, eccentric contractions produce more torque than slow, eccentric muscle contractions, but ballistic movements result, as when one slams a glass on a table. While more torque is produced in the fast contraction, this is not always the most desirable motion to produce, especially for those with fragile tissues, such as clients with rheumatoid arthritis or burns (Dutton, 1995). In addition, muscle injury and soreness are associated with eccentric contraction, and muscle strengthening is greatest using eccentric contractions (Magee, 2014; Nyland, 2006). Because eccentric contractions are physiologically common, even weak clients may be able to perform the controlled lowering of a body part but not be able to hold or raise the part. For this reason, it might be advisable to start strengthening programs with eccentric muscle contractions (Hamill et al., 2015) and then move to concentric and isometric muscle contractions. Most activities and exercises use alternating concentric and eccentric contractions.

It is important to match the type of contraction used in intervention to what is needed in the client's preferred and required occupational demands and interests. Analysis of the activities will help to determine the type of contraction needed to produce functional gains.

Fiber Type

The type of fiber that predominates in the muscle (e.g., type I, type II) will also be a factor. For example, larger, fast-twitch muscle fibers have a greater capacity to develop tension and show a more pronounced hypertrophy in response to strength training than do smaller, slow-twitch muscle fibers.

Frequency

Frequency is the number of times per day or number of days per week the activity or exercise is done. Frequency depends on the types of fibers being strengthened, type of activity for which the intervention is directed, client's endurance and general health status, muscle grades, joint mobility, diagnosis, intervention goals, position of client, desirable plane of motion, and level of fatigue. High-intensity, eccentric exercise is usually done less frequently due to higher incidence of delayed-onset muscle soreness (DOMS) and greater microtrauma. Rest periods are longer with high-intensity, eccentric contractions, and the purpose of rest is to recuperate from muscle fatigue (Kisner & Colby, 2012). With higher-intensity exercise, the rest interval between sets is greater than 3 minutes; with moderate intensity, there is a rest of 2 to 3 minutes between sets. Frequency of exercise sessions is usually every other day.

Intensity

Intensity is the level of exertion or energy expenditure and is the greatest amount of weight a muscle can move through full available ROM with control before fatiguing (Kisner & Colby, 2012). Typically, a baseline measurement of dynamic muscle strength is made by establishing the greatest amount of weight that can be lifted, pulled, or pushed 10 times through the full existing ROM (called *repetition maximum* [RM]). Baseline muscle strength can also be established using tensiometers or handheld dynamometers.

The intensity and number of repetitions is based on the client's failure to lift, in which all motor units in a muscle are strengthened. Optimally, one to three sets of 8 to 12 repetitions at 60% to 85% of 1 RM has been found to be adequate to increase strength if failure to lift occurs in the final repetitions (American College of Sports Medicine, 2009). Signs that the client is approaching failure to lift include mild shaking, difficulty completing the full movement, grimacing, grunting, or sweating (Demeter & Andersson, 2002). Watch for substitution movements because this would activate muscles other than the ones that need strengthening. Low-intensity activities affect the oxidative (slow-twitch) fibers, while high-intensity activities affect the glycolic (fast-twitch) muscle fibers.

Intensity can be gauged by the client's heart rate (HR), perceived exertion, and ability to speak normally. The Borg CR10 Scale provides a rate of perceived exertion, often used by the client to rate his or her perception of the level of intensity of the activity or exercise, the level of pain, and breathlessness (Borg, 1985).

Intensity can be graded by the type of exercise or activity that is performed, the amount of resistance used, changing the length of the lever arm, changing the point where the load is applied, or changing the plane of movement (Radomski & Latham, 2014). Given the variety of ways intensity can be graded, increasing strength can be accomplished by many activities as well as by exercise regimens. The number of repetitions varies from one to three sets of 10 repetitions, with rest periods of 2 to 4 minutes between, and no optimal number of repetitions or number of sets per exercise has been identified (Kisner & Colby, 2012).

As a rule, submaximal loading is used in early stages of soft tissue healing, after prolonged immobilization of a part, when initially learning an exercise, when the goal is to increase endurance rather than strength, to cool down/warm up, and for children and older adults. Near maximal loading will increase muscle strength and is used with healthy adults in advanced rehabilitation programs after healing, in conditioning programs for people with no pathology, and for competitive body building (Kisner & Colby, 2012).

Muscle Fatigue and Distress

The overload principles states that muscles must be worked, but only to the point of fatigue. The question is, what is muscle fatigue and how do you know when a muscle is fatigued? When there is a decline in muscle tension and the muscle has decreased shortening velocity and a slower rate of relaxation, then the muscle is fatigued. Fatigue may be caused by synaptic fatigue, depletion of glycogen, buildup of lactic acid, shunt of blood to skin to control temperature, electrolyte imbalance, increased blood viscosity due to dehydration, or blood flow constriction by prolonged muscle action.

The onset and rate of fatigue depends on the type of muscle and the duration of the contraction. A muscle that is fatigued can recover if given rest, and the rate of recovery depends on the duration and intensity of the exercise (Nyland, 2006). If the exercise was high intensity/short duration, recovery is rapid; if the exercise was low intensity/long duration, fatigue is due to the buildup of lactic acid and changes in the muscle proteins, so recovery is slower (Hall & Brady, 2005; Nyland, 2006).

Muscle overwork or trauma may result in injuries that disrupt the contractile unit (e.g., muscle or ligament tear), mechanically affecting the ability of the muscle to either produce or transmit force or disrupt the nerve supply and so do not permit recruitment, and no muscle contraction occurs (Trew & Everett, 2005). Decreased muscle force occurs because the force that each muscle fiber can produce is reduced or due to loss of motor neurons and the size of motor units.

Fatigue can be differentiated from overwork weakness. Fatigue is the result of a maximal motor unit response, whereas overwork is an insidious loss of strength due to an overload on individual muscle strands. Overwork weakness occurs in clients with spotty denervation (with or without sensory losses) who have impaired neuromuscular function or a systemic, metabolic, or inflammatory disease (Kisner & Colby, 2012). These clients have fewer motor units and fewer contracting muscle fibers, so each fiber must work maximally. Because there is less waste product buildup, there is less sensation of fatigue, and the client does not interpret the fatigue sensation properly. Overwork is frequently irreversible but, fortunately, rarely occurs.

Being aware of the level of fatigue will help prevent overwork of weak muscles and will prevent substitution movements. Muscle fatigue levels vary from person to person. One's threshold for fatigue decreases in pathological states (Dutton, 1995), and clients may lack the sensation to be aware of their level of fatigue, while others may push themselves beyond their tolerance. Local fatigue is normal and is characterized by a diminished response of muscles to repeated stimuli (Kisner & Colby, 2012).

Table 12-8

MUSCLE GRADES AND TYPES OF ACTIVITIES AND EXERCISES

	PASSIVE	ACTIVE ASSISTED	ACTIVE	RESISTED
Gravity eliminated	0	T P-	P	P+
Against gravity		F-	F	F+
Against resistance and gravity				G- G G+

Signs of fatigue may include the following (Demeter & Andersson, 2002; Kisner & Colby, 2012; Levangie & Norkin, 2011):

- Slowed performance
- Distraction
- Perspiration
- Increased rate of respiration
- Decreased ROM
- Inability to complete prescribed number of repetitions
- Inability to maintain a given force
- Decreased time of contraction
- Increased time for muscle lengthening
- Tremors with contraction
- Increased HR and respiration with no increase in load
- General sense of tiredness
- Attention wanders
- Incoordination
- Loss of concentration
- Substitution movements

As the client performs activities, observe for signs of fatigue and distress. Distress may be evident in shortness of breath (dyspnea); confusion; profuse sweating in association with cold, clammy skin (diaphoresis); and straining while holding one's breath (Valsalva maneuver), which is especially dangerous in that it raises blood pressure. More subtle signs of distress might be seen in escalating frustration, hurrying to finish the task, less ROM, chest pain, nausea, or light-headedness (syncope; Demeter & Andersson, 2002). In the cases of chest pain or syncope, confusion, diaphoresis, or level 2 dyspnea (defined as one who needs three breaths to count to 15), it is advisable to discontinue the activity and consult with a physician for further evaluation of these symptoms (Hamill et al., 2015).

Muscle Injury, Strain, and Soreness

Injuries to muscles can occur because of muscle strain or microtears in the muscle fibers. Client symptoms would be pain or muscle soreness, swelling, and possible deformity and dysfunction. Muscles at greatest risk are two-joint muscles, muscles used to terminate an ROM, and muscles used eccentrically. Two-joint muscles are especially prone to fatigue and strain because they can be stretched at two joints simultaneously. For example, to extend at the hip and flex at the knee, the rectus femoris muscle is vulnerable to injury because it is put on an extreme stretch (Hamill et al., 2015). Muscles that are used to terminate a motion are at risk because they are used to eccentrically slow a limb moving very rapidly, such as the hamstrings when slowing hip flexion or the posterior rotator cuff muscles when slowing the arm on the follow-through phase of a throw (Hamill et al., 2015). While muscles may be the site of damage, soreness and strain are due to the connective tissues, especially at the muscle-tendon junction. Common injuries at this site are in the gastrocnemius, pectoralis major, rectus femoris, adductor longus, triceps brachii, semimembranosus, semitendinosus, and biceps femoris (Hamill et al., 2015).

Acute muscle soreness occurs immediately after the cessation of the activity when the muscle is exhausted due to inadequate blood flow and oxygen and buildup of metabolic wastes (e.g., lactic acid, potassium). There may a burning or aching sensation that is transient and subsides quickly (Kisner & Colby, 2012). DOMS is associated with eccentric muscle contractions and may be because eccentric contractions are capable of greater forces than concentric muscle contractions and in a reduction in compliance of the fascia (Tweed & Barnes, 2008). DOMS may occur 12 to 24 hours after exercise or activity and may continue up to 10 to 14 days after the exercise (Houglum & Bertoti, 2012). DOMS is characterized by decreased ROM due to pain, muscle soreness, local edema, and decreased muscle force.

Methods of Increasing Strength

Strengthening programs can use a variety of methods to increase strength that can include both activities and exercise. The exercise or activity needs to provide sufficient stress to the muscles to require adaptation but also permit smooth, pain-free movement. Based on the client's muscle grades and on the target movement pattern required in specific activities, activities and exercises can be done actively with assistance (active assisted), actively, or against resistance. Passive movements are done with muscles graded zero to maintain muscle lengths and joint integrity. Active assisted activities and exercises are done with muscle grades of trace, poor minus, or fair minus. Active activities and exercises are done with muscle grades of poor or fair, and resistive activities and exercises are done with poor plus, fair plus, good minus, good, and good plus muscle grades. Table 12-8 summarizes the relationships between muscle grades and types of activities/exercises.

Activity or Exercise

The use of therapeutic exercise is most beneficial to clients with muscle strength at the extremes of the manual muscle testing ratings (i.e., those muscles rated trace and poor or those with good muscle strength or better). Because occupational therapy intervention is based on the client's needs and interests, it is important to recognize that therapeutic exercise may be more acceptable to some clients than activities, while engaging in activities may be more meaningful to others.

There are eight purposes for the use of therapeutic exercise (Pendleton, 2012):

1. Develop awareness of normal movement patterns and improve voluntary, automatic movement responses.
2. Develop strength and endurance in patterns of movement that are acceptable and necessary and do not produce deformity.
3. Improve coordination, regardless of strength.
4. Increase the power of specific isolated muscles or muscle groups.
5. Aid in overcoming ROM deficits.
6. Increase the strength of muscles that will power hand splints, mobile arm supports, or other devices.
7. Increase work tolerance and physical endurance through increased strength.
8. Prevent or eliminate contractures developing as a result of imbalanced muscle power by strengthening antagonistic muscles.

Studies support the use of activities to improve strength and endurance. Studies have confirmed the advantages of embedding exercise within occupations over exercise alone (Nelson & Konosky, 1996; Sietsema, Nelson, Mulder, Mervau-Scheidel, & White, 1993). The use of object-oriented motor control training is more effective than non–object-oriented training (Yuen, Nelson, Peterson, & Dickinson, 1994). Purposefulness in activities results in enhanced performance with greater motor skill retention and motor learning (Ferguson & Trombly, 1997; Hsieh, Nelson, Smith, & Peterson, 1996; King, 1993). Functional activities that are meaningful are more effective in increasing performance (Neistadt, 1994; Thibodeaux & Ludwig, 1988; Wennemer, Borg-Stein, Delaney, Rothmund, & Barlow, 2006), and task-oriented treatment augmented with resistive exercises results in substantial gains in ADL, IADL, manual muscle test scores, and grasp (Flinn, 1995). Hoppes (1997) combined games and play with increasing standing tolerance in geriatric clients and found that clients were able to stand up for longer periods when engaged in a game. It is important to look not only at the force involved in the task or activity, but also at the motion as ADL frequently require hybrid force/motion tasks (Pekyavas & Baltaci, 2016).

Types of Exercise and Activity

Active Assistive

Active assistive activities and exercises are those in which the client moves actively as far as possible and the therapist or a device completes the motion through the existing ROM. Because the client moves actively as far as possible, there is stress to the muscle and recruitment, hypertrophy, and hyperplasia can occur. Exercise is graded so that the device/therapist gradually decreases the amount of support or assistance that is provided while the client provides more active (unassisted) movement.

Isotonic active assistive exercise is appropriate for clients with trace, poor minus, or fair minus muscle grades. For the trace muscle, the client contracts the muscle and the therapist completes the motion. Active assistive exercise in a gravity-eliminated plane is used for poor minus, while with fair minus muscles, gravity is included as a factor. Bilateral activities are useful for active assistive exercise if only one extremity is affected, and the assistance can be provided by the unaffected arm.

Progressive assistive exercise is a type of assistive exercise where equipment (e.g., the Swedish suspension sling) provides the minimal amount of weight required to complete a motion. A skate with weights and a pulley, dynamic orthoses, and towel and dowel exercises are other examples of exercises that can be done assistively. Few activities provide assistive exercise without resistance, although some examples cited by Trombly include adapting floor looms or polishing a smooth surface (Radomski & Latham, 2014).

Active

Active activities and exercise are those in which the client moves through the available ROM without resistance. Active activities and exercises increase muscle grades of poor to fair. There are very few activities or exercises that are purely active exercise, and even most ADL are at least mildly resistive. Needlepoint completed in a gravity-eliminated plane would be an active exercise for wrist extensors or elbow extensors. A fair muscle can move the wrist against gravity, as in a mosaic tile project (Pendleton, 2012). The goal of activities and exercises at this level is to progress to a point where some resistance other than gravity can be applied.

Resistive

Resistive activities and exercise are done when an outside resistance is required to apply maximal stress to the muscle to promote adaptation. Benefits of resistance exercise include enhanced muscle performance; increased strength of connective tissues; greater bone mineral density; decreased stress on joints during activity; reduced risk of soft tissue injury, which can enhance physical performance during work, play, and self-care; feelings of well-being; and possible improvements in perceptions of quality of life (Kisner & Colby, 2012). The resistance force may be applied manually (by the therapist or client) or by equipment, tools, or activity. Figure 12-7 illustrates Theraband (Performance Health) resisted exercises. Use of resistance is necessary to increase the strength of poor plus, fair plus, good minus, good, and good plus to normal muscle strength by means of either isotonic or isometric muscle contractions. Manual resistance exercises are particularly useful early in the recovery process when muscles are weak and ROM may be limited or needs to be controlled (Kisner & Colby, 2012).

Manual resistive exercise can be used as a transition from assisted to mechanically resisted movement since the resistance and amount of ROM can be more finely controlled than in mechanically resisted activities and movements (Kisner & Colby, 2012). In manual resistive activities and exercise, not only is the intensity of the resistance force controlled by the therapist, but also the site and direction of the force application. Force is usually applied at the distal end of the segment to which the muscle attaches, which provides a mechanical advantage for the therapist applying the force. The direction of force is directly opposite to the desired motion. Stabilization is important to avoid substitution or compensatory movements. The resistance is applied smoothly, steadily, slowly, and

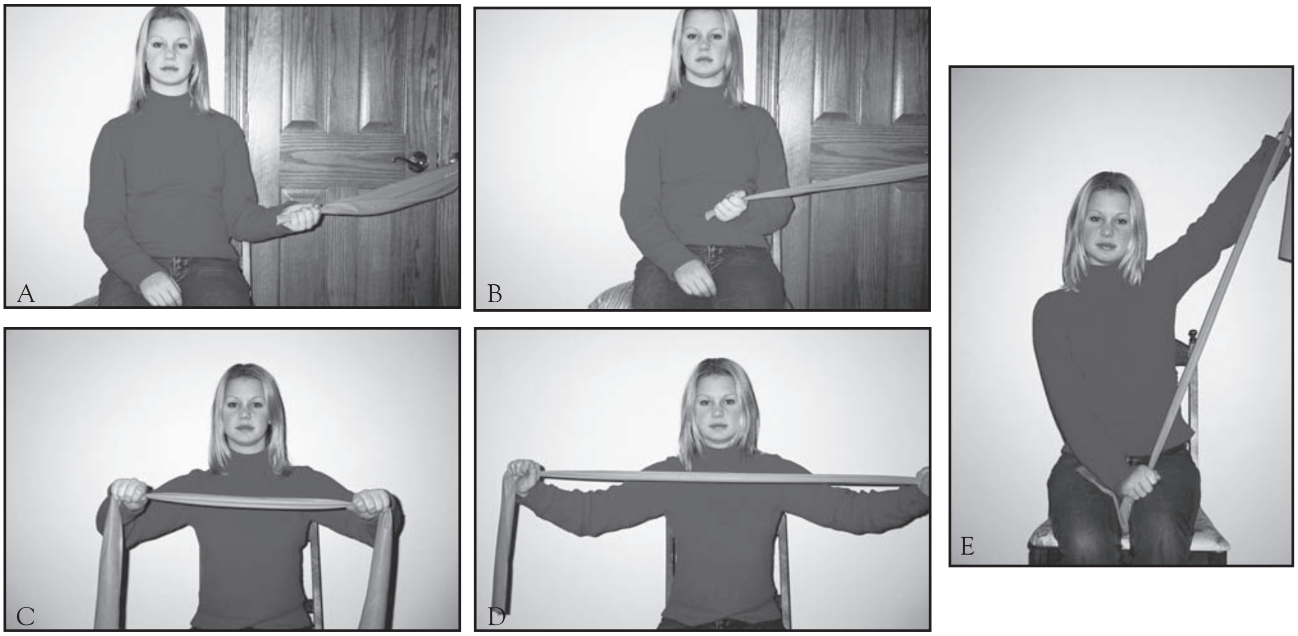


Figure 12-7. Theraband resisted exercises. (A) External rotation. (B) Internal rotation. (C) Horizontal abduction (start). (D) Horizontal abduction (end). (E) Shoulder abduction (end).

gradually so that the movement is pain free and through the maximal range. These criteria can be applied either to activities or to exercise regimens. For exercises, 8 to 10 repetitions are completed, 1 to 2 times per session, with rests of 2 to 4 minutes minimally between sets of application of resistance.

Mechanical resistive activities and exercise are any form of endeavor where the resistance is applied by mechanical equipment, tools, or the placement of the task. Isotonic resistance equipment may include free weights, elastic resistance devices (Theraband, tubing), pulley systems (using weights or springs) that may be freestanding or wall-mounted (e.g., Elgin exercise unit [Elgin Exercise Equipment], Variable Resistance or Dynamic Variable Resistance systems [Nautilus], Cybex Eagle, Keiser Cam II), or cycle ergometers (stationary bicycles; Levangie & Norkin, 2011; Rantanen et al., 1999). Many of these devices are part of circuit weight-training programs, where the client exercises in short bouts, using light to moderate workloads with frequent repetitions and short rests. A specific sequence of exercise is followed.

Adding resistance can be done by changing the effect of gravity on the activity with a gravity-eliminated plane (generally, this is parallel to the horizon). Additional resistance would be achieved by using an inclined plane, additional resistance to the weight of the objects or tools used, or the duration of the activity. Advantages to mechanically resisted activities or exercise are that the force can be quantified, enabling incremental increases, the amount of force can be more than can be applied by the therapist, there are a variety of methods of force application, and there may be better carryover to functional activities (Kisner & Colby, 2012). Activity analysis and activity adaptation are particular strengths of the occupational therapist, and these skills are especially helpful in developing intervention aimed at increasing strength by means of activities of value and interest to the client. Occupations done daily can have a strengthening benefit without being contrived and can have the added advantage of being a necessary part of one's life. Progressive resistive exercises (PREs) have been shown to reduce pain and disability and improve upper extremity muscle function in postsurgical head and neck cancer survivors (McNeely et al., 2008) and a high-intensity functional exercise program appeared to slow the decline in ADL and balance in older people with moderate dementia (Toots et al., 2016) .

Isometric Exercise and Activities: Static Exercise

Isometric activities and exercise are characterized by no visible joint movement nor appreciable change in muscle length, but there is increased muscle tension (Figure 12-8 shows examples of isomeric exercises.) The load is only applied to one joint position, so strength is only enhanced at the joint angle in which the muscle is stressed, not throughout the entire ROM.

Because the joint does not move, isometric activities and exercise are well-suited for clients with rheumatoid arthritis and those with pain or inflammation, and they are the only type of exercise for clients with trace muscle strength. This type of exercise is appropriate for those who are immobilized in casts, splints, or traction because muscle atrophy is minimized and in situations when dynamic movement would compromise joint integrity or cause pain (e.g., immediately following surgery; Kisner & Colby, 2012).

Isometric exercises have the advantage of being easy to perform with little setup or equipment needed, and it takes minimal time because isometric contractions can be very fatiguing (Nuismer et al., 1997). Disadvantages of isometric exercise and activity are that the gains in strength do not necessarily transfer to dynamic or functional activities, there is no effect on improving coordination, and it does not cause hypertrophy. The most serious disadvantage is that isometric contraction causes an increase in blood pressure and is contraindicated for clients with cardiovascular problems. Using isometric contractions in activities is easily done when one considers that holding tools requires an isometric contraction.

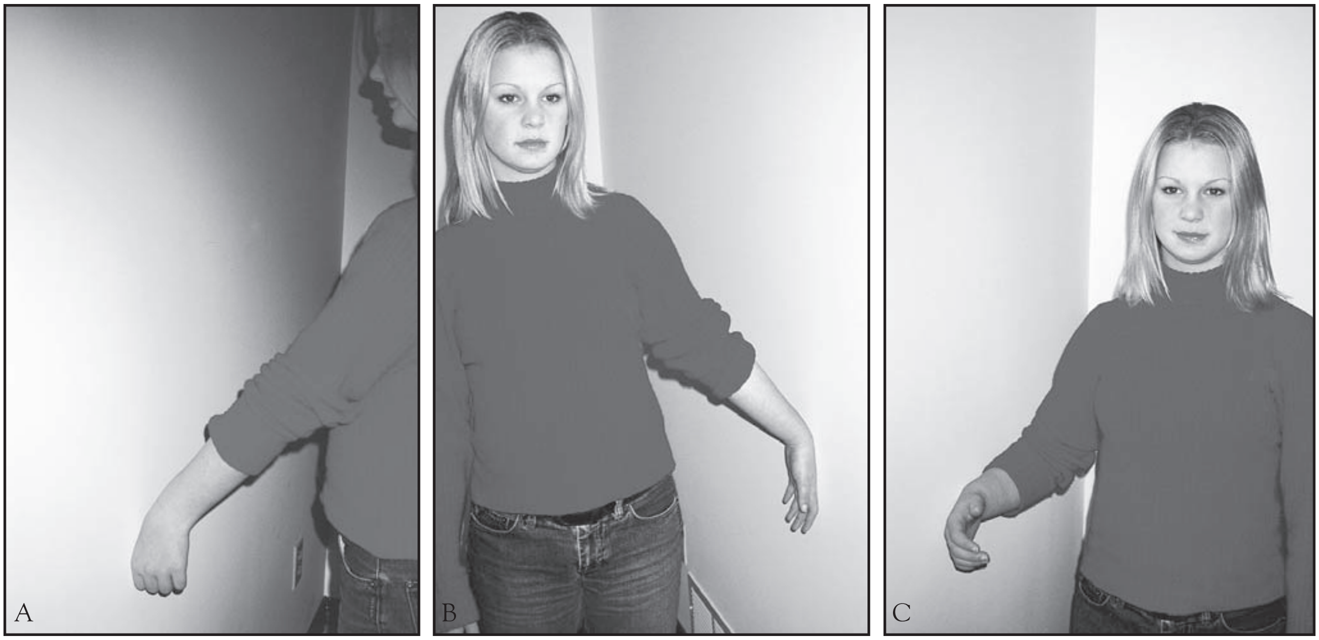


Figure 12-8. Isometric shoulder exercises. (A) Isometric shoulder flexion. (B) Isometric shoulder abduction. (C) Isometric shoulder external rotation.

Different types of isometric contraction exercises include the following:

- Brief maximal isometric exercise regimen: A single isometric contraction is held against a fixed resistance for 5 to 6 seconds, once per day, 5 to 6 times per week. Longer duration contractions have been found to be more effective in increasing strength than one held for 5 to 6 seconds (Tan, 1998).
- Brief repetitive isometric exercise regimen: The client completes 5 to 10 brief but maximum isometric contractions, each held 5 to 16 seconds, and performed against resistance. This exercise regimen is done daily (Tan, 1998).
- Multiple angle isometric exercise regimen: Resistance is applied at least every 20 degrees through ROM. For example, the client completes 10 sets of 10 repetitions, with each contraction lasting 10 seconds in every 10 degrees of the ROM ("rule of tens"; Tan, 1998).
- Prolonged method: Involves holding an isometric contraction as long as possible and then repeating the contraction 10 times. The amount of time the client maintains the maximal effort for 10 repetitions is increased (Radomski & Latham, 2014).
- Weighted method: The client holds a contraction against resistance for 30 to 45 seconds with a 15-second rest between each of the 10 repetitions (Radomski & Latham, 2014).

When using exercise machines such as Cybex, Biodex, Kin-Com, Lido, Merac, and Orthotron II (Cybex), isokinetic strengthening exercise is being done. This is a type of dynamic exercise performed with constant angular joint velocity (i.e., the muscle shortens/lengthens at a constant rate) against varying resistance.

When clients are engaged in resistive strengthening activities, it is important to caution them to avoid holding their breath while performing the task. By having them count, talk, or sing during the task, the Valsalva maneuver (holding the breath while exerting effort, which raises blood pressure) will be avoided. This is especially important during isometric exercise and activities with heavy resistance.

Dynamic Exercise

Strengthening activities and exercise that require a dynamic effort through a specified ROM include concentric and eccentric muscle contractions. Many activities require both concentric and eccentric contractions, with concentric contractions producing segmental acceleration and eccentric contractions decelerating the movement and acting as a shock absorber.

The actual load varies throughout the ROM because the resistance cannot be heavier than the muscle tension that can be developed at the weakest joint position. This means that isotonic strengthening may not be adequately overloading the muscle in midrange, where it is usually the strongest (Hamill et al., 2015).

DeLorme and Watkins (1948) developed a specific exercise program called *PRE*. DeLorme and Watkins (1948) based this exercise regimen on the overload principle, where several sets of repetitions are completed against a portion of the RM. The modified DeLorme PRE method first determines the RM, which is the greatest amount of weight that can be lifted, pulled, or pushed 10 times through the full existing ROM. The RM is based on the muscle grades as a guide and is determined through trial and error. The client then performs 10 repetitions at 50% of the RM, 10 repetitions at 75% of the RM, then 10 repetitions at 100% of the RM, with 2- to 4-minute rests in between exercise sets. These exercises should be performed once per day, four to five times per week for maximum strengthening benefit. An example might be that, if a client is able to lift 12 pounds 10 times, this would be the 10 RM. The PRE program would be 10 repetitions at 6 pounds, rest, 10 repetitions at 9 pounds, rest, 10 repetitions at 12 pounds.

Regressive resistive exercise or Zinovieff Oxford method is essentially the opposite of the modified DeLorme PRE program. The client completes 10 repetitions at 100%, rests, completes 10 repetitions at 75%, rests, then completes 10 repetitions at 50%. The regressive resistive exercise program was designed to diminish the resistance as muscle fatigue develops, but this has been disproven as a reliable form of strengthening exercise (Kisner & Colby, 2012; Nyland, 2006; Rothstein, Roy, Wolf, & Scalzitti, 2005).

Warming Up and Cooling Down

Warming up is any activity or exercise that raises total body and muscle temperature. Cardiovascular warm-up gets the heart and lungs prepared for exercise, prepares tissue for greater extensibility force, decreases viscosity, and increases tissue compliance. Increasing muscle temperature increases the uptake of oxygen and increases the metabolic rate and blood flow (Cooper, 2007).

The benefits of warming up prior to strenuous activities include the following:

- Cold muscles and tissues do not stretch very easily. Use of modalities will warm the tissues. Warming up the muscles and tissues tends to relax them, which makes them more easily stretched.
- With aerobic activities, the warm-up period prepares the heart, cardiovascular system, and muscles for activity. It has been shown that attempting to perform strenuous activities without adequate warm-up may precipitate cardiac arrhythmia, even in those without heart disease.
- Warming up causes the blood vessels that supply muscles involved in the activity to dilate and vessels supplying less-involved parts to constrict. This provides additional oxygen to the muscles, requiring the energy for the task.
- Muscles not properly warmed up may work anaerobically without sufficient oxygen. As a result, the muscles may become prematurely fatigued, and lactic acid will accumulate.

Warming up may involve 5 to 10 minutes of gentle activities or exercises, followed by a few minutes of low-intensity aerobic activities and then some gentle stretching. Prestretching muscles prior to concentric muscle action results in greater force because the stretch increases the tension by releasing potential elastic energy in the series elastic components of the muscle (Hamill et al., 2015). Predominantly, fast-twitch muscles benefit from high-velocity prestretches over a small ROM because myosin and actin cross-bridging occurs quickly, while slow-twitch muscles respond better to slower speeds and a greater ROM (Hamill et al., 2015).

Cooling down is similar to warming up, but with decreasing physical demands placed on the body. Cooling down enables the body to eliminate metabolic wastes, bring in additional oxygen, and gradually reduce the HR to resting level, which helps to reduce dizziness or fainting. Cooling down after exercise does not seem to influence DOMS because it is not due to an accumulation of lactic acid but instead is due to damage to muscle fibers (Law & Herbert, 2007).

Muscle soreness can be minimized or prevented by ensuring a sufficient warm-up and cool-down prior to initiation of the activities, stretching prior to heavy resistance, and gradually increasing the resistance as strength improves.

Sample goal statements, methods, principles, and examples are shown in Table 12-9.

Contraindications and Precautions to Strengthening

An extensive list of precautions and contraindications are included in Table 12-10 (Hall & Brady, 2005). These are helpful guidelines for clients of all ages. Use care when developing strengthening programs for clients with osteoporosis, which may be suspected if the client has rheumatoid arthritis, is a postmenopausal woman, or uses systemic steroids. While older adults gain less absolute strength and gains in strength are made more slowly, studies have demonstrated improvements in strength and functional activities following strengthening programs for older adults (Bamman et al., 2003; Carmeli, Reznick, Coleman, & Carmeli, 2000; Charette et al., 1991; Ferri et al., 2003; Fiatorone & Evans, 1993; Fiatarone et al., 1994; Frontera et al., 2000; Frontera, Meredith, O'Reilly, Knuttgen, & Evans, 1988; Khruda, Hicks, & McCartney, 2003; Meuleman, Rechue, Kubilis, & Lowenthal, 2000; Vincent & Braith, 2002).

Coordination

Coordination can be defined as the ability to produce accurate, controlled movements characterized by smoothness, rhythm, appropriate speed, appropriate muscle tension, a minimal number of muscles involved to accomplish the movement with adequate postural tone, and equilibrium. It requires more than just an isolated muscle contraction. A person is uncoordinated when there are errors in rate, rhythm, range, direction, and force of movement (Nuismer et al., 1997).

Notice from the definition that coordination involves the ability to move at the proper or appropriate rate (not too fast nor too slow). An example of a dysfunction in rate might be dysdiadochokinesis (the inability to perform rapidly alternating movement). The rate or timing problems may be due to the inability to generate sufficient force in muscles, decreased rate of force generation, insufficient ROM for the movement to occur, reduced motivation, or abnormal postural control (Shumway-Cook & Woollacott, 2000).

The lack of control might be seen in a tremor or ballism (where the limb flies out suddenly) or the arm rebounds after motion (Holmes rebound phenomenon). The client may be unable to reach a cup of coffee because he or she overshoots or underestimates the distance needed to reach the cup (dysmetria). Problems with coordination and the structure associated with the deficit are listed in Table 12-11.

Coordination involves smooth, rhythmical movement of multiple muscle groups, and that is a function of the cerebellum and extrapyramidal system. Also needed are intact proprioceptors and perceptual-motor systems, especially spatial orientation, vision, and body scheme (closely associated with proprioceptors). Lesions in the corticospinal tract can lead to loss of the ability to recruit muscle and to control individual joints (Shumway-Cook & Woollacott, 2000). Both the biomechanical and neuromuscular systems are needed for coordinated movement.

Table 12-9

INCREASING STRENGTH INTERVENTION AND DOCUMENTATION

GOAL

Strength will be increased in (indicate where/which muscle/muscles, right/left/bilateral) to (indicate what level of improvement) to perform (indicate what occupational tasks and level of performance) for a:

MUSCLE GRADE	METHOD	PRINCIPLE/RATIONALE	EXAMPLE
T muscle	Isometric exercise and activities against no resistance	That recruits more motor units and increases proprioceptive awareness of muscles as they contract	• Electric stimulation • Biofeedback machine • Vibrators • Manual contacts • Isometric exercises • Brief maximal • Brief repetitive • Multiple angle • Prolonged method • Weighted exercises
P- or F- muscle	Active assistive exercise and activities with assistance to complete the motion	That recruits more motor units, causes hypertrophy/hyperplasia of glycolytic type II fast-twitch muscle fibers	• Therapeutic skate • Deltoid aid mobile arm support • Manual assistance • Bilateral activities
P, F, or greater muscle grades	Active exercise and activities	That recruits more motor units and causes hypertrophy of glycolytic type II muscle fibers	• Shoulder wheel • Combing short hair • Electric typewriter or keyboarding • Clothespin races • Needlepoint • Mosaic tile project
P+, F+, G-, or greater muscle grades	Progressive or regressive resistive exercise and activities against the maximum resistance needed to produce failure-to-lift	That recruits more motor units, causes hypertrophy/hyperplasia of glycolytic type II fast-twitch muscle fibers	• Weight well • Exercise putty • Weighted weaving • Overhead rug knotting • ADL tasks like dressing, transfers • Manual resistance via another person, activity • Weighted exercises (isometric and isotonic)

Adapted from Dutton, R. (1995). *Clinical reasoning in physical disabilities*. Baltimore, MD: Lippincott Williams & Wilkins and Marrelli, T. M., & Krulish, L. H. (1999). *Home care therapy: Quality, documentation and reimbursement*. Boca Grande, FL: Marrelli and Associates, Inc.

Coordination not only refers to the upper extremities, but also to gait (ataxia), eyes (nystagmus), and facial muscles (dysarthria). Dexterity refers to coordination (smoothness, grace), especially skill and ease in using the hands. Incoordination may be due to pathology in the motor cortex, basal ganglia, or cerebellum, or it may be due to difficulty with sequencing or in the inability to appropriately time the action of muscles (initiating, slowing movement, terminating movement (Houglum & Bertoti, 2012).

The assessment and treatment of coordination does not seem to correspond with any one frame of reference. Observation is important to identify irregular movements or sudden movements meant to compensate for incoordination. Factors that increase incoordination may include poor balance, fear, too much resistance, pain, fatigue, strong emotions, and prolonged inactivity. Coordination depends on accurate somatosensory feedback for normal reciprocal innervation and cocontraction, which is inconsistent with the biomechanical approach assumption that sensation is intact for biomechanical treatment techniques.

Biomechanical techniques, such as exercise, are often performed in linear patterns along anatomical planes with a constant rhythm, while normal movements are often diagonal with rotary components, irregular rhythms, and large numbers of muscles working together. It is difficult to perform fine, coordinated movements when maximum resistance is applied

Table 12-10
Contraindications and Precautions Related to Increasing Strength

Contraindications	Precautions
Severe coronary artery disease	Marked obesity
Decompensated congestive heart failure	Congestive heart failure
Uncontrolled ventricular arrhythmias	Significant valvular heart disease
Acute myocarditis	Cardiac arrhythmias
Uncontrolled atrial arrhythmias	Hypertension
Recent pulmonary embolism of deep vein thrombosis	Fixed-rate permanent pacemaker
Severe valvular heart disease	Cyanotic congenital heart disease
History of metastases	Congenital anomalies of coronary arteries
Pulmonary hypertension	Marfan syndrome
Unstable angina	Peripheral vascular disease
Thrombophlebitis	Electrolyte abnormalities
Resting systolic blood pressure over 200 mmHg	Uncontrolled metabolic diseases (e.g., diabetes)
Resting diastolic blood pressure over 100 mmHg	Any serious systemic disorder (e.g., hepatitis)
Acute thyroiditis	Neuromuscular or musculoskeletal disorders
Hypokalemia	Severe obstructive or restrictive lung disease
Presence of inflammatory neuromuscular disease	Discontinue if client experiences pain, dizziness, shortness of breath
Unstable angina pectoris	Cardiomyopathy
Acute myocardial infarction	Unhealed fracture
Anemia	Avoid uncontrolled ballistic movements
Post-surgery (tendon or nerve repair, chest, neck)	Use caution with children, older adults
Uncontrolled systemic hypertension over 200/105 mmHg	Pain should not occur during exercise or activity
Avoid exercises that put excessive or unintended stress on spine	Do not apply resistance over unstable joint

Adapted from Hall, C. M., & Brady, L. T. (2005). *Therapeutic exercise: Moving toward function* (2nd ed.). Philadelphia, PA: Lippincott Williams & Wilkins; Rothstein, J. M., Roy, S. H., Wolf, S. L., & Scalzitti, D. A. (2005). *The rehabilitation specialist's handbook* (3rd ed.). Philadelphia, PA: F. A. Davis; Kisner, C., & Colby, L. A. (2012). *Therapeutic exercise: Foundations and techniques* (6th ed.). Philadelphia, PA: F. A. Davis; and Whalen, L. R. (2014). *Assessing abilities and capacities: Range of motion, strength and endurance occupational therapy for physical dysfunction*. Philadelphia, PA: Lippincott WIlliams & Wilkins.

(Demeter & Andersson, 2002). The biomechanical approach considers structural stability, tissue integrity, ROM, strength, and endurance. However, if you have strength and good endurance but are clumsy, you will not be able to resume satisfying life roles in the community. When coordination is an intervention goal, it is usually included after increased range and strength and may be the responsibility of the client—as an outpatient or as a home health goal—because length of stay is so reduced in inpatient facilities.

Neurodevelopmental or sensorimotor approaches (neurodevelopmental treatment, PNF, Rood) are often cited as treatment approaches to use for deficits in coordination. However, the focus of these interventions is not directed toward the improvement of coordination. These approaches assume that good coordination will naturally follow if tone is remediated (Dutton, 1995). While neurodevelopmental approaches stress the sense of normal movement, these approaches are not designed to provide intervention directly for coordination training (Dutton, 1995).

Many structural systems are involved in coordinated movement. Guidelines for evaluation are varied and include the following:

- Assess tone and joint mobility.
- Observe the client's sitting position and locate any hypertrophied muscles.
- Observe for ataxia proximally to distally.
- Stabilize joints proximally to distally and note differences in performance compared to performance without stabilization.
- Observe for resting or intention tremors. Are the eyes and speech involved?
- Does the client's emotional status affect the incoordination?
- How does ataxia or incoordination affect function?

Table 12-11

Coordination Dysfunction and Associated Structures

Posterior Column Dysfunction	• Results in loss of proprioception, misjudgment of limb position, and balance	• Ataxia: Reeling, wide-based, unsteady gait • Romberg: Inability to maintain balance with eyes closed
Cerebellar Dysfunction	• Seen in regulation of loss of smooth voluntary movement and maintenance of upright posture	• Adiadochokinesis or dysdiadochokinesis: Inability or impairment in the ability to perform rapidly alternative movements • Dysmetria: Inability to estimate the ROM necessary to reach the target of the movement (e.g., touches cheek instead of nose); "overshooting" • Tremor: Intention tremor during voluntary movement intensified at the termination of the movement (often seen in MS); tremor is in proximal parts due to lack of stability • Nystagmus: Involuntary movement of the eyeballs up and down and back and forth or in rotary motion • Hypotonia: Decreased resistance to passive stretch • Dysarthria: Explosive or slurred speech • Rebound phenomenon of Holmes: Lack of reflex to stop a strong, active motion (e.g., therapist applies pressure in the direction of elbow extension, releases pressure, and arm rebounds toward flexion) • Asthenia: Weak and easily tired muscles
Basal Ganglia Dysfunction	• Functions in control of automatic, patterned movements of locomotion, and initiation of rhythmical movements	• Athetosis: Slow, writhing motion primarily in distal parts; lack of stability in neck, trunk, and proximal joints; excessive mobility with increased speed, but movement is involuntary and purposeless; not present during sleep • Dystonia: Form of athetosis, characterized by postures (e.g., lordosis); not present during sleep; bizarre writhing and twisting movements of trunk and proximal muscles of the extremities
Extrapyramidal Dysfunction	• The descending motor pathway is actively involved in the initiation and selective activation of movements, and their coordination	• Tremors: Resting tremors in pill rolling tremor in Parkinson's disease • Choreiform movements: Irregular, purposeless, coarse, quick, jerky, and dysrhythmic movements; may occur during sleep • Spasms: Involves contractions of large groups of muscles in arms, legs, and/or neck • Ballism: Rare; produced by abrupt contractions of axial and proximal musculature of the extremities, resulting in limb flying out suddenly; hemiballism = ballism on one side caused by subthalamic lesion on opposite side

There are many tests of coordination and dexterity. Many are standardized, and some are not (Table 12-12). As with any standardized test, it is important to administer the test exactly per protocols and to know with what population the test was standardized (e.g., norms for children ages 8 to 12 years would not be applicable to adults). Some coordination and dexterity tests use functional tasks. For example, the Jebsen Hand Function Test includes seven subtests (writing a short sentence, turning 3 × 5-inch cards over, placing small objects in a container, stacking checkers, simulated eating, and moving large cans that are light and those that are heavy). Some tools simulate ADL tasks, and others have functional tasks plus grasp and pinch evaluations. Some coordination assessments evaluate unilateral function, some only bilateral use of the hands, and some test both. Some tools evaluate gross coordination, fine coordination, or both (Levangie & Norkin, 2011; Pendleton, 2012; Radomski & Latham, 2014). Knowing the performance skills required by the client in daily activities will aid in the appropriate tool to use in assessment of coordination.

Treatment of coordination deficits may require several theoretic approaches. Lesions of the corticospinal system often use sensorimotor approaches to normalize tone and develop normal movement patterns. Normal motor learning to attain proximal stability then mobility and modulation of reflexes and synergies are also used, as are relearning of motor control mechanisms such as righting and equilibrium reactions.

Involuntary movements of cerebellar or extrapyramidal systems may be controlled pharmacologically to control tremors; weighting extremities with tremors is often suggested as a compensatory approach but is impractical in daily activities (Pendleton, 2012).

Table 12-12

Coordination and Dexterity Tests

Coordination Tests	Commercial Dexterity Tests, Work Samples, or Workstations
Block and Box Test	Baltimore Therapeutic Equipment Bolt Box and Assembly Tree
Minnesota Rate of Manipulation Test	Easy Street Environments
Jebsen Hand Function Test	Singer Work Samples
Crawford Small Parts Dexterity Test	Tower Work Samples
Bennett Hand Tool Dexterity Test	Skills Assessment Module
O'Connor Tweezer Dexterity Test	Coats Work Samples
Pennsylvania Bi-manual Work Sample	Bennett Hand Tool Dexterity Test
Purdue Pegboard Test	The Work System
Stromberg Dexterity Test	Valpar Component Work Samples
Nine-Hole Peg Test	Microcomputer Evaluation and Screening Assessment computerized screening tool
Moberg's Pickup Test	Philadelphia Jewish Employment and Vocational Service Work Sample System
Sister Kenny's Hand Function Test	Baltimore Therapeutic Equipment Work Simulator
Rebound Test	LIDO Work Set (Loredan Biomedical)
Finger–Nose Test	ERGOS Work Simulator (Work Recovery)
Finger-To-Finger Test	Jacobs Prevocational Skills Assessment
Heel–Shin Test	
Dysdiadochokinesia Test	
Disabilities of the Arm, Shoulder, and Hand	

Exercises for training coordination have the general goal of achieving multimuscular motor patterns that are faster, more precise, and stronger. Repetition is used, and the parts of the activity are broken down and attempted separately at first. Initially, the tasks are simple and slow, requiring the conscious awareness of the client. Frequent rests are permitted, and when the client can perform each step precisely and independently, the steps are made more difficult by grading for speed, force, and complexity (Pendleton, 2012).

Repetition and practice of functional tasks is often used, and the therapist can provide feedback to the client about performance (Shumway-Cook & Woollacott, 2000). Adaptation to tools and tasks, such as weighted utensils for tremors, is also used for some types of incoordination.

Endurance

Endurance is defined as "the ability to sustain cardiac, pulmonary, and musculoskeletal exertion over time" (AOTA, 1994). Endurance is the ability to maintain muscle actions for long periods of time, which requires a continuous restoration of energy resources (Cooper, 2007). Muscular endurance is the ability of an isolated muscle group to perform repeated contractions over time and plays a vital role in maintaining postural stability. Cardiovascular endurance is the repeated performance of large muscle exercise over time requiring adequate oxygen from the circulatory and respiratory systems (Kisner & Colby, 2012; Whalen, 2014). It would be reasonable to expect endurance limitations with clients who have deficits in local muscle metabolism (e.g., diabetes), cardiovascular system (e.g., congestive heart failure), respiratory system (e.g., emphysema), those on total bed rest 6 or more days, and in clients with paralysis (Dutton, 1995). Endurance may be limited due to activity restrictions, pathology of cardiac or pulmonary systems, or muscular diseases.

Endurance is influenced by three factors: muscle function, oxygen supply, and their combined effects. With cardiorespiratory dysfunction, breathing itself may be exhaustive. Cardiovascular function is a factor of fitness. This is the ability of the body to take in, transport, and use oxygen (Christiansen & Baum, 1997). Ways to assess cardiorespiratory function include the following:

- Pulse
- Blood pressure (hypertension, hypotension, postural hypotension)
- Respiration (rate, rhythm, and depth)
- Lung volume
- Vital capacity
- Pulmonary ventilation
- Cardiac output
- HR and rhythm

Minor adds that:

> [I]n the absence of pulmonary disease (e.g., chronic obstructive lung disease [COLD] or chronic obstructive pulmonary disease [COPD]), most of the limitation to endurance performance depends not on

> our ability to inspire and diffuse oxygen, but on the ability of the heart and circulatory system to deliver oxygen and cellular mechanisms to use the oxygen for energy production. (Christiansen & Baum, 1997, p. 261)

If there are disruptions in the blood supply, there is not nutrition or waste removal, resulting in reduced respiratory capacity and decreased endurance.

Cardiorespiratory decondition is seen in increased resting HR, decreased heart volume, loss of blood volume, decreased stroke volume, decreased cardiac output, decreased coronary blood flow, impaired orthostatic response, and diminished aerobic capacity. Clinical manifestations of cardiorespiratory deconditioning might include the following:

- Reduced exercise tolerance demonstrated by increased HR and respiration at low workloads
- Early onset of fatigue
- Exertional dyspnea
- Perception of doing heavy or maximal work at low to moderate loads
- Rise in HR and drop in blood pressure upon standing up (orthostatic hypotension), which produces syncope and fainting

Assessment of Endurance

The Borg rate of perceived exertion scale (Borg, 1985) is often used by the client to rate his or her perception of the level of intensity of the activity or exercise as well as the level of pain. While a subjective rating by the client, this scale is commonly used to rate angina, aches in muscles, levels of pain and exertion, and in exercise tolerance testing (Tan, 1998). The Borg CR10 category scale relates to verbal expressions to rate intensity. Ratings of 6 or less indicates no exertion at all, while ratings between 12 to 14 suggest activity at a moderate level of intensity, and 19 is considered extremely hard. There is a high correlation between the perceived exertion rating times 10 and the actual HR. If a person rates his or her level of exertion as 15, this is a fairly good estimate of an HR of 150 bpm (Centers for Disease Control and Prevention, 2015; Zamunér et al., 2010). Target heart rate range (THRR) is one way of monitoring aerobic activities. If the pulse rate exceeds the upper limit of the THRR, then the activity is too strenuous; similarly, if the HR is below the lower limits, then the intensity should be increased (Tan, 1998). Another way of monitoring endurance aerobic activities is to use the Karvonen formula (Rothstein et al., 2005), which is maximal HR - resting HR (40% to 85%) + resting HR = THRR.

Formulas have been developed to account for age differences as in the age-adjusted maximal HR, where the formula is (220 - age) (65% to 85%) = THRR. This formula is commonly used but is less accurate than the Karvonen formula.

It is the interaction of the cardiovascular and respiratory systems that influence endurance. A conditioned heart produces a greater cardiac output at a lower HR than the untrained heart. Less work results in lowered oxygen demand. Mean and peak HRs have been established for different types of jobs, which can be helpful in planning intervention (McKenna & Maas, 1987).

Muscular endurance is defined as the "ability to move a submaximal load repetitiously without degradation in performance" (Nyland, 2006, p. 181). Diminished muscular endurance may be due to inactivity, resulting in disuse atrophy. The deficits are most notable in the muscles of locomotion following bed rest and are associated with fast-twitch (type II) muscle fibers. Muscle endurance relies on the ability of the lungs, capillaries, and muscles to transport and uptake oxygen. The decreased maximal oxygen consumption is not only a consequence of diminished capacity of the heart to deliver oxygen, but also the result of the diminished capacity of the muscle to use oxygen. (Hamill et al., 2015). Tonic (slow-twitch) muscles primarily require oxygen from the vascular system, while phasic (fast-twitch) muscles require glucose for nutrition (Cooper, 2007). Each type of muscle will have enhanced muscular endurance when there is increased function of the cardiopulmonary system. Muscular endurance is measured by the number of repetitions that can be done per unit of time or by the amount of time a muscle contraction can be held (Sidebar 12-4; Whalen, 2014).

Sidebar 12-4 Increasing Endurance

To increase endurance, submaximal exertion will require adaptation to stress, resulting in hypertrophy and hyperplasia of oxidative type I (slow-twitch) muscle fibers and increased function in cardiorespiratory systems

Treatment of Decreased Endurance

To increase cardiorespiratory and muscular endurance, there must be stress imposed on the systems to facilitate adaptation. The overload principle is applicable, but the system needs far less than maximal stress applied. The amount of resistance varies according to different authors from 15% to 40% (Pendleton, 2012) of the RM to less than 50% of the RM (Radomski & Latham, 2014), or 60% to 90% of the maximum HR or 50% to 85% of maximum oxygen uptake.

The American College of Sports Medicine recommends light to moderate loads (40% to 60% of 1 RM) for at least 15 repetitions, with short rest periods to increase muscular endurance (American College of Sports Medicine, 2009).

Clients with very low endurance often resume activities based on metabolic equivalent (MET) levels. One MET equals the basal metabolic rate, which is the amount of oxygen necessary to maintain metabolic processes, such as respiration, circulation, peristalsis, temperature regulation, and glandular functions at rest. MET levels can vary according to humidity, temperatures, and emotion (Radomski & Latham, 2014). MET levels indicate endurance and activity tolerance, and these levels are often used in cardiac rehabilitation programs. By referring to a table, one can determine the energy required to complete specific activities. Energy is measured by the amount of oxygen consumed while engaged in activities as well as the oxygen required to maintain metabolic functions (Radomski & Latham, 2014). The higher the MET level, the more vigorous the activity.

Usually, endurance activities and exercises are designed to have less load for a longer duration (low load, high duration). These activities generally target the slow-twitch/type I muscle fibers. While there is less than maximal load, there must be some resistance, or adaptation will not occur. The probability that a client will engage in activities for a longer period is greatly enhanced if that activity is of interest and is meaningful because the client needs to sustain effort for increasingly longer periods of time (Smith, Weiss, & Lehmkuhl, 1996). For example, the client may play 2 hours of wheelchair basketball but only do wheelchair laps on a track for 30 minutes (Dutton, 1995).

To facilitate cardiorespiratory and muscular endurance, an activity should require rhythmic, dynamic contractions of large muscle groups (Christiansen & Baum, 1997). As with exercises and activities to increase strength, the intensity, duration, and frequency are carefully controlled. Gradations are based on the client's current level of function with gradual progression. It is important to note that mental fatigue can negatively impact submaximal endurance activities and exercise attributed to changes in perceived exertion rather than changes in physiological variables (Martin, Thompson, Keegan, Ball, & Rattray, 2015), so keeping the activity interesting or having exercise that is meaningful may influence the perceived level of exertion.

Warm-up and cool-down activities are recommended to diminish muscle cramping, soreness, and syncope. Activities and exercises involving excessive use of the arms overhead or those requiring sustained isometric contractions should be avoided because these tend to elevate the blood pressure without cardiovascular (aerobic) benefits. A general guideline of 20 full-range repetitions and sustaining the activity for at least 30 seconds done 3 to 5 times per week is suggested, but that is variable based on individual client abilities. The intervention goal is to increase the client's ability to perform repeated motor tasks in daily living and to carry on sustained levels of activity.

Long-term effects of greater endurance and cardiorespiratory fitness include decreased resting and submaximal HR, submaximal effort with increased peak blood pressure during maximal exercise, increased cardiac output, increased coronary blood flow, improved oxygen delivery, and decreased exercise recovery time (Hall & Brady, 2005).

Low-impact aerobic activities, such as a stationary bicycle, cycling, race-walking, calisthenics, swimming, aquatic exercise, rowing, hiking, and cross-country skiing, can be used for less-conditioned clients. High-impact activities for more well-conditioned clients might include jogging, running, volleyball, hopping, jumping, rope skipping, aerobic dance, and downhill skiing. Tai chi has been used to increase balance control, flexibility, and cardiorespiratory fitness in older clients (Hong, Li, & Robinson, 2000). These activities can be used to increase endurance and strength and can be incorporated into discharge plans for the client's continued wellness. Aerobic capacity training combined with muscle strengthening is recommended for clients with rheumatoid arthritis (Hurkmans, van der Giesen, Vliet Vlieland, Schoones, & Van den Ende, 2009).

The terms *tolerance* and *endurance*are often used interchangeably by therapists. For example, in documentation, it may be stated that a client has "increased sitting tolerance from 10 to 20 minutes." This ability to remain upright in the wheelchair has an influence on how well the client can feed him- or herself or work at a computer and can be linked to a functional long-term goal. Increases in the number of repetitions of an activity are indicators of increased endurance, such as increasing the number of spoonfuls per meal (Pendleton, 2012). The client is increasing aspects of endurance where the activities or exercises are being performed at less than maximal levels of intensity for increased periods of time or number of repetitions.

Clients with decreased endurance often have cardiopulmonary, cardiovascular, and musculoskeletal limitations, with serious precautions related to these conditions. Clients with cardiopulmonary diseases need to avoid isometric exercise because this type of muscle contraction increases the HR and blood pressure. Clients with asthma, pulmonary diseases, and shortness of breath may need to be referred to a physician if they have excessive coughing, wheezing, substernal chest lightness, and elevated respiratory rate. Symptoms of headache or blurred vision; pain in the chest, substernal, or left arm; lightheadedness; irregular heart rhythms; or uncontrolled hypertension are red flags for people with cardiovascular disorders. Diabetes clients may have hypoglycemic episodes characterized by shakiness, weakness, blurred vision, anxiety, confusion, and decreased cognitive ability and should be given a carbohydrate snack or protein and not begin aerobic exercise or activities. If a client has a hypercoagulable disorder or has been immobilized by best rest or casts (calf, thigh, arms, pelvis), he or she is at risk for deep vein thrombosis characterized by pain in the calf or thigh, swelling, and tenderness. If the thrombus has traveled to the right side of the heart to occlude a pulmonary artery, the client may have symptoms of pleuritic pain, shortness of breath, fast rate of respiration, and rapid pulse rate and may be coughing up blood. This is an urgent condition and needs immediate medical care (Hall & Brady, 2005).

Table 12-13 provides sample goal statements, principles for intervention, and treatment examples to increase endurance.

Table 12-13

INCREASING ENDURANCE INTERVENTION AND DOCUMENTATION

GOAL

Client will initially increase endurance (indicate level) to enable performance in tasks by using:

Method	**Principle/Rationale**	**Example**
• Increased duration • Increased level in a cardiac step program • Increased intensity • Increased repetitions	Which gradually stresses the cardiopulmonary system while ensuring rest	• Sitting tolerance in minutes • Tolerance for full evaluation • Standing instead of sitting to shave • Graduate to eating while sitting up in a chair • Cardiac target HR • Dress 10 minutes faster • Feed self an additional 10 bites of food • Walk 10 additional steps

GOAL

Client will maximize endurance (indicate level) to enable performance in tasks by using:

Method	**Principle/Rationale**	**Example**
• Increased duration • Increased level in a cardiac step program • Increased intensity • Increased repetitions	Which gradually stresses the cardiopulmonary system and local muscle metabolism of oxidative slow-twitch muscle fibers	• Increase the time involved in an activity (e.g., standing at table, completing a full meal) • Increase levels on MET of task charts • Perform activities at 50% to 70% maximum levels • Dress 10 minutes faster than baseline • Increase number of spoonfuls of food per meal • Increase the number of wheelchair pushups

Adapted from Dutton, R. (1995). *Clinical reasoning in physical disabilities*. Baltimore, MD: Lippincott Williams & Wilkins and Marrelli, T. M. & Krulish, L. H. (1999). *Home care therapy: Quality, documentation and reimbursement.* Boca Grande, FL: Marrelli and Associates, Inc.

Summary

- The biomechanical frame of reference is a remediation intervention approach. In this approach, there is an expectation of an improvement in a performance component that will lead to improved occupational performance.
- The biomechanical frame of reference focuses on musculoskeletal system functions that include strength, endurance, ROM, tissue integrity, and structural stability.
- Because this frame of reference focuses on the musculoskeletal system, physical fitness and health also are parts of this approach. Strategies to improve muscle function and ROM in those with activity and participation limitations also apply to those without restrictions as part of an overall health promotion objective.

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13

Rehabilitation Approach

Melinda F. Rybski, PhD, MS, OTR/L

Your client is unable to wash his or her face, brush teeth, apply makeup, and groom and style hair. This person is limited in the performance of personal hygiene and grooming skills. The meaning of this deficit is elucidated by the person and includes individual beliefs about hygiene, self-concept concerns, gender issues, and cultural requirements for appropriate grooming. An understanding of the typical roles, routines, rituals, and habits of this person is necessary to the performance of hygiene tasks for this individual. The person also needs sufficient range of motion (ROM), strength, trunk balance, coordination, cognition, vision, sensation, and muscle tone to accomplish the tasks associated with grooming. Characteristics about the task and level of skill involved also are a factor in the person's ability to engage successfully in hygiene tasks. The steps involved in the process, the time and timing required by the task, the hazards, and the types and characteristics of objects needed for each type of hygiene task may be the cause of the performance limitation. Finally, the environment may or may not be conducive for task completion. Perhaps the mirror is too high or the sink too low for ease of achievement of hygiene tasks. The role of the occupational therapist is to facilitate this person's performance in areas of occupation (in this case, hygiene) and to consider all aspects of the person, environment, and occupation.

The distinct value of occupational therapy in rehabilitation is to "improve health and quality of life through facilitating participation and engagement in occupations, the meaningful, necessary, and familiar activities of everyday life" (American Occupational Therapy Association [AOTA], 2016c, p. 1). By individualizing intervention, occupational therapy outcomes are meaningful for our clients, are cost effective, and have positive influence on health and well-being (AOTA, 2016c).

The rehabilitation approach is particularly useful for those clients with chronic diseases to enable individuals to participate in meaningful and productive activities of daily life (AOTA, 2015a). The ways in which occupational therapists use this compensatory and adaptation approach in chronic disease management may include:

- Teaching strategies to incorporate energy conservation and activity modification techniques into daily activities
- Individualizing adaptations to effectively perform health management tasks
- Teaching and incorporating health management tasks into existing habits so they become part of the daily routine
- Developing coping strategies, behaviors, habits, routines, and lifestyle adaptations to support physical and psychosocial health and well-being

Using the Person-Environment-Occupation (PEO) Model (Law et al., 1996) as a structure to conceptualize the process of occupational therapy, Figure 13-1 illustrates the relationship between the person, environment, and occupation in the ability to engage successfully in occupational performance (hygiene).

The biomechanical treatment approach (discussed in Chapter 12) provides intervention methods to restore or remediate client factors of strength, ROM, tissue integrity, structural stability, coordination, and endurance. These are aspects related to the "person" in the PEO Model. The question this chapter answers is, if ROM, strength, endurance, coordination,

Rybski, M. F.
Kinesiology for Occupational Therapy, Third Edition (pp. 367-438).

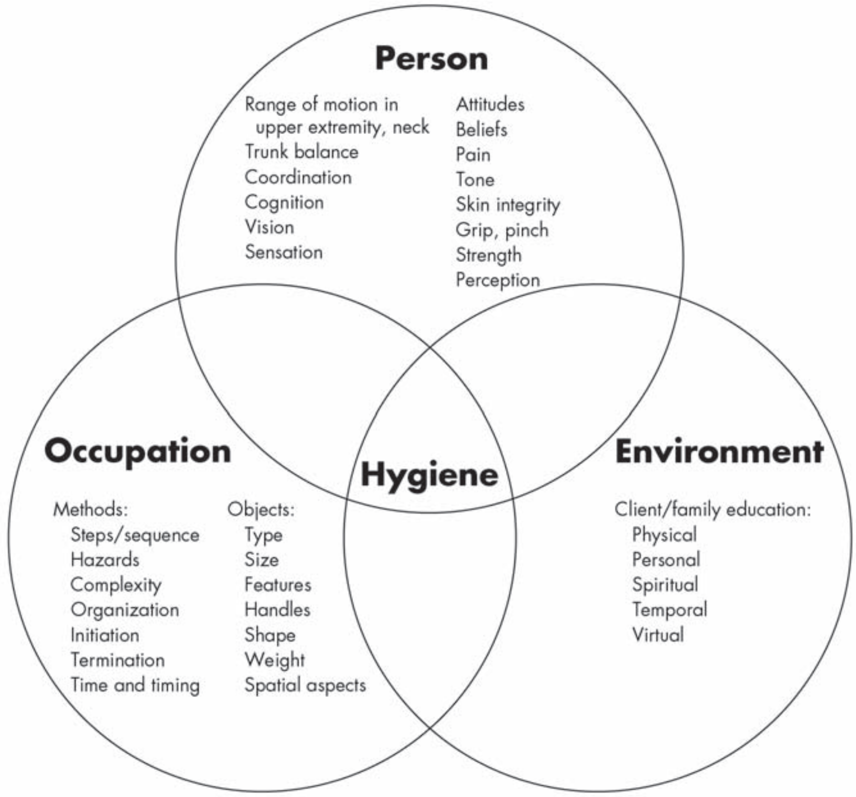

Figure 13-1. PEO analysis of hygiene.

tissue integrity, and structural stability cannot be regained through remediation intervention, then how can activities (occupation) or the context (environment) be modified to adapt to or compensate for these limitations?

Conceptual Background

The rehabilitation intervention approach is a compensatory and adaptation approach (Table 13-1). Often, this approach is used when there is little or no expectation for change or improvement in the performance skills and abilities or when there are residual impairments, and further remediation attempts are unproductive (Holm, Rogers, & James, 1998). When there is limited time for intervention or the client or family prefers a more immediate resolution to functional problems, rehabilitation approaches may also be used.

Compensatory and adaptive strategies are valuable when activity limitations and participation restrictions interfere with occupational performance and when there are problems of safety during occupational performance (Moyers, 1999). While some authors suggest that rehabilitation is a group of techniques rather than a theoretical approach (Dutton, 1995), this intervention approach has been used extensively in occupational therapy since the beginning of the practice of the profession.

This approach capitalizes on the client's abilities. The focus of this approach is not on the client-level impairment but on the client's ability to participate in areas of occupation. For this reason, this approach is considered a top-down approach where occupational performance is the first consideration, and factors that influence performance are secondary. The focus of this approach is successful accomplishment of activities of daily living (ADL), work tasks, and play and leisure pursuits rather than specific changes in anatomical, physiological, or psychological attributes. Rather than trying to restore skills that are impaired, changes are made to the task (e.g., adapt the method or task object) or to the environment (e.g., environmental modification, caregiver education).

In a top-down hierarchy, the intervention steps are to first identify the environmental demands and resources of the individual. What aspects of the context (including temporal aspects such as time and disability status) and environment (physical and social aspects) are important variables to this person? It is imperative to ask the client and caregiver about the volitional and habitual subsystems. What does the client want to do? What does the client usually do? What does this person need to do to successfully engage in desired roles? How important are specific activities to this person? After gathering this information, an evaluation of the areas of occupation (ADL, instrumental activities of daily living [IADL], rest and sleep, education, work, play, leisure, and social participation) is completed to determine the functional capabilities of the individual. Prerequisite skills that the client lacks and task demands are compared with intervention aimed at matching the compensatory or adapted method with the prerequisite skills that the client lacks. Some authors indicate that, in the rehabilitation approach, the client needs to acquire the ability to set his or her own life's direction, control it, and take

Table 13-1

APPROACHES TO INTERVENTION

Occupational Therapy Framework
↓
Theory
↓
Intervention Approaches

Create/Promote	*Remediate*	*Maintain*	*Compensate*	*Prevent*
	Cognitive Behavioral		Cognitive Behavioral	Cognitive Behavioral
		Cognitive Disabilities	Cognitive Disabilities	
	Neurodevelopmental			
	Proprioceptive Neuromuscular Facilitation			
	Biomechanical	Biomechanical		Biomechanical
	Sensory Integration			
	Psychodynamic		Psychodynamic	
		Rehabilitation	Rehabilitation	

Note: Lighter text indicates a secondary emphasis in intervention.

responsibility for it with the acquisition of an attitude of independence as a basic part of the theoretical base.

The rehabilitation approach is often used after restorative approaches in treatment of sensorimotor aspects has occurred or can be used concurrently with restorative approaches. Intervention often uses restorative methods initially, especially with neuromuscular diagnoses, in which the first 4 to 6 weeks are critical to the recovery of function. Compensation and adaptation rehabilitation techniques are seen as abnormal movement patterns in some neurodevelopmental treatment (NDT) and motor control approaches and are viewed as conflicting with remediation efforts (Pal, 2003).

The rehabilitation intervention approach is also used with clients in whom there is a need for immediate success in occupational performance to sustain motivation for rehabilitation or if there are problems of safety during occupational performance (Holm et al., 1998; James, 2008).

The rehabilitation approach is an "occupation-as-end" intervention, where the focus is on adapting the task and/or environment and may include various educational aspects for the client and family (James, 2014). As a collaborative learning process, factors such as readiness to learn and positive self-efficacy are important in the interaction between the client, therapist, task, and environment. The client takes an active part in identifying and setting goals and deciding what routines and skills are needed. This enhances problem solving, increases ownership of the problem and solutions, and enhances self-efficacy (James, 2014).

The client must have an awareness of the problems interfering with performance and use this information to know how and when to adapt the task or environment or use new devices. The client must be able to make these accommodations in different situations and places and without therapist cues. This requires learning or relearning skills needed for engagement in areas of occupation.

Teaching and Learning

In this intervention approach, occupational therapists teach clients, families, and caregivers. Clients and their families learn new ways of performing daily tasks, how to do common activities with new tools, or relearn skills that have been lost.

Theories of Learning

How learning occurs and what factors are involved in learning vary based on the theory used to explain learning. The behaviorist theory, developed by John B. Watson, includes theorists Edwin Ray Guthrie, Clark L. Hull, Ivan Pavlov, B. F. Skinner, and Edward Lee Thorndike. This model assumes that observable behavior is the focus of learning. It is a stimulus-response theory of learning where the environment shapes behavior (not factors within the individual). Reinforcement and the time between stimulus and response are the major ways that learning occurs. In this approach, it is important to structure the environment to control the learning that occurs (Merriam & Caffarella, 1999).

The cognitivist theory is helpful in that this approach has developed theories about transfer of knowledge (theorists: David Ausubel, Jerome Bruner, R. Gagne, Kurt Koffka, Wolfgang Kohler, Kurt Lewin, and Jean Piaget). The focus is on memory and metacognition and how to acquire different types of knowledge because the locus of control is within the individual learner. The learner's needs and learning style are considered, and perception, insight, and meaning are important parts of learning. Learning involves the reorganization of experiences to make sense of information from the environment (Merriam & Caffarella, 1999). The therapist using this approach would structure the content of learning activity to facilitate memory and transfer of knowledge.

Carl Rogers and Abraham Maslow considered the affective as well as cognitive dimensions of learning in the humanist theories. The client-centered therapy is often equated with the student-centered learning espoused by this theory. The focus of this approach is on the individual who has potential for growth and self-development. Behavior is not predetermined by either the environment or one's subconscious, but is the consequence of choice. Humans can control their own destiny, and people are expected to assume responsibility for their own learning.

Social learning theories combine elements of the behaviorist and cognitivist approaches. People learn from observing others, and these observations take place in a social setting. Therefore, learning involves both imitation and reinforcement (theorists: Albert Bandura and Julian Rotter). Learning is influenced by attention, retention, behavioral rehearsal, and motivation and involves both the individual and the environment. Learning occurs by the process of socialization, social roles, mentoring, and locus of control.

The constructivist theorists assert that learning is a process of constructing meaning, and this occurs at personal and social levels (theorists: John Dewey, Jean Lave, Jean Piaget, and Lev Vygotsky). Learning involves practice, and practice provides a history of the learning (Merriam & Caffarella, 1999). Experience provides a resource and stimulus for learning because, due to experiences, cognitive conflict or shared problems or tasks encourage learners to develop new knowledge schemes. Learning is a process of constructing meaning and is how people make sense of their experiences. Experiential learning and self-directed learning is how learning occurs. Reflective practice, associated with the constructivist theories, is postulated to be part of the mechanism in the progression from a novice to expert clinician.

Different theoretic conceptual understandings of learning can be used with different types of clients. A client with traumatic brain injury may require a very structured environment initially to decrease outside distractions to enable occupational performance, which would be consistent with the behaviorist approach. The meaning of the activity is important to all theories except the behaviorist approach, so occupational therapy's emphasis on meaningful and purposeful activity; role of the environment; and interaction of person, environment, and occupation seem well-suited to the use of the cognitivist, humanistic, social learning, and constructivist theories of learning.

Research about learning has debunked three common myths about learning. First, learners are not blank slates who are waiting to receive knowledge passively. Our clients come to us with experiences and knowledge. To gain new knowledge, the new knowledge must be used and manipulated in such a way that enables the new knowledge to fit with the old knowledge schemata. This requires motivation and practice. Learning takes work. Second, learning is not merely a behavioral process of stimulus-response (as proposed in the behaviorist theory). In much of the learning we do, there is not a right or wrong answer. Learning is not a simple process. Third, learning is not independent of the context in which it is learned. The learning process is deeply embedded in the setting, which provides critical cues for performance (Shotwell & Schell, 1999).

Application to Practice

When thinking about teaching new skills to your client to adapt or compensate for performance limitations, you need to consider the client's readiness for learning. What are the specific learning needs of this individual? What is this individual's focus of learning? How does this individual learn, and has this style changed? Consider the client's preferred modes of information processing when presenting new information.

Start by understanding the client's goals as this enhances learning because it reflects a valued skill. How well does this individual currently perform the skill, and how confident is the client in his or her ability to change skill performance? Self-efficacy is positively linked to performance and persistence in task performance (Gage & Polatajko, 1994; James, 2008), so if the client feels unable to change, that may need to be addressed first. Depression can influence the individual's belief in self-efficacy, and this is an area that is more difficult for cognitively impaired clients or those experiencing intractable or chronic pain. Other issues affecting the teaching-learning process are language and literacy.

Feedback to the client about performance is another variable affecting learning. Extrinsic feedback, provided by the therapist, is useful until the learner understands the movement, skills, or strategy required (Flinn & Radomski, 2008). Providing feedback either as a summary of the performance or gradually by decreasing the timing of the feedback is more effective than immediate or constant feedback. "Bandwidth feedback" (Goodwin & Meeuwsen, 1995) is feedback that is only provided when a skill is not performed within an acceptable range. Intervention should focus on decreasing the amount of extrinsic feedback provided by the therapist and increasing the client's perception, understanding, and realization of his or her own performance and reliance on intrinsic feedback. Having the client perform the skill in the normal context and experience the consequences in a safe way is a way of receiving natural feedback.

Considering the stage of learning of the client may facilitate client-centered motor learning and what intervention will be most successful. Initially, the client may be in the contemplative stage (Fitts & Posner, 1967), in which there is an awareness of the problem. The next stage, determination, is when the client resolves to do something about the problem. For both stages, verbal intervention is appropriate as the therapist and client collaboratively consider the components of the task, task sequence, and critical cues (Flinn & Radomski, 2008). Action is necessary for the next two stages. In the action stage of learning, the client works to address the problem. The final stage, maintenance, is the effort required to maintain the newly learned or relearned skill. To acquire the skill, the client does more than simple repetition; he or she needs to be attentive and interested in the task. This again stresses the importance of collaboration with the client in identifying and

Table 13-2

Teaching Strategies

1. Identify client needs, goals, and preferred learning styles.
2. Determine potential barriers to learning.
3. Evaluate current skills and potential barriers.
4. Use a collaborative approach to enhance the learner's participation, trust, and progression from extrinsic to intrinsic feedback.
5. Individualize the learning process to the learner's capabilities, and provide the "just right" challenge.
6. Provide opportunities for active learning and practice.
7. Present learning in real contexts with common objects.
8. Arrange practice environments to reflect skill objectives of automaticity, transfer of learning, or generalization.
9. Test the client's learning by requiring the task to be done independently or in the appropriate time and place.
10. Collaboratively discuss progress and revise learning plans with the client.

working toward improved performance in occupational tasks that are meaningful to the person.

Contextual characteristics include the client's length of stay; environment (physical, social, cultural); and relationship between context, person, and occupation. The length of stay may suggest different learning strategies that would be more successful given temporal restrictions. An understanding of the expected environment provides information about the critical aspects of the task and cultural meaning to the client. Structuring the environment for optimal learning would include having the client perform tasks in a pleasant, authentic, and natural way (MacRae, 2010).

Use real task objects in real task situations (Ma, Trombly, & Robinson-Podolski, 1999; Wu, Trombly, & Lin, 1994). Tasks encountered in the environment must include the typical challenges in a graded way so the client can verbalize steps, perform the task, and receive feedback about performance. This is the "just right" challenge. Because you are collaborating with the client in shared goals, this provides a cohesive and safe environment for the client to learn new skills.

Task-specific outcomes are achieved when skills are acquired within the same context in which they will be used. Having a client practice hygiene skills in the bathroom in the morning is a task-specific skill if this is the way the client has previously done the task and will do it in the future. The client can perform this skill in a consistent environment and a consistent sequence to develop routines and habits that can be performed automatically.

Task skills can be learned by performing the skill in a consistent sequence but by varying the environment. This will enhance skill transfer to different contexts. Varying both the task and environment provides the learner with general strategies that can be used in different situations. Generalization is often the intent of teaching adapted techniques to clients. Teaching a person with quadriplegia how to transfer from the mat to the bed can be generalized to transferring to and from other surfaces. Table 13-2 summarizes the teaching strategies presented.

Assumptions

One assumption of this frame of reference is that the ability to function is essential to well-being and that there are secondary benefits to be gained by improving performance despite physical, cognitive, psychological, or social dysfunctions (Turner, Foster, & Johnson, 1996). Humans can adapt to their limitations by learning new methods of doing activities, responding to new teaching processes, and using adapted objects and environments to their advantage. Clients are capable of capitalizing on their strengths as a healthy means of compensating for their limitations.

See Table 13-3 for a summary of the adaptation process.

Through adaptation and compensation, clients can regain meaning and resumption of roles and a sense of purpose. Motivation for independence is based on the client's personal, cultural, temporal, and virtual contexts and environments (physical and social). The individual's involvement in choosing methods to improve daily life activities is also seen as an important part of the rehabilitation collaborative intervention approach. Use of compensatory strategies can facilitate integration of the client into the family, community, and previous life roles.

Function and Dysfunction Criteria

The theoretical base of the rehabilitation frame of reference is in medicine, education, and the physical sciences. Function is the ability to maintain oneself and take care of others and the home; the ability to advance oneself through work, learning, and financial management; and to enhance the self through self-actualizing activities. This would necessitate certain levels of motor, sensory, cognitive, intrapersonal, and interpersonal subskills and role-relevant behaviors. Function is the ability to engage in constructive activity successfully along a continuum of independence.

Dysfunction is the loss of the ability to maintain and care for oneself, others, and the home. It is the loss of the ability to

Table 13-3

ADAPTATION PROCESS

1. Analyze activity demands, including performance and contextual demands.
2. Identify the problem.
3. Know principles of compensation for the given limitation (e.g., long-handled utensils for decreased ROM).
4. Creatively apply principles of compensation to solve the problem.
5. Select appropriate adapted methods and assistive devices, and specify environment adaptation to implement the solution.
6. Check out all modifications to verify that they solve the problem.
7. Train in safe use of the assistive device or modified environment.

Adapted from James, A. B. (2014). Restoring the role of independent person. In M. V. Radomski & C. A. T. Latham (Eds.), *Occupational therapy for physical dysfunction* (7th ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

advance oneself through work or learning, the loss of financial management, or the loss of participation in self-actualizing activities. While function occurs through normal development, dysfunction occurs through degenerative disorders, disease, or trauma (problems in structure or function). Table 13-4 provides a summary of the focus, assumptions, function/dysfunction, expected outcomes, and methods used in the rehabilitation intervention approach.

Strengths and Limitations

Some merits to this intervention approach are that it is widely documented and extensively used. The foundational concepts are easy to explain to the client and caregiver with intervention and are often visual, concrete, and with rapid results. A range of options are available and can be easily matched to the needs of the individual. There is no rigid sequencing of intervention steps, and the rehabilitation approach can be used to meet short-term needs as well as to compensate for permanent deficits. Often, the adapted methods require creative and innovative solutions to meet the specific needs of the individual.

Because the rehabilitation approach is associated with the medical model, there may be the tendency to be reductionist and use recipe-like thinking rather than clinical reasoning to evaluate the range of intervention options. For example, one may be tempted to provide a long-handled sponge to all clients with total hip replacements without evaluating the actual need for the device or usability and acceptability of the device to that specific individual. The match between the person, occupation, and environment will prevent provision of equipment that is unwanted, unused, or unnecessary.

Often, by providing adapted equipment or by teaching a modified technique, intervention can be relatively inexpensive and rapid. While this is a definite advantage to this approach, it is truly advantageous only if the intervention provided is what the client really needs and not just done because it saved time and money or was at the expense of a more in-depth evaluation of the client and his or her unique situation.

Some clients may refuse to participate in compensatory or adapted techniques or use of special equipment or tools because the use of the device forces recognition of loss of function. An understanding of the client's psychological adjustment to these losses is essential. Depression has been found to be a strong predictor of rehabilitation failure. An attitude of assertiveness and self-efficacy is helpful in adjustment, as is a high frustration tolerance and the ability to understand and learn new ways to do things.

Being able to understand abstract concepts, such as joint protection or safety precautions, is important in independent living. Use of Allen Cognitive Levels as a guide to determining the level of cognition required for learning new methods or the use of new devices can be helpful: in Level 4, it is recommended that a caregiver be trained; at Level 5, clients are unable to implement abstract procedures; and at Level 6, it is important to stress problem solving rather than attempting to train the client in every possible means of compensation via rote learning (Dutton, 1995). The strengths and limitations of the rehabilitation approach are shown in Table 13-5.

The therapists' role is to help the client identify goals, routines, and skills that are needed for optimal occupational performance and to determine the best teaching process for the client. Collaboratively, the therapist and client determine the best method for performing a task. The occupational therapist will design, construct, recommend, make or order, and train in the use of the adaptive equipment needed for successful task completion.

The therapist provides intervention that is at the "just right" level for the client, provided at a level at which the client can best benefit and at the appropriate time and place for that task. Learning is embedded in the context and opportunities for feedback are provided. Adaptations to the home, work site, or school will be collaboratively decided upon by the therapist, client, family, and others. Identification of community resources is also an important part of the rehabilitation process in returning the client to his or her home environment and in enabling the client to assume responsibility for his or her own health and well-being.

Table 13-4

Rehabilitation Approach

Focus

- Top-down approach
- Evaluation of the performance areas of work, play, and self-care
- Identify environmental demands and resources
- Focus on the client's strengths and ability to participate in areas of occupation
- Little or no expectation for change or improvement in impairments
- Focus on context, activity demands, performance patterns, activity limitations, and participation restrictions

Assumptions

- The ability to function is essential to well-being.
- Motivation is based on the client's values, roles, and context.
- There are secondary benefits to improving performance.
- Humans can adapt to their limitations and capitalize on their strengths.
- Through adaptation and compensation, clients can regain meaning, resumption of roles, and a sense of purpose.

Function

- To maintain oneself, take care of others and the home
- The ability to advance oneself through work, learning, and financial management
- To enhance the self through self-actualizing activities

Expected Outcomes

- Learning new skills or use of devices to resume life roles
- Maintaining or improving quality of life
- Prevention of disability
- Enhanced self-efficacy and satisfaction with performance
- Improved adaptation to occupational challenges

Methods

- Changing the task via:
  - Adapted task methods or procedures
  - Adapting the task objects, adaptive devices, or orthotics
- Changing the context via:
  - Environmental modification
  - Training the caregiver or family
  - Mobility adaptations
  - Disability prevention

Table 13-5

Strengths and Limitations of the Rehabilitation Approach

Strengths

- Widely documented
- Extensively used
- Concepts easy to explain
- Intervention often visual, concrete
- Range of options available; can be easily matched to the needs of the individual
- Intervention results may be rapid

Limitations

- May have the tendency to be reductionistic
- Needs full analysis of need of device or method matched with person, environment, and occupation
- Not appropriate for clients with impaired cognition
- Seen as conflicting with other types of intervention
- Need to understand what the changes mean to the client (psychologically, socially, culturally, etc.)
- Transfer and generalization may not occur

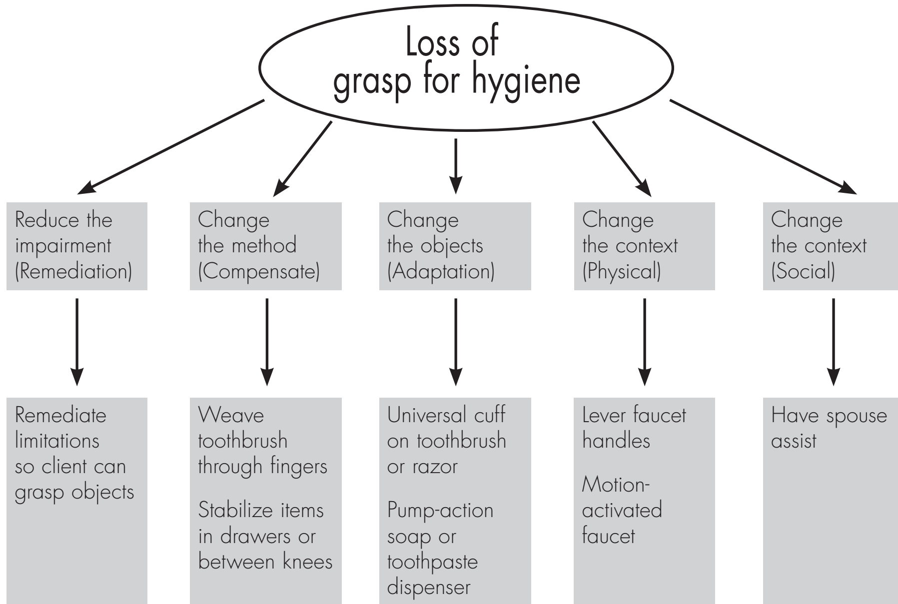

Figure 13-2. Intervention approaches for loss of grasp needed for hygiene tasks. (Adapted from Moyers, P. A. [1999]. Guide to occupational therapy practice. *American Journal of Occupational Therapy, 53*, 247-322.)

In Figure 13-2, five different strategies are proposed for intervention of loss of grasp needed for hygiene tasks. Deciding what approach is most appropriate requires a clear analysis of hygiene tasks (occupation), of the client (person), and of the context in which the tasks usually occur (environment). Understanding the task characteristics (tools used, time requirements, space, etc.) is necessary to ensure that the individual's skills can be matched to the task. Table 13-6 provides a partial analysis of hygiene tasks in general and possible adaptations that might be possible. Not all suggestions apply to all hygiene tasks, and suggested strategies do not include all functional limitations.

An assessment of the client's skills would involve looking at body structures and functions to ascertain if limitations in client factors are influencing task performance.

Remediation approaches would be appropriate if there is an expectation of improvement in the limitation and if restoration of the anatomical, physiological, or psychological attributes would result in improved occupational performance. If remediation is not possible, progress has plateaued, or more immediate results are desired, rehabilitation approaches would be used. These adaptations replace normal function or compensate for abnormal function.

Safety considerations may be due to client factors (e.g., poor judgment, impulsiveness, tremors), hazardous tools or methods (e.g., razors), or environmental constraints (e.g., inadequate space or lighting). Education is the fifth approach represented in Table 12-4 in which family members and the client are taught ways to enhance performance and, at times, the caregiver may even perform the task in lieu of the client. A task as seemingly simple as brushing teeth or applying makeup, when viewed from the PEO perspective, requires much analysis of the component parts.

Rehabilitation intervention involves:

- Changing the task via:
  - Adapted task methods or procedures
  - Adapting the task objects, adaptive devices, or orthotics
- Changing the context via:
  - Environmental modification
  - Education for the client and caregiver

Changing the Task

Modification and adaptation may be made by altering the way the task is done or by changing the objects used to match the task to the abilities of the client. Increasingly there are apps being developed to help with various aspects of daily living and for specific diagnostic categories. For example, Autism Reading Room (http://readingroom.mindspec.org/?page_id=10606) is a list of applications for clients with autism in developing social skills, language, home routines, self-care, and problem solving. Other links offer lists of downloadable apps on a variety of topics useful for our clients (https://ios.lisisoft.com/t/functional-skills-system.html; http://www.friendshipcircle.org/blog/2011/02/23/11-social-skills-life-skills-apps-in-ipad-app-store/; https://www.pinterest.com/cmcormier/apps-functional-life-skills/?lp=true). The AOTA website is a useful resource for application recommendations (https://www.aota.org/Practice/Rehabilitation-Disability/RDP-apps.aspx). Many YouTube videos provide excellent examples of adapted techniques used for dressing, mobility, and other aspects of ADL and IADL tasks.

Table 13-6

Analysis of Hygiene Tasks and Related Rehabilitation Intervention Strategies

Activity Limitations (Unable to)	Impairment in	Safety Considerations	Adapted Task Method	Adapted Task Objects	Adapted Context	Educated Client and/or Caregiver Will:
• Reach face, all areas of head • Reach faucet • Pick up/hold/ manipulate tools and utensils • Use both hands simultaneously • Attend to activity • Locate needed items • Use items appropriately • Reach sink, mirror • Initiate tasks • Complete tasks • Perform tasks due to pain	• ROM in upper extremity, neck • Trunk balance • Coordination • Cognition • Vision • Sensation • Perception • Upper extremity, lower extremity • Grasp, pinch • Pain control • Tone • Joint precautions • Wound healing	• Bathroom layout • Caregiver availability • Equipment use • Compliance with precautions • History of falls • Judgment • Medication • Sensory status • Sharp and potentially dangerous tools and utensils	• For decreased ROM: ∘ One arm assists the other if unilateral deficit ∘ Use mouth to open containers ∘ Stabilize items in drawers or between knees ∘ Use nonskid surfaces ∘ Grow a beard • For decreased strength and grasp: ∘ Use tenodesis grasp ∘ Weave utensils through weak fingers ∘ Use of dynamic or tenodesis splints • For decreased stability: ∘ Stabilize items in drawers or between knees ∘ Use nonskid surfaces • For decreased coordination: ∘ Rest elbow on counter for distal stabilization	• For decreased ROM: ∘ Splints for positioning hand ∘ Pump-action containers of soap, toothpaste ∘ Sponge with strap ∘ Long-handled sponge with or without strap or universal cuff ∘ Suction sponge ∘ Built-up handles • For decreased strength and grasp: ∘ Splints for positioning hand ∘ Pump-action containers of soap, toothpaste ∘ Soap on a rope ∘ Flip-top lipsticks ∘ Electric toothbrush ∘ Wash mitt ∘ Adapted nail clipper ∘ Adapted deodorant ∘ Universal cuffs for utensils and tools • For decreased coordination: ∘ Use weighted tools and utensils ∘ Use electric razor, toothbrush	• Store items in accessible locations • Store items in a basket or plastic container to be transported easily • Remove cupboard doors for wheelchair access • Locate mirror for easy viewing • For decreased strength and grasp: ∘ Mount hairdryer or use stand so no need to hold ∘ Single-lever faucets • For decreased stability: ∘ Provide chair to sit and do tasks	• Demonstrate adapted task methods • Demonstrate use of adaptive equipment • Assist with the tasks

Adapted from Holm, M. B., Rogers, J. C., & James, A. B. (1998). Treatment of occupational performance areas. In M. E. Neistadt & E. B. Crepeau (Eds.), *Willard & Spackman's occupational therapy* (9th ed., pp. 323-363). Philadelphia, PA: Lippincott Williams & Wilkins and James, A. B. (2008). Restoring the role of independent person. In M. V. Radomski & C. A. T. Latham (Eds.), *Occupational therapy for physical dysfunction* (6th ed., pp. 774-816). Philadelphia, PA: Lippincott Williams & Wilkins.

Adapted Task Methods

Altering the task method involves teaching the client new, more efficient, and more effective ways to complete a task using skills that closely correspond with the client's remaining capacities (Sidebar 13-1). Use of client skills and abilities in which there are no deficiencies is the aim in the adapted task method. Because the client is changing a method and doing a daily task in a new way, the client must have a sufficient capacity for new learning as well as adequate time for supervised practice of the new skill. Often, the change in method depends on the application of abstract concepts that may be difficult for cognitively impaired clients in addition to requiring changes in established habits.

Sidebar 13-1 Changing the Task: Adapted Task Method Principles

Adapting task methods substitutes for loss of ROM, strength, use of one side of the body, limited vision, impaired cognition, decreased endurance, inadequate stability, or to minimize the effects of spasticity.

Changing the method that one uses to put on a shirt or the way one eats requires motivation by the client and/or caregiver to learn the new method and to apply the new method to the task (Moyers, 1999). This may be a change in the routine or habit that the client has consistently and repeatedly performed in the same way for many years, and performing the task in a different way may be difficult for the client. There is often ambivalence about adaptive devices that can enhance physical independence but at the same time elicit feelings of vulnerability and debility. Devices or new task methods may not be used due to denial, embarrassment, or social stigma (Oakes, 2013).

Altering the task method may require modifications of techniques, learning new skills, or transferring existing skills to new situations. An example of a modifying technique is having a client, who has experienced a cerebrovascular accident resulting in a paralyzed arm, put the affected extremity into the shirt first and then dress the unaffected arm. A "trick" movement may be used by a client with C6 quadriplegia who extends and locks the elbow and externally rotates the shoulder as a compensatory movement for the loss of triceps function to maintain balance in sitting. Learning to use gravity as an assist rather than as a force to overcome is an adaptive technique, as is changing body mechanics or leverage used in activities so that they work to the client's advantage (e.g., letting gravity pull the forearm down to extend the elbow when there is paralysis of the triceps muscle). Adapting the method in which daily activities are done can result in successful performance of the task that is safe and efficient. For example, when taught to sit while bathing, 82% of the clients reported that the adapted method permitted independent function that was safe (Chamberlain, Thornley, Stow, & Wright, 1981).

Ways of altering task methods are numerous, flexible, and easily personalized. The collaboration between client and therapist can result in creative, individualized, and unique solutions to client functional problems. When the client is successful in performing the task, this enhances self-confidence and self-esteem. Modifying the procedure is usually cost effective with long-term effectiveness. Another advantage to altering the task method is that the changes made in how the task is done are rarely visible, and this may be more acceptable to clients (Dutton, 1995).

While this is an advantage to some, to others, the lack of external prompts as reminders is a disadvantage. Disadvantages to changing the task by altering the procedure are that this requires new learning and a change of habit. The client and/or caregiver must be motivated and committed to making this change in daily activities.

The adaptations made for an individual client are based on the unique characteristics of that person, his or her goals, the expected environment, and the specific tasks that person needs and wants to do. The adaptations are limited only by the collaborative creativity of the therapist and client. Table 13-7 provides suggestions for changing the methods and task objects for a variety of client limitations.

Some specific methods useful to both clinicians and a wide variety of clients are energy conservation and work simplification. These guidelines are applicable to many different tasks and diagnoses.

Energy Conservation

Energy conservation principles are designed to be used to decrease fatigue and increase participation in activities. Decreased energy can occur due to chronic illness, such as arthritis, asthma, diabetes mellitus, Parkinson's disease, and low back pain. Strokes and spinal cord injuries can make doing daily activities more time consuming and physically taxing, resulting in increased fatigue.

The major concepts of energy conservation are shown in Sidebar 13-2. Having the client stop an activity when he or she is in pain is an important way to decrease fatigue. Not only might the pain restrict activity participation today, but it may also limit activities later in the day or the next day.

Sidebar 13-2 Energy Conservation Principles

Respect pain.

Rest frequently.

Prioritize activities.

Avoid sustained, static positions, or isometric muscle contractions.

Consider the environment.

Planning regular rest periods throughout the day also helps to conserve energy. Using a planner or calendar will help to avoid overscheduling on any one day or week. Alternating difficult tasks with easier tasks helps to maintain vigor throughout the day. Avoid too much or too little activity by balancing tasks with rest. Pacing is also important, so allow for sufficient time to complete a task without rushing.

Have the client prioritize the activities that really need to be done, and delegate difficult tasks if necessary. Eliminate unnecessary tasks, or combine tasks to reduce work. Combine or delegate tasks to reduce work. Plan ahead so that all materials are available for the task prior to starting the activity.

Table 13-7

Rehabilitation Intervention Strategies for Various Limitations

Limitation	Activity	Adapted Method	Adapted Objects
Limited strength	• Eating	• Weave utensil through the fingers • Table at axilla height to support the arm; this eliminates the force of gravity so one with elbow flexors 3 or 3+ can bring food to mouth	• Universal cuff • Spork • Lightweight, enlarged utensils • Serrated or rocker knife • Cup with D-shaped handle • Powered feeders available • Mobile arm support or suspension sling
	• Grooming	• Lengthen lever arm relative to resistance arm via adapted sprays (e.g., deodorant) and nail clippers and file	• Pump dispensers • Universal cuff for toothbrush, comb, hairbrush, razor • Hook-and-loop fastener cuff to adapt electric razor • Friction material to reduce force to hold
	• Toileting	• Catheters • Bowel program	• Raised toilet seat • Drop-arm commode
	• Bathing	• Terrycloth bathrobe rather than toweling off	• Transfer tub seat • Grab bars • Handheld shower head • Lever faucet handles • Nonslip material on bottom of shower or tub • Soap on a rope or pump dispenser • Electronic bath lifts
	• Dressing	• Spinal cord injury, dress lower extremity in bed, upper extremity in wheelchair • Hands/thumb in pockets to pull up pants	• Loop sewn into socks for absent pinch • Universal cuff with buttonhook or built-up handle • String to pull zipper • Adapted clothing commercially available • Slightly larger clothing items including shoes • Slip-on shoes or do-not-tie laces • Elastic laces or one-handed lacing • Replace closures with Velcro (including bras) • Keep bra hooked, and pull on
	• Holding a book	• Audiobooks	• To help turn pages, eraser tip or rubber thimble on splint or use a pencil in universal cuff • Electric page turners • Mouthstick with friction tip
	• Writing		• Typing stick, mouthstick, eraser in universal cuff • Voice recognition software • Pencil holder, made or purchased • Felt-tipped pens, little pressure
	• Opening containers		• Rubber sheets • Jar openers • Ask for non-childproof medication containers

(continued)

Table 13-7 (continued)

Rehabilitation Intervention Strategies for Various Limitations

Limitation	Activity	Adapted Method	Adapted Objects
	• Phone use		• Typing stick, mouthstick, eraser in universal cuff • Speaker phone • Speed dial, favorites • Virtual assistant
Limited ROM	• Feeding	• Joint protection techniques	• Enlarged or elongated utensils • Angled utensils (the longer the handle, the heavier and less stable) • Universal cuff • Electric feeder
	• Grooming	• Caregiver assists with washing and styling hair • Simple hairstyle	• Enlarged or elongated utensils
	• Toileting	• Bidet or personal cleansing system • Tissue around hand for poor grasp	• Wiping tongs • Dressing stick to manage clothing • Raised toilet seat
	• Bathing		• Tubseat • Handheld shower • Grab bars • Walk-in tub • Lever faucet handles • Soap on a rope • Bath mitt • Long-handled bath sponge
	• Dressing	• Do not wear some items of clothing (e.g., bra, socks) • Button or zip items easier than pull-over for limited upper extremity ROM • Velcro in lieu of any fasteners	• Dressing stick • Reachers • Stocking aid • Long shoe horn • Elastic laces
	• Writing		• Built-up handles or commercial grips
	• Phone use		• Speaker phone • Cordless phone; larger cell phone • Virtual assistant • Hands-free phone
Loss of use of one side of the body	• Feeding	• Caregiver assistance	• Rocker knife • Spike board • Adapted cutting board

(continued)

Table 13-7 (continued)

Rehabilitation Intervention Strategies for Various Limitations

Limitation	Activity	Adapted Method	Adapted Objects
	• Grooming	• Spray deodorant for unaffected hand is easier • Electric razor	• Suction brush to clear fingernails of unaffected arm, clean dentures • Stabilized nail clipper for affected hand; stabilized emery board to move unaffected nail across • Pump toothpaste
	• Toileting	• Hand in pocket or belt loops to prevent pants falling below knees or on floor • Toilet paper on unaffected side	• Grab bars • Toilet seat with frame/arms
	• Bathing	• Lower part of unaffected side bathed by putting soapy washcloth across knees and rubbing arm back and forth	• Long-handled sponge • Pump bottles of soap and shampoo • Tub seat
	• Dressing	• Affected extremity on first	• Velcro fasteners
	• Writing	• Stabilization of paper with affected hand or object or tape	
Low or decreased vision	• General concepts	• Contrast through better lighting or color • Reduce glare • Use auditory or tactile cues (e.g., raised mark on dryer setting, talking clock)	• Enlarge objects • Magnification
	• Feeding	• Consistent orientation of food on plate • Insert finger while pouring liquid • When cutting, keep knife in contact with fork • Plate, utensils, glass contrasting color with table coverings and food	
	• Grooming	• Consistent placement of objects • Identify items by touch • Talking bar code scanner	
	• Dressing	• System to coordinate colors and styles • System or assistance to identify stains	
	• Writing and reading	• Black felt-tipped pen on white paper • Audiobooks	• Online periodicals and newspapers can be enlarged with screen magnifier
Decreased or impaired sensation	• Bathing and grooming	• Adjust hot water heater to no more than 120°F (49°C) • Shower faucets to set temperature • Test temperature on areas of intact sensation	• Wheelchair users can insulate pipes under sinks
	• Dressing	• Compensate visually	

(continued)

Table 13-7 (continued)

REHABILITATION INTERVENTION STRATEGIES FOR VARIOUS LIMITATIONS

LIMITATION	ACTIVITY	ADAPTED METHOD	ADAPTED OBJECTS
Incoordination and poor dexterity	• Feeding	• Stabilize plate on friction surface or damp towel • Avoid soup, foods with sauces, peas	• Plate guard • Scoop dish • Weighted utensils • Enlarged handles • Plastic-coated utensils protect teeth • Covered cup or use straw with straw holder
	• Grooming	• Stabilize arm on wall or surface • Simple hairstyle • Stabilize emery board to surface and move hand • Cutting nails done by someone else	• Weighted cuffs • Stick deodorant rather than spray • Electric razor • Electric toothbrush is heavier and can be held steady while moving head
	• Dressing	• Front opening, loose fitting with large buttons, Velcro closure or zippers are easiest • Sports bra • Keep tie-knot loose, then don and adjust • Slip-on shoes	• Button hook with enlarged and/or weighted handle • Loop on zipper pull • Velcro on bra • Shoe horn • Elastic laces
	• Bathing	• Terrycloth bathrobe rather than drying off	• Nonslip on tub • Grab bars • Tub bench • Soap on a rope • Bath mitt

Avoiding positions that are particularly stressful, such as overhead postures or sustained positions, also helps to decrease fatigue. Sitting requires less energy than standing, and if prolonged standing is necessary, shift positions frequently, rest one foot on a footstool or raised surface, and alternate foot placement every few minutes.

Consider the environment as a potential cause of stress and strain because loud, crowded, poorly lit, smoky rooms are factors that can lead to fatigue. The level of noise and impact of the environment on individual stamina varies from one person to another.

Bunyog and Griffin (2007) conducted workshops on energy conservation with people aged 66 to 93 years and found that bathing and toileting activities were the most fatiguing, followed by dressing. After the workshop, the levels of fatigue decreased significantly in all areas, particularly grooming, washing dishes, and shopping.

There is strong evidence in the efficacy of energy conservation programs that looked at changes in fatigue, self-efficacy, and quality of life (Mathiowetz, Matuska, & Murphy, 2001; Matuska, Mathiowetz, & Finlayson, 2007; Vanage, Gilbertson, & Mathiowetz, 2003); reduction of energy expenditure (Ip et al., 2006); and managing fatigue in individuals with multiple sclerosis (Mathiowetz, Finlayson, Matuska, Chen, & Luo, 2005; Matuska et al., 2007).

Various methods of presenting the energy conservation principles to people have been used. Gerber and colleagues (1987) used a workbook to convey the information, resulting in behavior changes, decreased pain and fatigue, and increased participation and rest. Using phone conference calls did not seem to be an effective way to teach people about these principles (Finlayson, 2005), and the use of an educational behavioral program did not result in significant differences between the experimental and standard groups, although further study was recommended (Furst, Gerber, Smith, & Fisher, 1987).

Work Simplification

Work simplification techniques are related to energy conservation, and the use of these strategies also results in decreased fatigue (Sidebar 13-3). Often, energy conservation and work simplification are used together, and the principles have some overlap. Related to both energy conservation and work simplification are joint protection techniques. These techniques can be considered adapted ways of doing activities and often are used to prevent disability.

Sidebar 13-3 Work Simplification Principles

Organize storage.
Plan ahead.
Easy flow of work.
Eliminate steps or tasks.
Use efficient methods.

Organizing storage by having similar items placed together eliminates unnecessary steps and movement to retrieve items from outlying areas. For example, have canisters of flour and sugar near the mixer in a baking center in the kitchen. Organize heavier items on lower shelves to minimize overhead lifting, which is often a safety issue as well. Keep items used frequently at waist height.

Planning ahead distributes the more strenuous tasks throughout the week so work can be easier, and energy can be conserved. This will limit the amount of work at any one time and, if the task is too difficult, it can be delegated to others. Big tasks can be broken down into smaller parts so sufficient time and energy can be devoted to the entire task over time. Making a grocery list, arranged according to item placement in the store, makes grocery shopping easier and makes meal preparation more efficient because all ingredients are available with fewer trips to the store. Shopping when the stores are less crowded and when assistance is more available will help to avoid crowds and a rushed, noisy environment. Pacing again can be useful so that important tasks can be completed before fatigue sets in.

Having an easy flow of work simplifies work. An analogy of easy flow of work can be applied to how your automobile operates. When you drive your car on the highway at a constant rate, there is less wear and tear on the mechanical parts of your car, and you get better gas mileage. Compare this to driving in the city, where there is stop-and-go driving. This is harder on your car, and you get much less mileage per gallon of gas. A functional task can be done in a smooth flow of work by being organized, planning ahead, and having sufficient time to complete the task. Examples of having an easy flow of work would be to lay out hygiene articles in the order in which they are used (e.g., soap, towel, clothing) or items needed in a cooking task (e.g., cutting board, knife, salad bowl, lettuce, tomatoes, salad dressing, salad tongs).

There are some tasks that the client may not even need to do. Elimination of tasks is a way to simplify work. While this is not always possible, minimizing steps to a task also can make the task easier. Purchasing permanent press shirts and wrinkle-free clothes eliminates ironing, and letting dishes air-dry or using a dishwasher eliminates steps by adapting how these tasks may be done. Leaving a tie knotted and then just pulling it over the head eliminates the need for tying, and using premeasured laundry detergent can eliminate steps and conserve energy.

The use of efficient methods also simplifies work. Sitting to iron or cut vegetables is a way to conserve energy while being more efficient. Use both arms whenever possible and slide rather than lift objects. A wheeled cart can transport objects in the kitchen or laundry room, and using electric appliances is often more efficient. Making a bed can be done more efficiently by only going around the bed once. Start by smoothing the sheets and covers at the head of the bed on one side. Next, walk to the foot of the bed, and smooth covers there. Finally, walk to the other side of the bed, and smooth the covers toward the head of the bed on that side. Using a ping pong paddle or yardstick to tuck in the sheets can also be done to minimize reaching (Jacobs & Jacobs, 2009).

Of the methods included in energy conservation and work simplification programs, the strategies used most often were changing body position, planning for rest periods, adjusting priorities, and reducing frequency of or simplifying work. Least-used strategies were changing the time of day to do an activity and using adaptive equipment (Matuska et al., 2007).

The next sections will address adaptations made for clients with specific limitations in physical function. The specific examples presented are not meant to be an exhaustive list of all possible adaptations that can be made to the ways we do everyday activities. Whole textbooks are devoted to presenting numerous options for techniques if one has weakness on one side, as occurs with a stroke, or weakness or paralysis in all four extremities, as may occur with a spinal cord injury. These examples are either commonly encountered or are considered representative of adaptations that are encountered in practice.

Range of Motion

Problems associated with decreased ROM involve being able to reach objects or body parts or being able to have sufficient ROM to grasp and use objects. For example, decreased shoulder ROM may result in the inability to reach back to put on a coat or to reach up to put dishes away in a kitchen cupboard, and decreased grasp would prevent holding a hairbrush. Often, adaptations are made to the objects used in task performance for limited or impaired ROM, but some ideas for changing task methods are:

- Wrap toilet tissue around the hand so grasping is not necessary during toileting.
- Use garments with zippers and fasteners in the front, which may be easier to don, rather than pullover garments.
- Slip-on shoes are easier to don/doff for individuals with decreased ROM.
- An extra wide base of support (BOS) is a helpful position to assume to prevent slacks and underpants from dropping to the floor when readjusting clothes after toileting.
- An extra broad BOS while seated on the toilet may help to prevent imbalance or falls.
- Some clients opt to eliminate wearing underwear not only because of the difficulty of donning/doffing, but also because of potential skin breakdown in areas that are insensate.
- A change in toileting habits may occur by using a bidet or personal cleansing system.
- Changes in grooming methods might be to simplify the hairstyle and makeup routines, use a beauty salon, or grow a beard.
- It may be desirable to have a caregiver wash and style hair or to have a simple haircut.

- After a shower or bath, instead of drying off with a towel, have the client don a terrycloth bathrobe.
- Child care may be more difficult with decreased ROM, and keeping the child in close proximity will facilitate tasks.
- Feeding a child in an infant seat or propped on pillows and using clothing with elastic and large closures are some considerations for child care.
- Online shopping eliminates the need to travel to a store.
- Shopping when stores are not busy may make the task easier.
- Raised flower beds and using low-maintenance plants are ideas to make gardening feasible.

Specific joint mobility restrictions may also apply, such as after joint replacement surgery. Precautions for clients with total hip replacement are designed to reduce the possibility of hip dislocation during the first 10 to 14 days following surgery. While individual orthopedic surgeons may have slightly different preferences, the following are guidelines generally accepted for clients following total hip replacement surgery: do not bend the trunk more than 90 degrees; do not reach past the knees; do not cross the ankles or legs when sitting, laying, or getting in/out of bed; and keep legs apart when lying in bed and toes pointed toward the ceiling. There are similar postoperative restrictions for other joint replacements, which may vary from one facility or from one surgeon to another. Activities such as dressing, perineal care, and bathing may need to be modified to adhere to these precautions.

Decreased Strength in All Four Extremities

Adapted procedures and methods that substitute for loss of strength reflect the principles of letting gravity assist, using the mechanical principles of levers, using increased friction to decrease power requirements, and using two hands (James, 2014). Some general adapted methods that can be used due to decreased strength are to teach the client to use the muscles that are intact or stronger to perform tasks. For example, use the strength in the arms and legs to push up to get out of a chair if there is weakness in the lower extremities or trunk. When getting on/off the toilet, put one hand on the counter and one on a thigh to push up to a standing position to help support the spine and body weight. While standing at the sink, use one hand to support the body and to avoid bending.

Lessen the force demands of activities to accommodate weaker muscles. Consider storing a 5 pound bag of flour in more than one canister so lifting the canister requires less strength. Use this same principle for items in all areas of the house (e.g., kitchen, closets, bathroom, garage, basement) and for a variety of tasks (e.g., laundry detergent in one-load sizes). Placing a table at axilla height to support the arm and eliminate force of gravity may enable a client with elbow flexors with muscle grades of 3 or 3+ to move food from a plate to the mouth.

Using both hands to do tasks also is a method to compensate for decreased strength. It is easier to push than to pull objects because pushing uses the muscles in the legs and back and produces better posture.

Weakness can be restricted to only one part of the body (e.g., only one hand) or may affect all four extremities (e.g., spinal cord injuries). The suggestions presented are for those clients with more pervasive loss of strength but also apply to clients with less severe losses. The adaptations presented can be generalized from the specific categories to similar client factor and performance skill deficits that may not have been presented. For example, in clients with weakness in all four extremities due to multiple sclerosis, some of the adaptations for the spinal cord–injured client may also apply.

Adapted methods to compensate for loss of grasp may be accomplished by wedging or weaving utensils (or even some finger foods) or tools between tight fingers. Normally, when the wrist is actively extended, the fingers are passively flexed. If the fingers of a client with quadriplegia are allowed to develop some finger flexion tightness, then by using this tenodesis grasp, the client can pick up light objects and hook the wrist behind the wheelchair upright to help compensate for decreased trunk strength. The tightened hook grasp can also be useful in hooking fingers on the edge of a transfer board for sliding board transfers.

The following descriptions of dressing and mobility describe how these activities could be done for a client with a C6 spinal cord lesion. A client with a C6 level of spinal cord injury has weakness in wrist flexion, elbow extension, and hand and grasp, and paralysis of the trunk and lower extremity. Consider the consequences of these patterns of weakness on the ability to dress independently. First, the client will need to learn new ways of moving in bed, coming to a seated position, and rolling from side to side to don pants. Lower extremity dressing will be done in bed to take advantage of gravity, use of two hands, and momentum. Bed mobility is a necessary prerequisite for lower extremity dressing in bed.

Bed Mobility With Decreased Strength in All Four Extremities

Mobility training follows a hierarchical pattern, beginning with bed mobility. Clients then practice mobility skills with mat transfers, wheelchair transfers, and progressing to functional ambulation for ADL tasks. Toilet and tub transfers are the next type of mobility in the sequence, followed by car transfers, community mobility, and driving (Pierce, 2014).

Many activities require adaptation in the way that they are done if there is weakness in all four extremities. Some clients will require assistance with bed mobility where the caregiver will roll the client's body at one time with the client assisting as possible (log roll). Bed mobility will require altered methods to roll from side to side and to come to a sitting position. Rolling is made easier if the hands can be clasped together and the legs crossed prior to beginning the roll. To return to supine from sidelying, extend the wrist, lock the elbow in extension, and force the left shoulder back toward the bed (Pierson, 1994).

Clients with weakness of all four extremities may need to hold onto a bedrail or use a rope ladder attached at the side of the bed, a trapeze bar overhead, or the arm of a wheelchair placed next to the bed in order to roll from side to side. To use these devices, the clients need good scapular, elbow, and shoulder strength. They may need to grasp or hook their extended wrist or flexed elbow on these items if there is a decreased grasp.

Coming to a sitting position when there is weakness of all four extremities can be achieved by doing the following:

- Rolling to one side (e.g., right)
- Flinging the top arm (left) backward to rest the elbow on the bed, having momentum assist with the body motion

- Rolling onto the left elbow, and quickly flinging the right arm back to rest the palm of the hand or fist on the bed
- Rolling to the right and quickly move the left arm to rest the hand on the bed
- Having achieved a semi-sitting position resting on both hands, with the elbows extended or locked, the client "walks" his or her hand forward to come to a forward-leaning position of greater than 90 degrees of hip flexion to maintain balance

Clients at the C6 spinal cord level can be taught to use their scapular muscles and external rotators to perform the motions of shoulder external rotation and scapular elevation and depression to compensate for the lack of triceps so that the client can move forward in the bed. Using shoulder muscles to substitute for triceps paralysis will enable the client to engage in activities, such as moving up to a sitting position or transferring via a sliding board to a wheelchair.

An alternative way to come to a sitting position might be for the client to do the following:

- Place the hands under the hips or in pockets for stabilization.
- Flex the neck and elbows until weight is on the elbows.
- Shift the elbows backward, one at a time, until weight is on the forearms.
- Fling one arm backward, laterally rotating and extending the shoulder and elbow until the heel of the hand contacts the mattress (the interphalangeal joints should be flexed).
- Come to sitting by shifting weight onto the extended arm and repeat this with the other arm.
- Gain balance with weight on both extended arms.
- Walk hands toward the hips.
- Using a rope ladder, overhead loops, or a trapeze can also assist with coming to a sitting position.

Once in a seated position, the client needs to learn how to maintain balance while in a long-sitting position on the bed. Bedrails, an overhead trapeze, and learning to balance on extended locked arms will help to compensate for the lack of trunk musculature. The client needs to learn how to regain the upright position after leaning forward, often by leaning over and using the bedrails, flexing the arm, and pulling back up into a seated position. These are additional prerequisite skills to be learned before lower extremity dressing. Adjustable, electric hospital beds make the task of bed mobility easier for clients with weakness of all four extremities.

Dressing With Decreased Strength in All Four Extremities

Many conditions and diseases may result in weakness or paralysis in all four extremities. Adapted dressing methods will be discussed for both the upper and lower extremities.

Lower Extremity Dressing. Minimum criteria for lower extremity dressing would include (Pierson, 1994):

- Muscle strength fair to good in the pectoral muscles, rhomboids, supinators, and radial wrist extensors
- ROM: Knee flexion and extension 0 to 120 degrees to permit sitting with legs extended; hip flexion 0 to 110 degrees
- Body control, such as the ability to transfer from bed to wheelchair with minimum assistance, the ability to roll from side to side, and balance when sidelying

In a seated position, the client will position the pants using adaptive equipment or by placing the pants between both hands and extending the wrists (motions available at C6 level and below) to hold and pull the pants into position. By hooking an extended wrist under the distal thigh, the leg can be pulled over, or momentum can carry the legs. The foot is inserted into the pants, and the pants are pulled to knee height. Repeat with the second foot so that both pant legs are at knee height or higher. An alternative method is to have the client cross one leg over the other, insert the foot into the pants, and return the leg to the extended position. Repeat on the other side. At this point, the client will need to return to supine.

The client will insert the wrist into a pocket or under the waistband to pull the pants up, rolling from one side and then to the other to pull the pants up over the buttocks. Momentum can be gained by rolling back and forth using proximal musculature and head when the trunk muscles are affected. Once the pants are pulled up to the waist, adaptations to clothing (e.g., hook-and-loop fasteners) or adapted devices (e.g., zipper pull, string/embroidery floss on zipper) will complete the lower extremity dressing.

Different types of clothing may be more difficult to don than others. While pants with elastic in the cuffs and waistband (e.g., sweat pants) initially seem easier to put on, sometimes pulling them up over the buttocks proves to be discouraging because the elastic will pull the pants back down if not pulled up far enough. Another disadvantage is that there may not be pockets in which to insert the wrists when pulling the pants up, but the waistband is usually sufficient.

Stiff clothing (e.g., blue jeans) has some unique challenges. It is difficult to pull jeans up against cotton sheets. Silky material slides easier on sheets. The most difficult aspect about jeans is fastening the metal button. The button is usually larger than most button hook devices, so many clients opt to leave it unbuttoned or remove it completely. If the skin is insensate, the double seams on jeans may cause skin breakdown if the pants are too tight. Clothing that is slightly larger is easier to don, is less constrictive, and is less likely to cause skin irritation.

Many people choose not to continue wearing undershorts or underwear for several reasons. One, this would be one more piece of clothing to put on in the morning. Dressing is very energy-consuming, and if it takes more than 1 hour to complete, it is not considered functional (James, 2008). A second reason for not wearing undershorts or underwear is that this is an additional potential source of skin breakdown. Clients should be cautioned to wear larger clothing that is loose fitting and that does not bind or impinge the skin. A final reason might be that the undershorts may interfere with the client's bowel and bladder programs.

Upper Extremity Dressing. Adapted techniques for clients with weakness in all four extremities require that certain levels of performance be met as prerequisites for dressing. The following are the minimum criteria for upper extremity dressing (Colenbrander & Fletcher, 1995):

- Neck stability is medically cleared.
- Muscle strength is fair to good in shoulders (deltoid, trapezius, serratus anterior, rotators) and elbows (biceps).
- Shoulder flexion and abduction 0 to 90 degrees, external and internal shoulder rotation 0 to 30 degrees, and elbow extension and flexion 15 to 140 degrees.

- Sitting tolerance and sitting balance in bed and/or wheelchair achieved with assistance of bed side rails or wheelchair safety belts.

Upper extremity dressing can be done seated in a bed or in a wheelchair or chair. Clients at the C6 spinal cord level lack triceps function and are unable to extend the elbow. The functional implications are that, whenever the arm is brought to heights above the shoulder, the elbow will flex due to the pull of gravity. This use of gravity as an assist is very helpful when dressing and is a good principle of intervention.

For a client with shoulder and scapula muscles, elbow flexion, and wrist extension, the process of putting on a cardigan or button-up shirt is similar to the customary method of dressing. Put one arm into the shirt, using wrist extension under the material or in the armhole to pull it up over the elbow and up to the shoulder.

A very useful muscle action added at the C_6 level is that of wrist extension due to the innervation of the extensor carpi radialis longus and brevis muscles (radial wrist extensors). The addition of wrist extension is very helpful when trying to dress because the client can use an extended wrist in the sleeves and pant legs to assist with putting on the clothing. Two wrists extended and placed with palms together can hold clothing to pull it on or to straighten a shirt or blouse.

Licking the heel of the hand helps to provide friction to aid in pushing the material toward the shoulder. The client can reach around for the armhole and insert the other arm. Balance can be maintained in the wheelchair by hooking the elbow around the wheelchair upright push handle. This positioning permits increased reach without loss of balance. Using both wrists in an extended position, hold the collar and adjust the shirt so the shirt fronts are aligned. Use adapted equipment (e.g., buttonhook device) to button the shirt.

Putting on a bra is much the same procedure as putting on a cardigan as described previously. It is easier to hook the bra in the front with the bra at waist level and then pull the straps up over the shoulders. Adaptations such as sewn loops or hook-and-loop fasteners will enable independent fastening by the client.

An alternative method to putting on a cardigan would be to place the shirt on the lap, collar facing toward the legs. Place one hand into the sleeve, shaking the sleeve to help move it along the arm. Push the heel of the hand along the outside material of the sleeve to push the sleeve up to the elbows. Clients often use their teeth to assist with this, and licking the heel of the hand helps as well by providing a friction surface. At the axillary border of the sleeve (where the sleeve is sewn to the body of the shirt), have the client extend the wrist and pull the sleeve up over the shoulder. Putting the shirt material between the heels of each extended wrist also helps in pulling the shirt front down.

Have the client hook the arm with the shirt sleeve pulled up to the shoulder over the upright push handle of the wheelchair for balance. The client can then lean forward and insert the other arm into the remaining armhole. Pull the arm through the sleeve. Using both extended wrists, straighten the shirt by putting shirt material between the heels of both hands. A summary of adapted dressing methods is shown in Table 13-8.

There are some contraindications relative to upper and lower extremity dressing. Decreased breathing capacity and decreased vital capacity (below 50%) may prevent individuals from performing lower extremity dressing activities, but they may be able to do upper extremity dressing. Ischial tuberosity decubiti ulcers or for clients with a high frequency of skin breakdown during rolling and transfers may be a contraindication for lower extremity dressing. If the client experiences pain in the neck or trunk, then dressing activities should be discontinued (Pierson, 1994). If the client is continually resistant to dressing practice, you need to ascertain if this is a valued goal for this person. If not, then a caregiver or aide needs to learn the most efficient ways to assist with dressing.

Decreased Use of One Side of the Body

Consider a client who has paralysis due to a stroke. The limitations will be primarily limited to one side of the body, including the arm, leg, and trunk muscles. There may be tone limitations ranging from total flaccidity to spasticity; there may be no volitional movement or a gradual return of function beginning at the shoulder and scapula and ending with grasp and release. Greater volitional control and less tone problems will enhance task performance.

The difficulty in completing self-care tasks with the use of only one side of the body is in stabilization of items used in the task and in completing tasks on the unaffected side. Dressing for a client with loss of function on one side of the body generally follows the pattern that the affected extremity is dressed first and undressed last. When putting on a shirt, the overhead method is seen as less confusing for clients with sensory and perceptual impairments, often common sequelae following a cerebrovascular accident. This overhead method, however, is cumbersome for dresses and not possible for use with coats, so training in both methods is often necessary. Both methods are described in Table 13-9, as are methods for donning trousers, shoes, and socks. The table describes how a person with a left cerebrovascular accident with resultant right-sided weakness or limitation would dress. One-handed shoe tying or slip-on shoes are examples of adaptation methods for footwear.

Clients with loss on one side of the body will be able to roll toward the affected side but will have greater difficulty rolling toward the unaffected side. To roll to the unaffected side from supine, the client places the unaffected foot under the affected leg, then slides the legs to the edge of the bed. Using the unaffected arm, the client carries the affected arm across the body, and then pulls him- or herself over onto the unaffected side by holding the side of the bed. An alternative method is to have the client clasp both hands together with the thumb of the affected hand above the sound one, elbows extended, and shoulder flexed above 90 degrees. The client then swings the clasped arms side to side to build momentum, which will carry him or her onto the side.

Either method can be carried to the next step or that of coming to a sitting position. Once rolled onto the side, with the unaffected arm, the client pushes against the bed while swinging the legs over the side of the bed to come to a sitting position. An alternative to crossing the affected leg over the unaffected is to bring the unaffected leg over the edge of the bed while simultaneously pushing against the bed with the unaffected arm. The affected leg will follow, and the client will be in a sitting position. In either case, it is important to roll all of the way onto the side before pushing to sit up, as this will

Table 13-8

Adapted Dressing Methods: Bilateral Upper Extremity Weakness

Putting on a Cardigan Garment

This method may be adapted for jackets, blouses, sweaters, shirts, and top portion of dresses that open down the front.

1. Client is sitting in a wheelchair or chair.
2. Position the shirt on the lap with the back of shirt up and collar toward the knees. The label of the shirt is facing down.
3. Put arms under the shirt back starting at the shirt tail and into the sleeve starting at the armhole and working toward the cuff. Push the shirt past the elbows.
4. Using wrist extension, hook the hands under the shirt back and gather up material.
5. Using shoulder abduction, scapular abduction and adduction, elbow flexion, and slight neck flexion, pass the shirt over the head.
6. By relaxing the wrist and shoulders, and with the aid of gravity, the hands may be removed from the shirt back. The arms are now completely through the sleeves. Most of the material of the shirt is gathered up at the back of the client's neck across the shoulders and underarms.
7. The shirt is worked into place over the shoulders and trunk by alternately shrugging shoulders, leaning forward, using aid of wheelchair arms for balance if necessary, and using elbow flexion and wrist extension.
8. Close the shirt using buttons, snaps, or Velcro. If the shirt has not been buttoned previously, use a button hook, starting with the bottom button, which is easier to see.
9. Exceptions to this procedure would be as follows:
   - Arrange the shirt on a table prior to putting the shirt on.
   - When trunk stability is a problem, support the elbows on a table to assist in flipping the shirt over the head.

Removing a Cardigan Garment

1. Client is in a wheelchair or chair. Unbutton only the necessary buttons. Use a buttonhook, if necessary.
2. Push one shoulder of the cardigan at a time off the shoulder. Elevate and depress the shoulders, rotate the trunk, and use gravity so the cardigan will slip down the arms as far as possible.
3. Use thumbs alternately in the armholes to slip the sleeves farther down the arms.
4. Hold one cardigan cuff with the opposite thumb and flex the elbow to pull the arm out of the garment. Repeat for the other arm. The thumb is used as a "hook" in this step.

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help to position the arm to push up and will create less strain on the back. Once positioned at the side of the bed, the client can prepare to pivot transfer to a wheelchair or use a cane or walker for ambulation.

Clients who have experienced a loss of ROM and strength on one side of the body (e.g., stroke) can use the unaffected arm and leg to independently propel a wheelchair. Using the affected hand to hold or be placed on objects can also be helpful for stabilization. For example, when writing, the affected hand can be placed on the paper to hold it during the writing process. Different ways of performing the everyday activities of cutting meat, opening packages, and brushing teeth can be accomplished with little or no extra equipment or devices. Taping a nail file onto a table for filing nails or placing a jar inside a drawer to stabilize it are two alternative methods for everyday tasks. After toileting, use a wide BOS while standing to pull up pants to prevent pants from sliding down or put the affected hand in the pants pocket.

Child care by one who has one functional upper extremity or impairment of one side of the body would be facilitated by propping an infant on pillows for ease or placing the child in an infant seat. If the client can get up off the floor, dressing the child may be easier done seated on the floor. A hook-and-loop fastener strap is helpful on a dressing table to secure the baby during clothing changes, and suction-based bath seats are useful for bathing, again for stabilization.

A final suggestion about adapting methods for all tasks is to determine the tasks that the client is able to do and wants to do and then decide which tasks can be delegated to others.

Mobility

Prior to beginning any type of transfer, it is important to know the client's strengths and limitations in all areas of function, including physical, cognitive, visual, perceptual, and levels of assistance required with current mobility. Be aware of medical precautions. Be able to identify any line or tubes that may be attached to the person (e.g., IV lines), and be knowledgeable about the purpose of the line and precautions related to movement.

Table 13-9

Adapted Dressing Methods: Loss of the Use of Right Side of the Body

Putting on a Pullover Shirt

1. Begin sitting with the shirt in the lap, backside up, and neck away from the body (label is facing down).
2. With the left hand, gather up the back of the shirt to expose the right armhole.
3. Using the left hand, lift the right hand and place it through the armhole and sleeve.
4. Place the left arm through the left armhole and sleeve up to the elbow.
5. Using the left hand, push the right sleeve above the right elbow.
6. Gather the back of the shirt from collar to hemline.
7. Continue holding the shirt, and work the shirt up both arms toward the shoulders.
8. Duck the head, and pull the shirt over it.
9. Pull the shirt down in back and front.

Putting on a Cardigan Garment

1. Begin sitting with the shirt in the lap, inside up, and collar away from the body.
2. Using the left arm, place the right hand in the right armhole (the armhole is diagonally opposite the arm).
3. Pull the sleeve over the hand, grasp the collar, and pull the sleeve up onto the right shoulder.
4. Toss the rest of the garment behind the body.
5. Reach the left hand back and place it in the armhole.
6. Work the sleeve up the arm, and straighten the shirt.
7. Button the shirt (easier to start from bottom).

(continued)

Anticipate any safety issues in the environment, and ensure that adequate space for the transfer is unencumbered by electric cords, excessive furniture, or equipment. Review the transfer to preplan the transfer setup, being sure that transfer surfaces are level and even. Explain these planning steps to the client and caregiver so that generalization of learning can occur, and transfers can be safely executed in a variety of contexts.

You also need to be aware of your own strengths and limitations and freely ask for help with transfers when needed. Use proper body mechanics when assisting with transfers, and train caregivers to use these as well.

Table 13-9 (continued)

Adapted Dressing Methods: Loss of the Use of Right Side of the Body

Putting on Trousers

1. Begin sitting on the side of the bed.
2. Using the left hand, cross the right leg over the left.
3. Check to see that trousers are opened completely.
4. Grasp the trousers at the bottom of the front opening and toss down toward the right foot.
5. Pull the right trouser leg up and over the right foot.
6. Place the right foot on the floor, and put the left leg in the other trouser leg.
7. Pull the trousers up over the knees.
8. Lie down, bend the left hip and knee, push against the bed, and raise the buttocks.
9. Pull the trousers over the hips; fasten. If able to stand, omit step 8 and pull the trousers on while standing; sit to fasten the trousers.

Putting on Socks

1. Cross the leg, and pull on socks with the left hand.

Putting on Shoes or Orthoses

1. Sew the tongue to the top of the shoe at one side to prevent it from doubling over.
2. If a brace is attached to the shoe, be sure that the leg is in front of the brace when putting the shoe on.
3. Begin sitting on the side of the bed with the right leg crossed over the left.
4. Slip the shoe on the foot as far as possible.
5. Place a shoehorn in the heel of the shoe, and place the foot on the floor.
6. Push down on the knee, making sure the shoehorn stays in place.
7. Fasten the shoes (buckles, Velcro, or one-handed tie).

Tying a Shoe With One Hand

1. Knot one end of the shoestring and lace the shoe, leaving the knotted end at the lowest eyelet.
2. In the top eyelet, feed the end of the shoestring from outside to inside. Throw the end over the top of the laces.
3. Make a loop in the free end of the shoestring and pull it, loop within a loop.
4. Pull the lace tight, being careful not to pull the free end all the way through.
5. To untie, pull the free end.

Note: For loss of the use of the left side of the body, the instructions would be reversed.

Consideration of the person, environment, and task is given prior to the transfer. Activity demands include the objects that will be used in the transfer (e.g., a sliding board, transfer belt), space demands, steps involved in the process (and the cognitive, visual, and perceptual skills associated with implementation), required actions (including safety aspects such as locking the wheelchair prior to transfer), and physical requirements and skill prerequisites (e.g., strength, ROM, bed mobility; Merano & Latella, 2008).

There is a range of types of transfers that can be done with clients, ranging from dependent transfers (where the client is moved by equipment or one or more people) to independent transfers (client requires neither cues nor assistance). Sliding board transfers are for clients who have weakness and cannot bear weight on the lower extremities. Pivot transfers are for people who can stand and bear some weight on their legs. Clients may need some assistance with pivot or sliding board transfers, or they may be independent.

Levels of assistance are defined to describe the skill of the client and assistance needed. If the client can complete the task, including setup with or without adaptive equipment, then the client is independent. Standby assistance is when assistance of one other person is needed to perform the activity. Independent with setup is sometimes used to indicate that someone is independent once someone sets up the activity (gets the transfer board, gets grooming supplies, etc.). If the client does not require physical contact but does need cueing or coaxing or cannot be left alone due to cognitive deficits, poor balance, or other safety concerns, the client requires supervision. Minimum assistance describes a task in which the client requires assistance with only 25% of the task performance. Similarly, moderate assistance is a task requiring 25% to 49%, and maximum assistance requires 50% to 75% assistance. Total assistance or dependence is when the client is unable to perform any part of the task (75% to 100%). *Modified independence* is a term that is used to describe a client who is able to

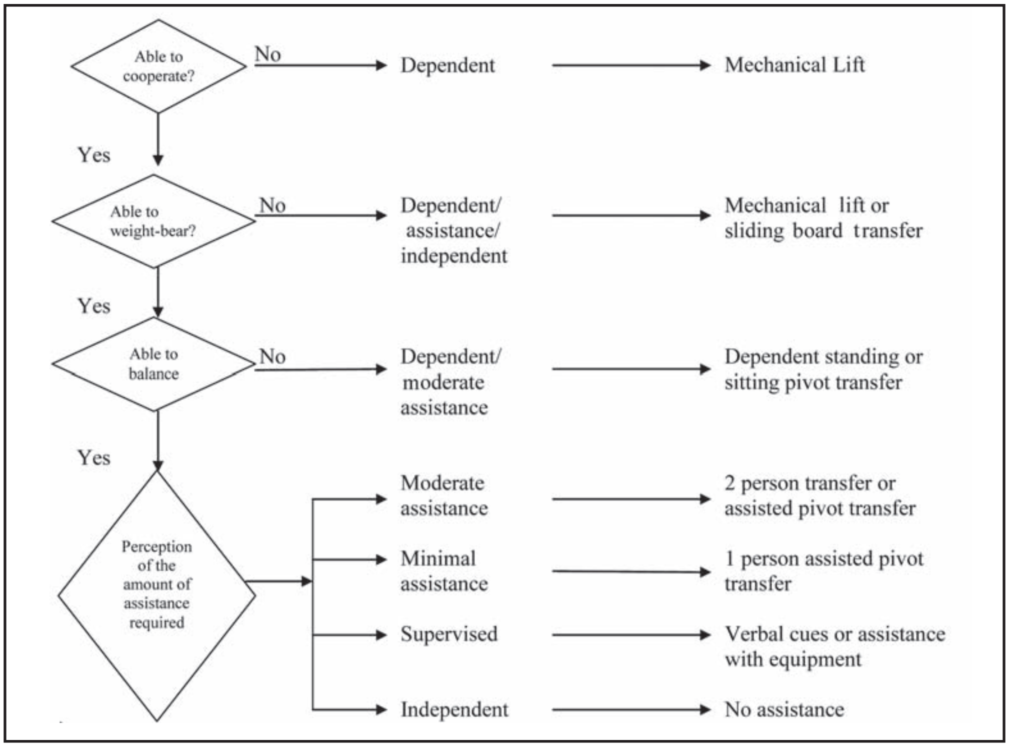

Figure 13-3. Graphic flowchart for transfer decisions.

Table 13-10

One-Person Transfer Techniques

One-Person Technique (Clients Without Limited Hip Flexion)

1. Stand in front of the client.
2. Place the client in a forward flexed position with chest lying on the thighs.
3. Client shifts body weight over the knees and ankles rather than on the buttocks, which allows the buttocks to be more easily moved.
4. A helper can control the movement.

One-Person Technique (Clients With Limited Hip Flexion)

1. Slide the buttocks toward the edge of the wheelchair.
2. Place the client's knees between the helper's knees.
3. Rock the client forward slightly and simultaneously pull the client's transfer belt and rotate the hips to the surface to be moved to.

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perform the task but requires adaptive equipment or an assistive device or takes more than a reasonable amount of time, or if the activity involves safety considerations. *Contact guard* is another term used that denotes that the therapist has a hand on the client at all times (Matthews & Jabri, 2001).

Figure 13-3 provides a graphic flowchart to aid in deciding what type of transfer is appropriate for a particular client.

Dependent Transfers

If the client is unable to assist with the transfer, then a dependent transfer will be done. This transfer requires the assistance of one or more people to move the client from one surface to another. One-person transfers can be done with clients who need assistance as well as those with and without the ability to flex at the hip (Table 13-10).

To help a person roll from side to side or to transfer a recumbent person, a draw-sheet, mattress pad, or bed liner can be used, which may also help with transfers. The sheet or pad is rolled and grasped close to the client. One person assists at the head and another one at the hips on one side of the client, and another person assists at the hips on the other side, opposite to the movement. If the client has extraneous movements that cannot be controlled, then wrap the sheet around the client to control the movements. At a given signal, all three assistants simultaneously lift and move the client toward the surface (Minor & Minor, 2010).

An alternative method for dependent clients would be use of a hydraulic lift, which is a good choice for very large or dependent clients and/or small caregivers. Other mechanically assisted transfers have been made from adapted battery-operated winches or garage door openers.

Sliding Board

To transfer from the bed, chair, or mat to a wheelchair requires the skill of coming to a seated position and that the wheelchair be located near the bed with the armrest removed on the side nearest to the bed. One of the client's arms is positioned behind to maintain balance, and the other arm is positioned underneath the leg closest to the wheelchair, sliding the leg toward the wheelchair. Once near the wheelchair, position one arm on the wheelchair armrest or seat, and pull the leg toward the chair. Once both legs are on the wheelchair footrests, the client can prepare for a sliding board transfer.

A functional consequence of the loss of triceps strength as in a C6 spinal cord injury is that the client will not be able to transfer using a sliding board without learning compensatory movements. Depression or sliding board transfers can be successfully performed by having the client externally rotate the humerus while locking the elbows as the weight of the body is shifted to that side. By depressing the scapula to shift the weight off the elbow, the client can inch forward on the sliding board. This same technique can be used in rolling onto the side and pushing up on the elbow during bed mobility activities and for push-ups in the wheelchair for pressure relief.

Use of a transfer or sliding board is the most common transfer type for clients with loss of strength in all four extremities and for clients with C6 injuries and below. In many cases, the client at this level of injury can manipulate the wheelchair parts and position the sliding board to become independent in the transfer. The sliding board acts as a bridge between two surfaces. Because clients can compensate for the lack of triceps by using shoulder external rotation and scapular elevation and depression, a sliding board transfer is also known as a *depression transfer*.

The use of a sliding board in a depression transfer is a specific example of using an adaptive device that compensates for loss of lower extremity function. Transfers are also adapted methods to achieve mobility. Impediments to successful sliding board transfers would be poor trunk balance that cannot be compensated, excessive spasticity, excessive body weight, joint tightness, and cognitive deficits, which can result in unsafe transfers.

The choice of a type of transfer board is dependent on how much space is available for the transfer, the type of transfer surfaces, and how much strength the client has. Plastic boards are lightweight and good for tub and car transfers. Wooden boards are also available but are heavier to use. Transfer boards can come with cut out areas for the hand to be inserted to help position the board even without grasp, using the hand as a whole to move the board. Webbing straps can be attached to assist with pulling the transfer board out from wheelchair pouches or from storage.

Sliding board transfers can be done independently by the client or with assistance, if needed. Assistance can be provided by holding the client around the ribs, waist, or waistband or by using a transfer belt and maneuvering the client's legs, if necessary. Transfer surfaces optimally should be at the same level for an even transfer.

Positioning the client prior to transfer requires that the trunk be aligned and upright and that there is slight anterior pelvic tilt. The client should be able to shift weight and maneuver the legs without losing balance. If the client is not able to attain these skills, then a caregiver needs to be trained, and the client needs to learn how to tell others the ways in which help is needed. Table 13-11 lists the steps of a depression transfer.

Pivot Transfer

A pivot transfer is a common transfer type for clients with loss of function on one side of the body. Because the client can partially bear weight on one lower extremity, this transfer is a good choice and can be done independently or with assistance. A modified pivot transfer, called a *dependent standing* or *dependent sitting pivot transfer*, involves the client remaining in a semi-crouched position, with the body over the legs, as the therapist or caregiver pivots the buttocks from one surface to the other. If the client is unsafe with a pivot transfer or is unable to perform the transfer even with assistance, sliding board transfers would be the next viable transfer option.

Pivot transfers generally are set up to move the person in a 90-degree angle, although some pivot transfers are in a 180-degree arc if in restricted spaces (e.g., a bathroom). Table 13-12 lists the steps in a pivot transfer. Even in an assisted pivot transfer, have the client assist with the transfer as much as possible. Initially, clients are taught to transfer to the uninvolved side (strong side), but teaching the client to transfer to the involved side, as well, is necessary for greater independence. For the client to be considered independent in transfers, he or she should be able to demonstrate adequate safety awareness, have independence in bed mobility, maintain sitting trunk balance, and be able to follow simple directions (Palmer & Toms, 1992). Table 13-13 can be used as a checklist to consider all variables related to a safe, efficient transfer.

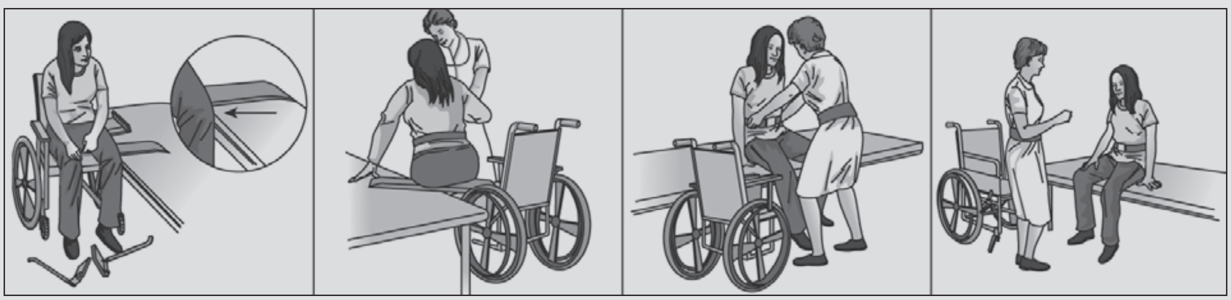
Functional and Community Mobility

Being in a wheelchair necessitates learning how to get around in the environment in new ways. Even going through a door in a wheelchair requires a new method. Table 13-14 lists the steps for going through a door with varying levels of strength and functional capacities. Table 13-15 provides sample goal statements, methods, and principles behind why you are changing the task. Examples are provided for each goal. The goal for a client who is expected to become independent in grooming would read: "Client will be independent in all grooming tasks using adapted task methods to substitute for loss of ROM in the right upper extremity in 3 days." An alternative way to state this might be, "Using adapted methods to compensate for the loss of ROM in the right upper extremity, the client will be independent in grooming tasks in 3 days."

Table 13-11

Sliding Board Transfer Technique

1. Use a wheelchair with removable armrests and footrests.
2. Provide level transfer surfaces.
3. Position the wheelchair at a slight angle to the transfer surface.
4. Lock the wheelchair brakes.
5. Move the footrest/legrest out of the way on the side toward the destination surface; remove the armrest on the destination side.
6. Client shifts body weight (or is assisted) to the side opposite the direction of movement and places approximately 25% of the board under the buttocks.
7. Client places one hand on the board and the other on the wheelchair seat and leans forward.
8. Client then moves the upper body weight in the direction opposite to that in which he or she is going.
9. Client scoots along the board by flexing/extending the elbow or by externally rotating the humerus and locking the elbows to compensate for the lack of triceps.
10. Caregiver may assist with helping the client move along the sliding board by placing his or her hands on the client's hips, waistband, or transfer belt. Caregiver assists in ensuring balance as needed and by managing the client's legs.
11. After the transfer, the wheelchair armrest and footrest are repositioned.



Stability and Coordination

Adapting the task method or procedure to provide stability due to ataxia or incoordination involves using stabilization to counteract the tremors or lack of controlled movement. Teaching the client to stabilize objects being used and to position the body in as stable a position as possible are compensatory ways of providing stability. Ways to position the body may include sitting when possible, bearing weight on the part, and holding the arms close to the body. It is helpful to stabilize proximal parts so the need to control body movement is reduced to just the distal body parts. Stabilizing items in drawers or between the knees if seated makes opening containers easier. Heavier items also tend to dampen tremors, such as an electric razor or electric toothbrush.

Using larger and less precise fasteners, tools, and objects also helps decrease frustration due to incoordination. For example, using roll-on deodorant is easier and safer for the person with decreased coordination and control. Increasing friction can add stability and can be as simple as placing an object on a wet cloth or towel or using a nonskid mat. As with other limitations, simplifying tasks (e.g., hairstyle, omitting steps, less makeup) are also options that can be used with clients with incoordination.

Dutton (1995) recommends using a two-handed proprioceptive neuromuscular facilitation technique called *chop and lift* in daily activities, such as getting a glass from a cupboard or washing one's face. Another proprioceptive neuromuscular facilitation technique uses surface contact to increase friction and decrease instability. In this case, sliding the hand along the table toward the glass would be a steadier position for the arm (Dutton, 1995). When eating, it may be necessary to avoid eating messy foods with sauces, soup, or hard-to-manage items like peas if tremors are severe or to ask for help in eating these foods.

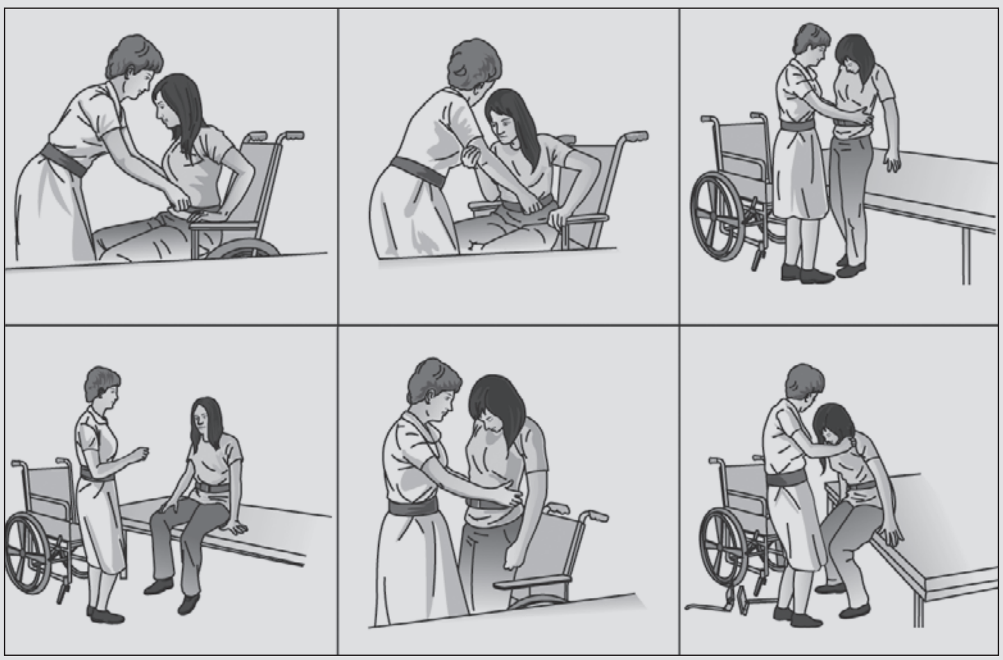
Spasticity

While control or inhibition of spasticity is not a remediation goal of either the biomechanical or an adaptation or compensation technique of the rehabilitation intervention approaches, some of the techniques advocated by theorists from the NDT/sensorimotor frame of reference are useful in controlling spasticity or at least in minimizing the effect spasticity has on the performance of daily tasks. Distal key points of control (NDT technique) can be used with clients who have had a stroke where it is recommended that the unaffected leg be placed under the spastic leg during bed mobility. Another technique is to clasp the hands in reaching activities and transfers. Using proximal points of control, another NDT method, is seen if a client is instructed to lean forward to dangle a spastic arm to use the weight of that arm to protract the scapula and extend the elbow while putting on a shirt

Table 13-12

Procedure for Pivot Transfer

1. Position the wheelchair.
2. Lock the wheelchair brakes.
3. Move the footrest/legrest out of the way on the side toward the destination surface.
4. Have the client come forward in the wheelchair; provide assistance so that both hips are even and that the client achieves an anterior pelvic tilt so that body weight is forward.
5. Make sure the client has a sufficiently wide BOS (shoulder distance).
6. Block the client's knees to provide stability.
7. Client is encouraged to assist by pushing up with the unaffected parts.
8. Client comes to a controlled stand; hold onto the client via gait or transfer belt.
9. Turn/pivot with the client, helping to move the client's affected foot.
10. Client is encouraged to reach toward the destination surface and ease onto the surface by using the unaffected parts. Assist by holding onto the transfer belt and easing the client onto the surface while practicing good body mechanics.



(Dutton, 1995). Dutton (1995) further recommends using placing, lowering, and weightbearing (NDT techniques) to control spasticity. An example of this may be seen when the client lowers a spastic arm to the table and uses the arm to hold down a piece of paper (Dutton, 1995). Further explanation of methods to minimize spasticity are included in Chapter 15.

Limited or Low Vision

Clients with limited vision use organization as a primary method of compensating. If objects are organized in a specific way, in a particular place, and routinely replaced after use, then the client with limited vision will know where to find the object. Instructing caregivers and family members to close drawers and open doors is important to the visually impaired person. Clothes can be organized by color in a closet. Pinning like items together after wearing them but before laundering will eliminate the need for visually sorting after washing and drying.

Using other senses to compensate for low or decreased vision is another adapted method. By folding money differently for each denomination, the person with limited vision will be able to differentiate paper money. Using touch through Braille labels will help in identification of items on a shelf. Food is cut by finding the edge of the food with the fork, moving the fork a bite-sized amount onto the meat, and then cutting, keeping the knife in contact with the food. Pouring liquid is based on the weight of the cup when it is full or inserting a finger in the cup while pouring. Contrasts in color between the plate, utensil, drinking glass, and table coverings with the color of the food will help the person with low vision differentiate items (James, 2014).

Auditory cues such as washing machines or dishwashers that chime when the cycle is completed or using talking scanners to identify bar codes on items is useful. Talking books or auditory books is another way to compensate via listening rather than visually reading.

Table 13-13

Pivot Transfer Checklist

Introduction

- Wash hands
- Introduction to the client
- Proper client identification

Mechanics

- Client and wheelchair position
  - Level surface
  - Wheelchair positioned 30 to 45 degrees relative to transfer surface
  - Lock brakes
  - Remove footrests
  - Feet on floor, shoes on
- Pre-transfer
  - Use nonaffected/stronger arm to push out of chair
  - Move to edge of seat
  - Push up on armrest
  - Come to stand
  - Stable in standing
  - Assessment of client status (dizzy)
- Transfer
  - Reach for transfer surface
  - Management of lower extremity
  - Pivot on strong lower extremity
  - Quarter-circle turn
  - Ease into chair
  - Client position after transfer
  - Awareness of therapist's body mechanics

Clinical Judgment

- Ongoing assessment of client status
  - Consistent eye contact
  - Short, concise, clear directions to client
  - Periodic verification of client understanding of task steps

Changing the lighting in the environment can improve function for the person with limited vision. Primarily by using trial and error, determine the lighting needs of the client during a functional activity with the best illumination, most contrast, minimal glare, and overall comfort (Young, 2012). This includes considering the task lighting (specific areas where the task is performed), accent lighting (used to provide extra attention to a selected area), and ambient lighting (overall lighting of the area). Use of a light meter can identify the levels of light in the home with recommended ambient light levels of at least 30-foot candles and task lighting at least 100-foot candles according to the Illuminating Engineering Society of North America (Dilaura, Houser, Mistrick, & Steffy, 2011). For task lighting, positioning the light source over your shoulder will ensure that the light falls on the task and reduces glare.

Contrasting colors on thermostats, wall outlets, locks on windows, light switches, oven and stove dials, and drawstrings on draperies are examples of color contrast.

Be aware that natural lighting changes throughout the day, which can change the client's visual abilities in the day. Also, balance the light levels throughout the rooms of the house to avoid big changes in the amount of light in different rooms, which would require rapid visual accommodation. Using more than one light in a room will also help distribute the light evenly throughout the space and decrease glare.

Reduction of glare is also a method used to improve visual function. Glare, caused by scattered light, raises visual brightness that can cause visual discomfort and limiting visual perception. Glare can be reduced by using blinds, sheer curtains, or window shades and by sitting with your back to the sun. Contrast and glare filters are also available to minimize glare and enhance contrast (Young, 2012)

Impaired Cognition

Clear, simple directions presented in a consistent, relaxed manner will help the client with cognitive impairment establish routines that are reinforced. Each step should be explained, and checklists can be provided to remind the client of necessary steps of the task. There can be checklists for toileting (reminding to flush, wash hands), dressing (bra first, followed by blouse) or cooking tasks (get pan, fill with 1 cup water, etc.). Use of clippers rather than scissors to trim nails is suggested, and awareness of object use and safety is always the primary concern.

Changing eating methods for cognitively impaired clients or those with dysphasia may include reminders via an alarm to eat. Teaching the client to eat only small amounts of food with small bites at one time with reminders to swallow after chewing each bite may also be necessary. Often, the use of soft foods and avoidance of sticky foods makes chewing and swallowing easier (Holm et al., 1998; James, 2008).

Graff et al. (2008) studied the effects of occupational therapy on the performance of daily activities by older adults with cognitive impairments and on the satisfaction with primary caregivers' sense of competence. They found that ooccupational therapy improved clients' daily functioning and reduced the burden on the caregiver, despite the clients' limited learning ability.

Decreased Endurance and/or Chronic Pain

Many clients experience decreased endurance, and they need to frequently schedule rests during the day. Energy conservation and work simplification principles are very applicable to those with cardiovascular and respiratory dysfunction, spinal cord injuries, and rheumatoid arthritis.

Table 13-14

Wheelchair Maneuvering Through Doors

Through Doors (High Quadriplegic, C4 or C5, Pulling Door to Open)

1. Starting position: Back the chair up to a double or single door with the handrims just clearing the door that will be opened.
2. Motion
   a. Place the hand in the door handle.
   b. Open the door slightly.
   c. Remove the hand from the door handle.
   d. Using the hand against the door, push the door open until it is past the rim of the wheelchair.
   e. Using the rim to block the door open, turn the chair toward the door, keeping the rim against the door.
   f. Propel the chair forward with the rim against the door until the door is fully open.
   g. With the wheel continuing to block the door open, back the chair with the arm that is opposite the door.
   h. Push off from the door and propel through the doorway backward.
3. Teaching tip: Because of the tenodesis effect, it is important to place the hand in the door handle before turning the chair completely backward.

Through Doors (Low Quadriplegic, C6 to C7)

1. Starting position: Back the chair up to a double or single door with the handrims just clearing the door that will be opened.
2. Motion
   a. Push the door open far enough so that the door is blocked by the foot pedals.
   b. With the foot pedals against the door, turn the wheelchair toward the open door.
      Caution: Feet will catch the door as the individual turns toward the door. To avoid injury to the feet, let the chair roll back a little as the individual turns through the door.
   c. Hold the elbow against the door to keep it open.
   d. Propel through.

Through Doors (Pushing Forward)

1. Starting position: Approach the door to be opened at a slight angle (30 to 40 degrees).
2. Motion
   a. Push the door open.
   b. Use toes and the foot pedals to brace the door open.
   c. Turn the wheelchair toward the open door.
      Caution: Do not bang into the door with your toes.
3. Teaching tip: The weight of the door will straighten out the chair as it goes through.

Through Two Doors (Pushing Doors Open)

1. Starting position: Center the wheelchair between the two doors with one foot pedal against each door.
2. Motion
   a. Push the doors with both feet until the wheelchair is through the doors past the handrims.
   b. With hands on the doors and elbows flexed, use trunk extension to push the doors open.
   c. Propel through the doors.
      Caution: If the individual does not get far enough through the doors, the weight of the doors will push the chair backward.

Many of the earlier suggestions for decreased strength and decreased ROM also apply to those clients with poor endurance. Stabilizing items so that they do not need to be held (via nonslip materials or in drawers or between the knees) and task simplification are useful. Dressing in bed may conserve energy, and maintaining good postural alignment throughout the day and during tasks will facilitate task completion. Use of good body mechanics and pacing of activities are useful for those with poor endurance and chronic pain (Fasoli, 2014).

Table 13-15

Changing the Task: Adapted Task Methods Intervention and Documentation

GOAL

Client will (be independent/modified independent) and (require maximal/moderate/minimal/standby assist or verbal/physical cue) to perform (specify tasks) in (specify number of weeks/days) by using:

Method	Principle/Rationale	Example
Adapted task procedures and methods that	Substitute for loss of ROM	• Pivot or sliding board transfers • Affected extremity in first one-sided limitations • Avoid twisting at the knees when transferring • Hip precautions for total hip replacement • Garments with zippers and buttons in front • Slip-on shoes • Wrap toilet paper around hand • Wide BOS when pulling pants up in standing position • Eliminate wearing underwear • Wide BOS on toilet to prevent falls • Simplify hairstyle, routines, tasks • Grow a beard • Use terrycloth bathrobe to dry off instead of towel • Large fasteners or Velcro for clothing fasteners
	Substitute for loss of strength	• Let gravity assist • Use principles of levers (force arm greater than resistance arm) • Apply force closer or farther from fulcrum to change length of lever arms • Increased friction decreases power required for pinch or grasp • Use two hands • Weave utensils through fingers • External rotation and abduction can substitute for supination • Hook elbow around wheelchair upright to increase reach • Extrinsic tightness for selective tightening for hook grasp • Elbow "walk" • Lock elbow using external rotation and scapular depression • Tenodesis action with wrist extension for grasp • Adapted bed mobility • Sliding board or pivot transfers • Adapted dressing • Limit the weight of task objects • Let unaffected parts assist • Use affected parts to hold objects • Careful selection of clothing items (type of material), preferably slightly large for ease in donning • Lick the heel of the hand to move shirt material up the arm • Adapted functional and community mobility • Simplify hairstyle, routines, tasks

(continued)

Table 13-15 (continued)

Changing the Task: Adapted Task Methods Intervention and Documentation

Method	**Principle/Rationale**	**Example**
Adapted task procedures and methods that	Compensate for loss of use of one side of the body	• Adapted dressing by putting affected arm in sleeve first (one-handed limitation) • Let unaffected parts assist • Use affected parts to hold objects • Adapted bed mobility • Pivot transfer • Affected part dressed first and undressed last • One-handed shoe tying, slip-on shoes, Velcro closures • Tape nail file to table to stabilize • Use unaffected arm and leg to propel hemi-wheelchair • Prop infant or use infant seat • Velcro strap on changing table • Adapted functional and community mobility • Simplify hairstyle, routines, tasks
	Provide stability (ataxic and uncoordinated movements)	• Proprioceptive neuromuscular facilitation patterns • Teach client to stabilize objects being used • Stabilize proximal part • Use body in as stable a position as possible • Use larger and/or less precise fasteners, tools, objects • Increase friction
	Minimize the effect of spasticity	• Use distal key points of control • Use proximal points of control • Use placing, lowering, and weightbearing • Use affected arm as stabilization
	Substitute for limited vision	• Organize; there is a place for everything • Food on plate organized like a clock • Adapted cutting by means of food placement • Pour liquid based on weight of cup when full • French knots in labels to identify colors • Store all colored clothes in one part of closet • Fold money for each denomination differently
	Substitute for decreased endurance	• Have grocery list • Frequent rests • Shop during nonpeak times • Work simplification • Energy conservation • Stabilizing items so that they do not need to be held • Dressing in bed • Good posture throughout day

(continued)

Table 13-15 (continued)

Changing the Task: Adapted Task Methods Intervention and Documentation

GOAL

Client will (be independent/modified independent) and (require maximal/moderate/minimal/standby assist or verbal/physical cue) to perform (specify tasks) in (specify number of weeks/days) by using:

Or

Client will consistently use work simplification techniques to (specify task):

Method	Principle/Rationale	Example
Adapted methods that	Simplify work	• Organize storage • Plan ahead • Have an easy flow of work • Eliminate steps and jobs • Use efficient methods • Consider the environment

GOAL

Client will (be independent/modified independent) (require maximal/moderate/minimal/standby assist or verbal/physical cue) to perform (specify tasks) in (specify number of weeks/days) using:

Or

Client will consistently use energy conservation techniques to (specify task):

Adapted methods that	Conserve energy	• Respect pain • Rest frequently • Prioritize activities • Avoid sustained, static positions or isometric muscle contractions • Avoid stressful positions • Consider the environment

Adapted Task Objects, Adaptive Devices, and Orthotics

Adapting the task object involves changing, adapting, or substituting the objects or tools used in activities (Sidebar 13-4). Adaptive equipment spans the continuum from low-tech buttonhooks to complex computer equipment and sophisticated environmental control units. Adaptive equipment can be used to enable performance, compensate for lost function, and aid in efficient and safe performance of activities.

Sidebar 13-4 Changing the Task: Adapted Task Objects Principles

Adapting task objects or using adaptive/assistive devices or orthotics compensates for loss of ROM, strength, use of one side of the body, limited vision, impaired cognition, decreased endurance, inadequate stability; minimizes the effects of spasticity to permit transportation of objects, to overcome architectural barriers; and ensures proper positioning for occupational performance.

Provision of adaptive equipment seems deceptively simple, but careful consideration of devices and client need is necessary to avoid costly errors in terms of equipment purchased and devices that are not used or are used incorrectly. Some devices, used incorrectly, may result in additional performance impairments or may prevent proper use of the device (Marrelli & Krulish, 1999). A proper fit between the needs of the individual and the functions and options of the device must be made. Included in the decision is the cost and availability of the device, what adaptations may be needed, and what is involved in maintaining and repairing the device. A large percentage of assistive devices are unused or abandoned. By considering user opinion in selection of devices, ease in obtaining devices, enduring device performance, and awareness of changes in user needs and priorities can increase acceptance rates of these devices (Hurst & Tobias, 2011; Lee, 2016; Scherer, 2002).

Adaptive equipment may radically change the way things are done. For example, a long-handled hairbrush may be recommended to a client to enable independent grooming. Use of the long-handled hairbrush minimizes the amount of shoulder ROM that is required to brush the hair, but the device still requires isometric contraction of the wrist and hand muscles with enough strength to hold the brush. In addition, coordination and arm strength is needed to control the longer lever created by the extended handle.

If the equipment or device is complex, the client will need higher levels of cognition to use the devices effectively and safely. It is easy to see that a reacher will compensate for decreased ROM, but judgment is needed when getting a heavy soup can down from a high cupboard. Not only might the soup can fall on the person, but there are additional stresses on the wrist and fingers as well as on the cardiovascular system with overhead movements.

Many items of adaptive equipment do not change the way the activity is done but make the task easier. This is seen with hook-and-loop fastened shoe closures and adding foam to utensils to build up the handles. A fork with a foam handle is used the same way as a fork without foam; the difference is that the person can hold the fork more easily because less hand closure is required.

Another difference is that the foam makes the fork look different, which is one disadvantage to adapting the task objects for some people. Consideration of the psychological impact of adaptive equipment on the person is important in the consistent use of the devices by the client. By using tools or devices that look different, unwanted attention may be drawn to the person using them, which may be a constant reminder of loss of function. Sometimes, a client would rather have assistance than use adaptive equipment. This emphasizes the collaborative nature of the therapist-client interaction in intervention and is part of the assessment for use of adaptive devices. Some orthotic devices (e.g., mobile arm supports) may be bulky and unattractive, which may be another disadvantage for some clients. Clients have both positive and negative attitudes toward adaptive devices. The device is valued for the function that it affords, but there may be a stigma when using the device (Ali et al., 2008; James, 2008).

Another disadvantage to using adaptive equipment is that the device needs to be available every time that activity is done. A person may have adapted utensils or use a mobile arm support or other equipment at home when eating but would need to take the equipment with him or her when he or she goes out to dinner. The device needs to be used in different contexts, so portability is a consideration or deciding on alternative ways of achieving the task in different situations.

The use of adaptive devices and orthotics has three advantages. First, adaptive devices have good face validity, and it is easy for clients to correlate improved function in daily activities with the use of the device (Gosman-Hedstrom, Calesson, & Blomstrand, 2002). Second, adaptive devices offer a concrete, immediate solution to a functional problem. The client cannot hold a fork, and foam on the utensil or the utensil inserted into a universal cuff resolves the limitation. Third, many adaptive devices are inexpensive (although given the variety of devices available, there is also a range of cost; Dutton, 1995).

Clients and caregivers need sufficient education about the use of the device and practice in using the device during activities. In a study by Matuska and colleagues (2007), 13% of respondents said they did not use adaptive equipment because they were unsure of how to use the device or they could not use it. Even if the clients are satisfied with the level of education about adaptive equipment use, they do not always use the equipment when they get home. In a study by Finlayson and Havixbeck (1992), 97% of the clients reported satisfaction of adaptive equipment education, but 75% of the clients used the equipment. Functional independence and satisfaction with and use of bathing devices improved in clients who received home visits after discharge from the hospital, inferring that contextual generalization of device use is helpful (Chiu & Man, 2004).

The following sections provide specific ideas about the selection and use of an assistive technology device as defined by the Assistive Technology Act of 2004 (Pub. L. 108–364), where assistive technology is "any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities" (29 U.S.C. § 2202(2)). Technology is the combination of assistive, basic, complex, electronic and information, and rehabilitative and educational technologies (Hammel & Angelo, 1996). Occupational therapists have a long history of assistive technology use and development (AOTA, 2010b; Angelo & Smith, 1993; Bondoc, Goodrich, Gitlow, & Smith, 2016; Gitlow, Dininno, Choate, Luce, & Flecky, 2011; Gitlow & Sanford, 2003; Goodrich, 2003, 2004, 2005; Goodrich & Garza, 2015; Hammel & Angelo, 1996; Hammel & Smith, 1993; Kanny, Anson, & Smith, 1991; Petersson, Lilja, Hammel, & Kottorp, 2008). Many of the following suggestions are considered basic technology and are commonly used with ADL and basic home modifications.

Range of Motion

To compensate for decreased ROM, handles are extended, so reaching an object is possible or the handle is built up to make grasping easier. Extensions can be added to the tool itself (e.g., adding a long lever to nail clippers) or can be accomplished with the use of a reacher. Built-up eating utensils are available for purchase, or regular forks and spoon handles can be enlarged by using cylindrical foam that fits over the utensil. Use of nonslip materials (Dycem [Dycem Corporation] or a damp washcloth) keeps items stabilized.

Velcro can be used as a replacement for fasteners and a loop of webbing can be sewn into socks to enable insertion of a thumb to pull up socks. When making these adaptations, the disadvantage is that this necessitates adaptation of many clothing items. A dressing stick or reacher can be used to reach the clothing without excessive flexion or external rotation and loss of ROM. Sock aids are often used for people with decreased ROM and are valuable to clients after discharge (Finlayson & Havixbeck, 1992). Elastic shoelaces and a long-handled shoe horn are important pieces of equipment for those with limited hip ROM and are often recommended after total hip replacements due to hip precautions after surgery. Buttonhooks can be used to button shirts (Figure 13-4), and they can be inserted into a universal cuff, enlarged with foam if grasp is limited, or may be mounted on a table with a suction cup to stabilize while buttoning if there is loss of function in one arm.

A wall-mounted hairdryer would be helpful for those who are unable to hold the hairdryer to style their hair. Enlarged or elongated utensils can help with grooming tasks, such as shaving, makeup application, and oral hygiene. Long-handled sponges making washing the feet and back much easier, and the plastic handle can be heated and angled slightly to provide better contact with skin surfaces. Pump-action containers for soap and shampoo are helpful at the sink and in caddies or

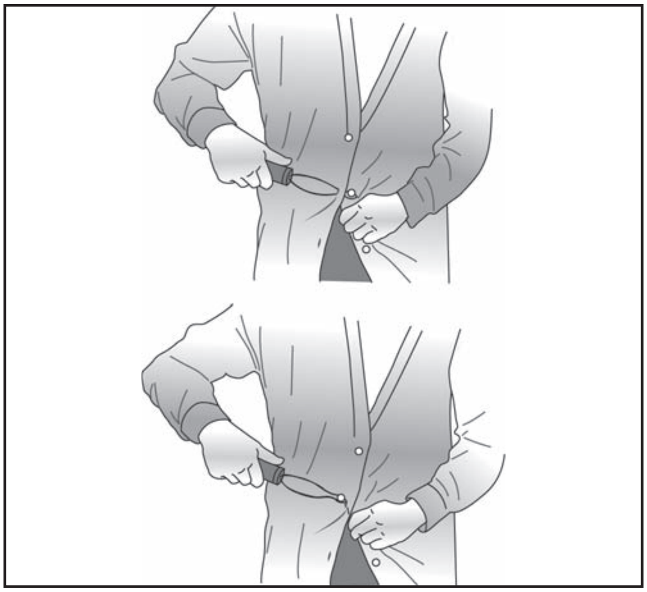


Figure 13-4. Using a buttonhook device.

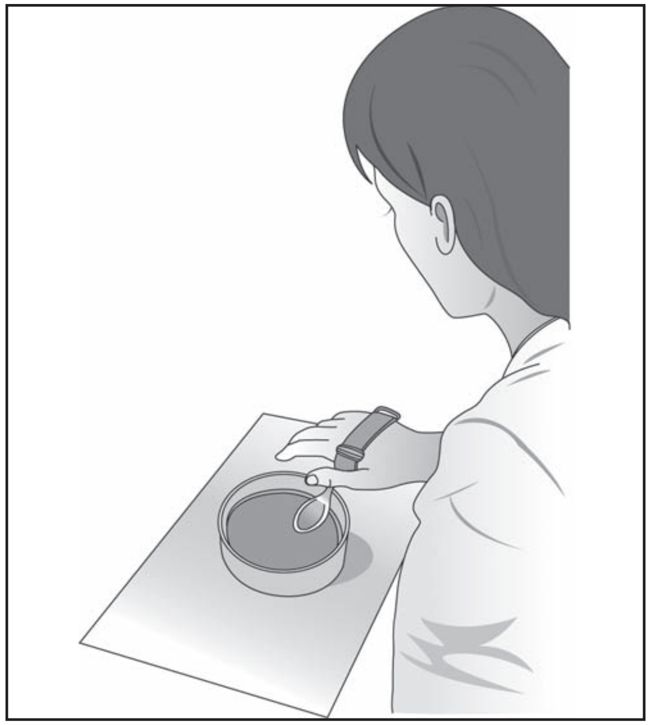


Figure 13-5. Universal cuff adaptation.

wall-mounted in the shower. Soap on a rope and using a bath mitt are also helpful for bathing. A tub bench or shower chair and handheld shower may enable safe bathing from a seated position.

Long-handled toilet aids or tongs can enable satisfactory toilet hygiene. A bedside commode or urinal near the bed may eliminate unsafe trips to the bathroom in the middle of the night. Grab bars near the tub and toilet make transfers to those surfaces safer. Elevated commodes make using the toilet safer and easier.

Decreased ROM may affect eating by disallowing grasp or reaching the hand to the mouth. For decreased grasp, enlarged handles on eating utensils, angled utensils, or inserting utensils into a universal cuff permit successful self-feeding (Figure 13-5). Long straws and adapted cups that do not require grasp enable independent drinking. Opening containers can be done by stabilizing the item in a drawer or between the knees, using an adapted wall-mounted jar opener, or using the teeth to open some packages.

For clients with decreased ROM and strength, playing with children and changing a baby can sometimes be done more safely on the floor. Having a crib that swings open on the side (rather than moving up and down) may make putting the child to bed easier. Clothing for the child is easier to put on if slightly larger and with large closures or Velcro.

Keys may need to be adapted so that a person with decreased grasp can use them. This can be done by either buying commercial key adaptations or by adapting the key using splinting material. Lamp switches may need extensions, or inexpensive environmental controls can be used (e.g., clap or motion sensors to activate lights).

Electrical appliances often make tasks easier, but not always. For example, some electric can openers require the use of both hands to align the can and force to depress the lever. Review the variety of equipment available online and in catalogs and try the device with the client before recommending it.

Bowls can be stabilized in a drawer or between the knees, and suction devices attach to the stovetop to stabilize saucepans during cooking. Cutting boards with or without suction devices are available with stainless steel nails so that food can be placed on the nail, stabilizing it so food can be cut safely. If drawers have small knobs or are difficult to open, loops can be added to the handles so that wrist or forearm movements can open the drawer rather than relying on grasp. Lever faucet handles in the kitchen and bathroom also makes operating a faucet easier. Silicone spray or bar soap rubbed on drawers will ease the sliding of the drawer.

Strength and Endurance

Many of the adaptive devices suggested for decreased ROM will also apply to the other functional limitations, including decreased strength. Decreased strength and endurance can result in a decreased ability to move the limbs, decreased sitting balance, and/or decreased grasp and pinch. Devices for stabilization eliminate the need for sustained muscle contractions and are helpful for those with decreased strength and endurance. Enlarged handles or items inserted into universal cuffs are helpful for people with decreased hand or arm strength. These adaptations can be made to eating utensils, grooming items (e.g., toothbrush, hairbrush, razor), dressing, and using electronic devices.

Loops on clothing and socks facilitate dressing, and loops on drawers permit a person easy access to cupboards, desks, and dressers. Replacing closures on bras and shirts with Velcro will secure clothing for those with limited grasp. Adapted clothing is commercially available from a variety of companies, or just using clothing that is slightly larger will also facilitate functional dressing.

Electric appliances, such as electric razors and toothbrushes, make hygiene easier. Plate guards and bowls with raised edges, enlarged handles, or utensils inserted into universal cuffs enable independent self-feeding.

Reachers are also useful but need to be considered carefully to determine which type works best for any individual. Wooden scissors-type reachers require bilateral hand use. Pistol-grip reachers can be used with one hand but require sustained grip and grasping action to open and close the device. Consider the change in forces when an object is picked up with reachers and how this changes lever arm mechanics.

Splints can be used to stabilize the wrist or to provide functional hand positioning. Dynamic splints (such as a flexor-hinge or tenodesis splint) can provide functional hand movements that permit wide gradations of force and skill levels.

Bathing adaptations that were recommended for decreased ROM are also helpful for those with decreased strength. Transfer tub seats, grab bars, and electronic bath lifts may be consideration for bathing independence and safety. A handheld shower with adaptations or lever faucet handles are useful in the shower, as are pump shampoo and soap dispensers.

Clients on specific bowel and bladder programs need special adaptations. Catheter adaptations are often necessary and may include Velcro straps for ease in removing and attaching leg bags, and adapted leg bag valves are available commercially to enable easier leg bag drainage. Suppository inserters are used in bowel programs, as are digital stimulators (or rectal stimulation splints). While occupational therapists do not design, prescribe, or teach bowel and bladder programs, we are responsible for assisting in devising methods for performing these programs as independently as possible and for providing adapted equipment and training in the use of these procedures and equipment. Raised toilet seats or drop arm commodes are also considerations for toileting.

Lapboards for wheelchair users provide a working surface that is easily reached while providing a means to transport items from one place to another, including hot items from a microwave or oven to a table. Wheelchair bags or pouches are often attached to either the side of the wheelchair on the outside of the armrest or between the push handles in the back. Walker bags or a wheeled cart help ambulators transport items.

For clients with severe upper extremity strength losses, a mobile arm support or bilateral feeding orthosis (also known as *bilateral forearm orthosis*) may permit movement in a frictionless arc. A mobile arm support supports the weight of the arm and assists with shoulder and elbow motion in a gravity-eliminated plane. Suspension slings may also be used by clients with weak or absent shoulder or elbow muscles. A strap is suspended from an overhead rod to support the arm, with springs attached to the strap to allow movement in specific directions. Both orthotic devices can be used to assist with daily living tasks.

Bedrails, overhead trapeze, or rope ladders are devices that assist in bed mobility and dressing tasks. In combination with adapted methods, these compensatory procedures can enable independence in these functional tasks for those with decreased strength and ROM.

Adaptations may need to be made to electrical appliances or electronic aids to daily living. These may include adapting remote-control devices, VCR and DVD players, iPods, door openers, lights, stereo systems, computer switches, and different types of cell phones (James, 2008). The speaker phone option, speed dial and favorites option, and voice-activated command on cell phones make verbal communication easier than with rotary or wall-mounted phones.

Writing devices come in a variety of options and are commercially available, or a figure-of-eight writing splint can be made from thermoplastic materials. Splints can be used for writing, and being able to write a legal signature is an important goal. Book holders and automatic page turners are available commercially, or a pencil inserted into a universal cuff with the eraser end pointed out is an easy way to turn pages, dial a phone, or use a keyboard. Books on tape or electronic readers can also be used. Mouth sticks can also be used to turn pages, write, or use a keyboard.

Coordination

Stabilizing objects and reducing fine motor movements will help in compensating for poor coordination. Suction devices will hold items (nail brushes, cutting boards, etc.) steady, and pump-action containers do not require prehension to operate. Using a plate guard or bowl with raised edges makes eating easier, and a bath mitt or sponge with a strap makes bathing more efficient.

Using elastic shoelaces or slip-on shoes eliminates the need for tying shoes. Having medications with non-childproof lids is helpful for those with poor coordination, decreased grasp, and low vision. Electric devices (e.g., an electric razor, electric toothbrush) may be good alternatives for the individual with poor coordination. Magnetic jewelry closures make wearing necklaces and bracelets possible.

If tremors are causing the incoordination, weighting the devices used helps to dampen the tremors. Weighted eating utensils have been found to be an effective way to improve feeding performance (McGruder, Cors, Tiernan, & Tomlin, 2003). Heavy cookware helps decrease tremors, and pans, pots, and serving dishes with double handles provide greater stability. A serrated knife is less likely to slip than a straight-edge knife (Holm et al., 1998). Oven controls in the front are easier for people with many types of limitations, including incoordination, loss of ROM, and decreased strength.

Vision

Contrast is used to differentiate items for the low-vision client, such as using a dark cutting board for cutting a potato and a light cutting board for cutting a tomato. Other contrast examples would be pouring coffee into a light-colored cup and using colored toothpaste, adding contrast to white brush bristles (Beaver & Mann, 1995; Cooper, 1985; Cristarella, 1977; Lempert & Lapolice, 1995). Contrasting dinnerware is another way that contrast can be used to compensate for decreased vision, and use of separate dishes for different food items is another suggestion for eating. Having the salt shaker in a round container and the pepper in a square one can provide shape contrast.

Use plastic tape of contrasting colors to mark different items. Contrasting colors of colored tape at the end of a cane may make locating the cane easier. Labeling items with large, black print, tactile labels, or Braille can also help discriminate one item from another on a shelf or in a cupboard. Floating a brightly colored object in water can enable judging water height when filling a bathtub (Holm et al., 1998; James, 2008).

Making things easier to see can also be done by changing the lighting. Replacing overhead incandescent lights with fluorescent lights and being aware of glare can help people with low vision. Avoiding shiny surfaces (tabletops, floors) and excessive clutter makes it easier to find objects easily and quickly.

Dressing can be easier if shirts are kept buttoned except at the neck. This makes dressing easier, and the clothing stays on the hanger better. Washable puff paints can be used as a color system of dots or letters on clothing (Holm et al., 1998; James, 2008). Using an electric razor, soap on a rope, and pump soap dispensers are helpful adaptations for grooming.

Magnifying images and types can be done by using a page magnifier, enlarging copies, or using large-print books. The font size on computers can be increased for easier reading, and many devices are "talking" or voice-activated, such as computers, watches, kitchen scales, and clocks. Oversized phone dials, calculators, and watches are helpful adaptations for the visually impaired. Computer optical scanning devices help make printed materials easier to read. Prism glasses can be useful while reading in bed. Phone apps are also available for eliminating the need to look at the phone screen that dials numbers by shaking the phone (A Special Phone), personalizing ringtones, remote video connections (Be My Eyes), or enlarged contact lists, among other alternatives available online.

Communication

Many apps have been developed to address a variety of communication needs. Dragon Diction uses voice recognition for easy communication and the Functional Conversation app (Linguisystems) addresses the conversation skills for older students and adults who have a variety of disorders including autism, aphasia, social language, auditory processing, and expressive language. Tap to Talk app turns a phone into an augmentative and alternative communication device and the Say Hi! app eliminates the need to touch the screen for those with severe disabilities, limited movements, and decreased dexterity. Bluetooth voice dialing also is useful for those with motor control problems. Video relay services on smartphones enable American sign language users to speak to call recipients and replace text for those who are deaf (Buning, 2014, pp. 520-557).

Impaired Cognition

The primary concern for clients with cognitive deficits is safety. Poor judgment or impulsiveness when using sharp objects or remembering to turn off the stove or iron requires objects that reduce risks to the client. Appliances that turn off automatically (e.g., irons, hairdryers) minimize safety threats to clients with decreased memory and attention span. Using alarms to alert the client to perform certain tasks at certain times of the day may help with task performance (e.g., an alarm might alert the client for when to eat or take medication). Many of the adaptations for cognitively impaired clients are made to the environment by the caregiver or family to ensure safety.

Use of One Side of the Body

In many tasks, one hand stabilizes the item and the other hand performs the activity. Consider peeling a potato: one hand holds the potato, while the other hand peels the potato. Consider washing a glass, cutting a sandwich, or applying toothpaste to the toothbrush, and the actions of the two hands follow this same pattern. One of the challenges for people who have the use of only one side of the body is that they have lost the stabilizing function of one of the hands, so adapted equipment is needed to provide that. Suction devices are used on many items (e.g., nail clippers, bottle brushes, buttonhooks), which provide this stabilizing function. A double-sided suction device ("octopus") can stabilize dishes in a sink with one side attaching to the sink and the other suction portion attaching to the plate. Using a suction device on a long-handled sponge may make bathing easier. Nonslip surfaces (Dycem or damp washcloth) secure items.

A freestanding toilet paper holder may make it easier for a person with use of one side of the body because the paper is positioned vertically and not horizontally (Ali et al., 2008) and can be positioned on either side of the toilet. Using suspenders or slacks with elastic or hooks may make donning clothing after toileting easier with one hand.

A rocker knife is an additional piece of equipment that makes cutting meat and food easier with one hand. Instead of a back-and-forth method of cutting (or sawing), the rocker knife has a curved cutting edge, so the knife is rocked along the edge to cut food. Adapted cutting boards with stainless steel nails enable stabilization of food while cutting. Often, these adapted cutting boards have suction feet or nonslip material for stabilization while cutting.

Functional Mobility

Wheelchairs, canes, walkers, and other ambulation devices and orthoses permit functional mobility that is otherwise limited by decreased strength, endurance, or ROM. Careful consideration of the client's capacities and limitations, the expected environment, distances covered by the client during daily tasks, and knowledge of mobility devices need to be coordinated. Proper measurement of the wheelchair to ensure a good fit is essential for function and to prevent further disability. For example, a self-reclining wheelchair is very useful for people with low blood pressure, but shear forces may cause skin breakdown in insensate areas. Matching the wheelchair to the person requires collaboration with the client and other health care professionals. A few of the adaptations to wheelchairs are listed in Table 13-16. This table provides sample goal statements, methods, and principles behind why you are changing the task by using adapted devices. This is not an exhaustive list of all of the possibilities, and there is redundancy in the types of equipment or devices that are beneficial for a wide variety of limitations.

Table 13-16

CHANGING THE TASK: ADAPTING TASK OBJECTS INTERVENTION AND DOCUMENTATION

GOAL

Client will (be independent/modified independent) and (require maximal/moderate/minimal/standby assist or verbal/physical cue) to perform ADL (specify tasks) in (specify number of weeks/days) by using:

METHOD	**PRINCIPLE/RATIONALE**	**EXAMPLE**
Adapted task objects or adaptive devices or orthotics that	Compensate for lack of full reach or ROM	• Long-handled sponge • Dressing stick • Stocking or sock aid • Elastic shoelaces • Long-handled shoe horn • Long-handled reacher • Long-handled utensils • Long straw with clip • Long-handled comb • Aerosol deodorant adaptation • Wiping tongs • Suppository inserter • Raised toilet seat • Long-handled dustpan • Sponge mop with squeeze handle on side • Long-handled dusters • Adjustable office chairs • Electric or spring-loaded lift for chairs to assist with standing • Mobile arm support or suspension sling
	Compensate for lack of strength	• Mouthstick for typing • Speaker phone • Mobile arm support • Overhead suspension sling • Elevated table to axilla height to support arm and eliminate gravity • Vacuum cleaner wand attachments • Dolly with large casters for carrying a pail of water • Self-propelled vacuum with automatic cord rewinder • Lightweight carpet sweeper • Cordless, handheld vacuum • Lightweight brooms • Rope ladder • Trapeze bars • Sliding board for transfer • Use powered tools and utensils • Wheeled cart to transport items • Wheelchair lapboard • Tub seat • Grab bars • Use of bicycle gloves to push wheelchair

(continued)

Table 13-16 (continued)

Changing the Task: Adapting Task Objects Intervention and Documentation

Method	Principle/Rationale	Example
Adapted task object or adaptive devices or orthotics that	Compensate for lack of full hand closure	• Lightweight, built-up handles on pencil, utensils, comb, brush, etc. • Universal cuff with utensils, razor • Flexor hinge splint (tenodesis splint) • Corel or nonbreaking dishes • Writing devices (use with roller ball pens for less friction) • Phone cuffs • T-shaped handle for tools, wheelchair control • Foam insulator to provide friction, plastisol • Plexiglass or plastic straws • Wiping tongs • Suppository inserter • Raised toilet seat • Digital stimulators • Adapted or lever faucet handles • Soap on a rope • Liquid soap • Bath mitts • Terrycloth bathrobe • Button hook device • Built-up handles on pots, pans • Built-up handles on brooms, irons • Bottle brush on suction mop with mechanism to wring sponge one-handed • Book holder • Electric page turner • Mouthstick • Levers to electronic aids to daily living equipment • Autodialing phones • Use of bicycle gloves to push wheelchair
	Compensate for lack of vision	• Page magnifier • Prism glasses • Long-handled skin inspection mirror • Braille labels • Magnify type or images • Devices to provide auditory, tactile, or kinesthetic feedback • Color contrast • Shape contrast • Computerized optical scanning devices • "Talking" or voice-activated computers, watches, kitchen scales, clocks • Oversized phone dial, watches • Large-print cookbooks, books • Autodialing phones • Corel or nonbreaking dishes

(continued)

Table 13-16 (continued)

Changing the Task: Adapting Task Objects Intervention and Documentation

Method	**Principle/Rationale**	**Example**
Adapted task object or adaptive devices or orthotics that	Compensate for cognitive deficits	• Appliances that turn off automatically • Alarms or reminder systems
	Compensate for the use of one side of the body	• Suction devices or suction added to tools, utensils (octopus device) • Nonslip materials • Long-handled sponge • Dressing stick • Stocking or sock aid • Elastic shoelaces • Long-handled shoe horn • Long-handled reacher • Aerosol deodorant adaptation • Wiping tongs • Suppository inserter • Raised toilet seat • Long-handled dustpan • Sponge mop with squeeze handle on side • Long-handled dusters • Adjustable office chairs • Electric or spring-loaded lift for chairs to assist with standing • Freestanding toilet paper holder • Suspenders or slacks with elastic • Rocker knife • Corel or nonbreaking dishes • Crack eggs one-handed • Separate eggs via egg separator, funnel, or large slotted spoon

Wheelchair (or cane, walker, etc.) that	Compensates for limited mobility by permitting self-propulsion (of the wheelchair) assisted mobility (cane, walker, etc.)	• Seat
		  ∘ Narrow adult (requires less upper extremity abduction, which is tiring)
		  ∘ Low hemi-seat (propelling foot easily reaches floor)
		• Wheels
		  ∘ 8-inch diameter (more stable on rocks, curbs, etc.)
		  ∘ 5-inch diameter (tighter turns)
		• Rims
		  ∘ Spoke extensions (clients with quadriplegia can push with palm or webspace; often use bicycle gloves for better traction)
		  ∘ Double rims (hemiplegic can push chair with one hand)
		  ∘ Flat rim (lighter weight)
		• Electric wheelchair
		  ∘ One-arm drive wheelchair for some clients with a cerebrovascular accident

	Compensates for limited mobility by permitting transportation of objects	• Pouches attached to wheelchair • Wheelchair laptray/lapboard • Crutch holders attached to wheelchair • Walker bag • Wheeled cart

(continued)

Table 13-16 (continued)

Changing the Task: Adapting Task Objects Intervention and Documentation

Method	Principle/Rationale	Example
Wheelchair (or cane, walker, etc.) that	Compensates for limited mobility by facilitating proper positioning	• Back ◦ Reclining back (better trunk stability) ◦ Reclines for low blood pressure ◦ Head extension (for poor head control) • Armrest ◦ Adjustable height (to ensure proper arm and trunk support) ◦ Arm troughs/lapboards (upper extremity positioning) ◦ Offset arms (increases inside width between uprights for wider hips) • Legrest ◦ Elevating (for edema or problems with blood pressure) ◦ Calf pad (prevents leg from sliding off footrest) • Footrest ◦ Heel strap (prevents foot from sliding off footrest) ◦ Lateral supports (for better and lateral stability) ◦ Seatbelt (keeps hips back so pelvis and trunk can rest against backrest and trunk is erect) • Seat ◦ Hard seat (inhibits lower extremity spasticity; promotes neutral pelvic tilt and symmetrical weightbearing) • Cushion ◦ ROHO (Permobil) seat cushion (for pressure relief) ◦ Jay seat cushion (for pressure relief and lateral support) ◦ Numerous abductor devices (inhibits leg scissoring and extension, which cause client to slide out of wheelchair) ◦ High-density foam
Wheelchair modifications that	Overcome architectural barriers	• Seat ◦ Narrow adult (for narrow doorways, navigating congested areas) • Legrest ◦ Detachable, reduces turning space for wheelchair • Armrest ◦ Wrap-around armrests are 2 inches less in overall width ◦ Desk arms permit movement under tables ◦ Detachable armrests to get closer to tables ◦ Lapboard when wheelchair will not fit under table, sink, etc.
Ambulatory aids that	Permit transportation of objects	• Walker pouch or bag • Backpack while crutch-walking • Lapboard • Apron

Changing the Context and Environment

Context includes all that surrounds the client including cultural, personal, temporal, and virtual circumstances (Sidebar 13-5). Environment includes the physical and social conditions that surround the client (AOTA, 2014). Social and physical environments influence the function and well-being of older adults (Day, Carreon, & Stump, 2000).

Sidebar 13-5 Changing the Context Principles

Changing the context includes consideration of physical, cultural, personal, temporal, and virtual circumstances of the client. Caregiver and client education will prevent disability and injury by using good body mechanics, ensure joint protection, promote health, protect the body from further structural damage, maintain the joints in functional positions, prevent falls, ensure safe mobility and transfers, maintain physical capacities, ensure safety for somatosensory impairments, and ensure that precautions are followed.

Occupational therapists are well-qualified to make recommendations and adaptations to these environments and contexts. Occupational therapists understand activity analysis, know how impairments limit functional performance, and recognize how occupational performance is promoted in optimal environments (AOTA, 2000; Cohen, 2016; Davison, Bond, Dawson, Steen, & Kenny, 2005). Entry-level educational standards mandate that occupational therapy practitioners can evaluate, design, fit, and fabricate assistive technologies and adaptive equipment (Accreditation Council for Occupational Therapy Education, 2011). Beyond the entry-level education of occupational therapists and occupational therapy assistants, the AOTA offers Specialty Certification in Environmental Modifications, and continuing education is available from the National Association of Home Builders to earn the Certified Aging in Place Specialist designation. The Rehabilitation Engineering and Assistive Technology Society of North America also provides advanced competencies through ongoing professional development and competence with certification as an Assistive Technology Professional and as a Seating and Mobility Specialist (Rehabilitation Engineering and Assistive Technology Society of North America, 2017).

Cultural and social changes may occur as a part of the teaching/learning process experienced by the client and caregivers as a part of intervention. Education is a necessary part of caregiver and client training, with a strong emphasis on safety to promote health, prevent disability, and increase participation. Training caregivers and family members to assist with or assume care for the client may influence the social environment of the client, which may result in changes in relationships and expectations of all involved. This may be reflected in the amount and degree of emphasis on the client's assumption of responsibility for his or her own care. In some societies, it is the responsibility of family members to care for a disabled person. In others, independence in as many tasks as possible is the valued outcome. The social context is the expectations of the members of society, while the cultural context is reflected in the laws and policies of the society (AOTA, 2014).

Within social contexts, there are always individual responses that may or may not include the views of the predominant cultural group. Making the assumption that this individual, who is your client, adheres strictly to all dominant social values is not realistic. The importance of learning what the client values and identification of his or her desired outcomes, needs, capabilities, goal orientation, values, and beliefs cannot be overemphasized (Bondoc et al., 2016). The specific meaning of occupational tasks to the individual is a vital part of the assessment process.

When considering what home modifications should be made, characteristics of the person, environment, and occupations are assessed. A thorough assessment of the client's balance, coordination, endurance, safety awareness, strength, attention, vision, problem solving, and communication skills are assessed (Fagan & Sabata, 2011) to determine if the client will benefit from the changes and will use the modifications safely. Ask what treatment ideas, strategies, and devices have already been tried prior to this assessment and what is the client's familiarity with the proposed modifications and technology (Mouldovan, 2016).

Assessment of the environmental surroundings, how much assistance is required to acquire environmental supports, and what level of training must be done to enhance safety and achieve occupational goals must be done as well (Stark & Keglovits, 2014).Universal design takes into consideration all of the possible users of the space in the home, so all members of the family should be involved when physical modifications are made in the home (Solet, 2014).

What one considers safe may vary from one person to another. Oakes (2013) suggests that older adults may not perceive a situation as hazardous, such as overloaded electrical outlets, inadequate lighting, and excessive clutter. Lifelong patterns of behaviors and habits might not be perceived to be hazardous, so understanding how older adults give meaning to the term *safety* and to safety practices may be the first step in home modification (Aminzadeh, Edwards, Lockett, & Nair, 2000; Gitlin, 1998). Efforts to make a home safer by using adapted methods or devices will be unsuccessful if the client does not perceive that the changes need to be made.

The socioeconomic status of the person may have some influence on the types and amount of home modification recommendations made by occupational therapists. Many older adults live in older homes, live on a fixed income, have high fixed costs, and are unable to repair and maintain their homes. Low-income and minority older adults, who are more likely to live in deteriorated housing, lack resources to make the necessary modifications to create a safe environment. Publicly insured clients receive fewer home modification recommendations compared to privately insured clients and are generally more limited in their ability to pay for equipment and modifications. Unfortunately, publicly insured clients are also discharged from rehabilitation facilities with significantly less functional independence and may have needed the modifications more and for longer periods (Lysack & Neufeld, 2003).

Organizations such as Rebuilding Together, a nonprofit organization, provides free home repairs and home modifications to low-income homeowners (Oakes & Leslie, 2012;

Table 13-17

SAMPLE OF TOOLS FOR ENVIRONMENTAL ASSESSMENT

TEST	RESOURCE
Assessment of Home Environments	Yarrow, Rubenstein, & Pedersen (1975)
The Home Observation for Measurement of the Environment	Bradley, Caldwell, Rock, Hamrick, & Harris (1988)
Housing Enabler	Iwarsson & Isacsson (1996)
Home Falls and Accidents Screening Tool	Mackenzie, Byles, & Higginbotham (2000)
In-Home Occupational Performance Evaluation	Stark, Somerville, & Morris (2010)
Safety Assessment of Function and the Environment for Rehabilitation—Health Outcome Measurement and Evaluation	Oliver, Blathwayt, Brackley, & Tamaki (1993)
Craig Hospital Inventory of Environmental Factors	Harrison-Felix (2001)
Environmental Functional Independence Measure	Danford & Steinfeld (1999)
Comprehensive Functional Assessment and Evaluation of the Home	Mann, Ottenbacher, Fraas, Tomita, & Granger (1999)

Waite, 2013) and has formed a partnership with the AOTA. Interdisciplinary programs, such as the Baltimore-based CAPABLE (The Community Aging in Place, Advancing Better Living for Elders program), funded by the Center for Medicare & Medicaid Innovation, address clients' self-identified problems in home safety, fall prevention, and basic and IADL (Bridges, Szanton, Evelyn-Gustave, Smith, & Gitlin, 2013; Szanton, Leff, Wolff, Roberts, & Gitlin, 2016; Szanton et al., 2011; Toto, 2017). In this program, occupational therapists, registered nurses, and handymen provide home modifications to promote occupational engagement and ensure that medical, functional, safety, and mental health needs are met as value-based care (Szanton et al., 2016). Since this program is client directed, it is less likely that modifications and devices will be abandoned.

Changing the context and environment includes changing the physical environment by providing home modifications and changes in routines and habits to support safe and healthy participation in activities within the home and the community. Education of the client and family are part of safety and emergency maintenance and health management and maintenance as important IADL that involve context and environment.

Changing the Physical Environment

Most people want to remain in their homes, and enabling clients to remain in their own homes is a major concern for the disabled and aging population. Home modifications benefit older adults attempting to age in place (Stark et al., 2009). Older adults with limitations significantly improved their occupational performance when modifications were made to their homes to remove environmental barriers (Stark, 2004).

Aging in place enhances the quality of life of older adults by allowing them to continue participation in valued activities in their own communities (AARP Research & Strategic Analysis, 2011).

Home-based education and training of clients and their families supports and enhances functional performance and competence (Dunst et al., 2001; Dunst, Trivette, Hamby, & Bruder, 2006; Szanton et al., 2016). Training in the home leads to a better understanding of the client's culture and social, physical, and emotional contexts (Benthall, 2016; O'Sullivan, 2016). Home-based skills training reduces caregiver burden and improves quality of life for caregivers and care recipients (Gitlin, Corcoran, Winter, Boyce, & Hauck, 2001; Gitlin et al., 2006) and has been found to be effective and cost efficient (Graff et al., 2008).

Changing the physical environment enables greater access to public and private facilities and greater participation in community, work, and leisure activities. Greater access to public and private facilities will promote independence that otherwise may not have been possible. Home modifications are intended to increase safety, security, and independence for the client and family. Environmental adaptation ranges from slight modifications to architectural design and new construction (Moyers, 1999). Environmental modifications are advantageous when problems cannot be solved any other way. By making these changes, valued roles may be regained.

Tools to assess the environment are provided in Table 13-17. Some tools listed have demonstrated reliability and validity (Housing Enabler, Home Falls and Accidents Screening Tool, Safety Assessment of Function and the Environment for Rehabilitation—Health Outcome Measurement and Evaluation, Craig Hospital Inventory of Environmental Factors, Environmental Functional Independence Measure), and some are standardized with established norms of performance (Housing Enabler).

Complex environmental modifications include a combination of environmental and structural changes as well as assistive technology and services. The intent of complex environmental modifications is to eliminate environmental barriers via modifications, assistive technology, provision of resources and products based on the client's level of function with increased performance, decreased caregiver burden, and increased participation in occupational tasks as the outcome of intervention. These interventions require advanced or specialized knowledge, training, and experience (AOTA, 2010b). Some examples of complex environmental modifications provided by occupational therapy practitioners may include (AOTA, 2015b):

- Consultation on projects requiring additional knowledge and experience, such as remodeling and construction of new homes, work environments, and community spaces
- Modifications that expand beyond consumer-grade and marketed adaptations, such as grab bars, ramps and assistive technology found at retail and medical equipment stores
- Advocacy for the needs of clients requiring modifications to home and community environments through interfacing with government agencies, payment sources, and community planners

Not all adaptations and home modifications need to be complex or expensive. The President's Committee on Employment of People With Disabilities developed a sample list of adaptations to homes and worksites, particularly in reference to reasonable accommodation and the Americans With Disabilities Act (https://www.eeoc.gov/policy/docs/accommodation.html and https://www.eeoc.gov/facts/accommodation.html). There are often simple solutions to problems of accessibility. A person who is unable to work because the wheelchair will not fit under the desk or a person who cannot transfer to a sofa because the sofa is lower than the wheelchair will benefit from raising these surfaces with wooden blocks. Changing how a task is done can also provide simple solutions to accessibility problems. Using a tape recorder or transcriber rather than writing is helpful for people who need to write reports and altering schedules to permit frequent rests is a helpful solution for people with poor endurance.

One disadvantage to environmental adaptations is expense. Ramps, chair glides, elevators, and modified vans are all very expensive solutions to environmental problems. Occupational therapists have long been what Cohen (2016) described as *makers*, where we create or adapt objects, including tools and devices. With the advent of new technology, such as three-dimensional printers, prototypes can easily be created for one individual. DIYAbility is an organization that works collaboratively with people with and without disabilities to increase independence with assistive devices. Another disadvantage is that, often, the changes are not portable. For example, if a ramp is installed at one home, it often is not easily transported to another. If the deficit is temporary, then the cost may not seem justified, so the person may be without sufficient modifications that might ensure independence (Oakes & Leslie, 2012). A good resource for device reutilization is the Pass It On Center, the National Assistive Technology Device Reutilization Coordination and Technical Assistance Center. A client with an unmet need can be provided with reutilized equipment that is less expensive and has a lower copayment for the client (Walker, Walker, & Bean-Kampwerth, 2012). The Association of Assistive Technology Act Programs (www.ataporg.org), also a helpful resource, provides technical assistance, educational programs, and support to its members.

Occupational therapy home modification intervention is effective and has a positive impact on the client's self-rated ability in daily life, especially on decreasing the level of difficulty of task performance and on increasing safety (Petersson et al., 2008). Home modification intervention results in fewer functional limitations and dependence on mobility devices (Fänge & Iwarsson, 2005) and is linked to increased satisfaction and occupational performance (Stark, 2004). There is strong evidence that occupational therapy practitioners should use home modification to improve functional performance, particularly in frail older adults (Stark & Keglovits, 2014). Wilson, Mitchell, Kemp, Adkins, and Mann (2009) provided assistive technology and home modification intervention for individuals who were aging with a disability, and results suggested a slower decline in function for the treatment group and that the treatment group was more likely to use equipment to maintain independence.

Home modifications also had strong evidence to support occupational therapy intervention to improve the ability to provide care to others in the home, especially those with dementia. Weaker evidence suggests that occupational therapists should use home modification interventions at discharge for postoperative hip repair clients, to improve function for older adults aging with physical disabilities, and for people with low vision (Siebert, Smallfield, & Stark, 2014). Home modification intervention for community-dwelling individuals with schizophrenia also has positive but limited evidence, and the available evidence of home modifications by occupational therapists are an effective intervention for reducing falls.

Specific environmental changes and considerations are provided in the following sections. Table 13-18 provides a brief summary of the physical adaptations that can be made and possible goal statements for documentation.

Entrances

Getting into the home is the first issue of accessibility. This includes having accessible pathways if the client traverses from the street or a garage to the house.

If there are steps into the house, check that they are not broken or uneven. Painting the first and last steps different colors provides contrast that is helpful when ambulating on stairs. Putting a grab bar or drawer pull on one side of your door can enable someone to pull with the arms and push with the legs to navigate steps. Stair glides are useful for interior stairs that are at least 22 inches wide to travel from one level of the home to the next. Securely mounted handrails on both sides is a safer option than handrails on only one side. Keeping a cane or walker on each level eliminates the need to use the device on the stairs (Trudeau, 2016). Keep stairs uncluttered and, if the stairs are carpeted, be sure the carpet is well secured and not unfastened or frayed.

When considering building a ramp, the client's strength and balance are factors, as is the length and slope of the ramp and the stability of the wheelchair. If a ramp is needed, ramps should follow a 1:12 ratio (i.e., for every rise in the slope, there needs to be 12 inches of ramp). Steeper ramps are possible for those clients in wheelchairs with good upper extremity strength. Because ramps that follow this ratio may become very long, switchback ramps are a good alternative, with at least a 5 × 5-foot platform between rises for an adequate turning radius.

Curbs on ramps prevent wheelchair wheels from moving off the ramp, and nonslip material applied to the ramp surface

Table 13-18

CHANGING THE CONTEXT: PHYSICAL ENVIRONMENT INTERVENTION AND DOCUMENTATION

GOAL

Client will (be independent/modified independent) and (require maximal/moderate/minimal/standby assist or verbal/physical cue) to perform ADL (specify tasks) in (specify number of weeks/days) by using:

METHOD	PRINCIPLE/RATIONALE	EXAMPLE
Change the context by modifying the environment, which	Provides access to transportation	• Transport system ∘ Paratransit will not take clients out of the house ∘ Kneeling bus ∘ Buses with lifts ∘ Wheelchair tie-downs in buses/trains • Private transportation ∘ Modified driver controls ∘ Vans with lifts ∘ Handrails on both sides ∘ Nonslip surface on ramp ∘ Curbs on ramp
	Provides outside access to housing, public and private facilities, and recreation	• Parking spaces ∘ Located near entrances, clearly marked ∘ 12 feet wide • Curb cuts ∘ Curb cuts should be textured ∘ Minimal lip ∘ No more than 2-degree cross slope ∘ No more than 5-degree rise • Doorways ∘ Minimum 36-inch clear opening (32 inches with door open) ∘ Electric doors with 13-second closure delay ∘ Use of offset or fold-back hinges ∘ Inset doors ∘ Remove door frame ∘ Door thresholds should be 0.5 inches or less with beveled edges ∘ Kick plates on the bottom of doors ∘ 5 pounds of force or less to open a door ∘ Lever door handles ∘ Adapted keys or keyless locks • Elevator ∘ Call button 36 inches from floor ∘ Door 32 inches wide ∘ Visual, auditory, tactile buttons • Signage ∘ Use of symbols and Braille • Ramps ∘ 1:12 ratio ∘ Switchback ramp if ramp is long ∘ 5 x 5 foot platform for turns

(continued)

Table 13-18 (continued)

CHANGING THE CONTEXT: PHYSICAL ENVIRONMENT INTERVENTION AND DOCUMENTATION

Method	Principle/Rationale	Example
Change the context by modifying the environment, which	Provides inside access to housing, public and private facilities, and recreation	• Floors ◦ Wooden floors, if even ◦ Low pile carpet ◦ Nonslip linoleum • Kitchens ◦ U or L shaped ◦ Cabinets 12 to 15 inches above counter, or 48 inches from floor; no more than 19 inches deep ◦ Oven 30 inches from floor ◦ Side-by-side refrigerator ◦ Sink 24 to 48 inches high, 36 inches wide, 5.5 inches deep • Bathrooms ◦ Diameter of 60 inches ◦ Toilet 17 to 19 inches high ◦ Grab bars ◦ Custom-made shower stall ◦ Roll-in showers

increases traction for the wheelchair user. This can be commercially available nonslip strips or simply mixing sand mixed in with paint to eliminate slippage. Handrails on both sides of the ramp that extend to the top and bottom of the ramp are useful for people in wheelchairs and for people with low vision as they ascend and descend a ramp.

Outdoor lighting and accessible doorbells and mailboxes are additional features to consider when making the outdoor areas accessible. Well-illuminated outdoor features (stairs, sidewalks) are especially useful for people with visual impairments.

Motion-detection lighting eliminates the need for finding a light switch in the dark and can save money on energy costs (Trudeau, 2016). Clients with low vision, poor balance, and decreased endurance should avoid open stairwells, low balcony rails, and doors that open directly to steps. Low-hanging objects are also hazards, such as signs, plants, and mailboxes.

In general, doorways need to allow a minimum 36-inch clear opening (32 inches with the door open). Adaptations for narrow doorways include removal of the doorframe, removal of the door, offset or fold-back hinges or inset doors, replacing the door with a curtain, or considering the construction of pocket doors (the door slides into the wall). Door thresholds should be 0.5 inches or less with beveled edges. Door sills can be removed and a thick mat can be placed over the threshold to eliminate the sill bump.

Kick plates on the bottom of doors prevent damage to the door when footrests are used to hold a door open. The force needed to open a door should be no more than 5 pounds. Lever door handles or doorknob adaptations permit easy access, and keyless locks are good for clients with limited hand use. Consider whether the client can unlock the door from the outside and also lock it from the inside.

Flooring and Furniture

Wooden floors are easy to traverse for ambulators and for people in wheelchairs as long as the floor is even. Linoleum with a nonslip finish is preferable to a floor with a high gloss. Carpets should have dense loops or be dense with a firm, thin pad. Removal of small area rugs is important to consider for those who are ambulatory, are in a wheelchair, have incoordination or ataxia, or have low vision.

Furniture may need to be rearranged to provide enough space for mobility and turning radius. Any unnecessary items can be eliminated, and furniture should be firm and high enough for easy transfer. If a chair or sofa is too low, leg extenders can be used. These can easily be made by drilling holes into a piece of wood or they can be purchased commercially. If the furniture is too high, sofa legs can be removed and chair legs can be cut to a more appropriate length. Furniture should provide postural support, and the texture of the furniture covering should consider the ease of transfers, risk of skin abrasions, and slipping and shearing forces.

Kitchen

Kitchens that have an L or U shape are most advantageous because turning and maneuvering a wheelchair is easier. Removable legrests and detachable armrests on wheelchairs enable further reaching into cupboards. Lapboards on wheelchairs and wheeled carts help to transport items in the kitchen and to other rooms. For ambulatory clients, a continuous countertop is good, so items can be slid rather than lifted. A drop-leaf kitchen table or a table attached to a wall can provide the proper height work surface and not be in the way. A slide-out board under the counter can add working space at an accessible height.

Cabinets are best if they are 12 to 15 inches above the counter or 48 inches above the floor and no more than 10 inches deep. With wheelchair users, there needs to be toe space to clear the wheelchair footrests. Often, removing cabinet and cupboard doors allows easier access. Lazy-Susan devices or turntables and storing frequently used items in cupboards that are between hip and shoulder height for clients who are ambulating prevents undue stretching or bending. Full-extension drawers pull out farther than standard drawers so that items in the back of the drawer can be reached. Drawers and cupboard doors may need to have new knobs or magnetic latches installed for easier grasp. Items that are used most frequently and those that are heaviest should be placed on lower shelves. Asking for help in reaching items on higher shelves may be a better option than using a stepstool when balance can easily be lost (Trudeau, 2016).

The stove or cook top can be at any level that is usable by the client. Leaving the area below the countertop open will provide knee space for a person in a wheelchair. The danger in that is that spillovers could spill through to the person below. Recessed burners or glass-top burners are easier for some to clean but may be unsafe for visually or cognitively impaired clients who cannot see that the burner is on. Front controls prevent reaching over the hot stove to adjust burner temperature, unless the person is unsteady and might bump into the burner controls inadvertently, the client has poor coordination, or for those with small children in the home. A mirror can be placed on the stove to help one see into pots and pans on the stove. A disadvantage to the mirror is that it frequently will get splattered, greasy, and fogged by steam.

A built-in wall oven located 30 inches from the floor is very useful. Large oven and stove dials and an audible click are useful, particularly for the visually impaired person. Having an oven with a side-swing door will permit the user to get closer to the oven and handle food more easily. Heat-resistant countertops make placement of hot items easier and safer, and a wheeled cart facilitates the transport of items for functional ambulators. A 15-inch flat stick is useful in pushing and pulling the oven rack, and oven mitts are easily obtained. A self-cleaning oven is the optimal choice. Microwave ovens and countertop appliances are easy to place at convenient heights.

A side-by-side refrigerator with adjustable shelves is good because the doors are smaller, are easier to open, and require less clearance to access food inside. Turntables on the refrigerator shelves enable easy access to all items. The heaviest items should be placed at lapboard height for clients in wheelchairs. Automatic ice makers and frost-free options save time and are efficient. Adjustable, slide-out shelves make food retrieval more convenient. If a side-by-side refrigerator is not available, a single-door refrigerator with the freezer on the bottom can be used by people who ambulate and by wheelchair users. Newer refrigerator models have split upper doors for the refrigerator and a lower freezer drawer.

Sinks should be between 24 and 48 inches high, 36 inches wide, and 5.5 inches deep. If the sink is too low, the client can develop back strain; if the sink is too high, the elbow may become chafed, and there may be shoulder strain. An overturned dishpan can be placed in the sink with dishes placed on top to raise the level of the sink. A mirror angled above the sink will provide visual assistance in seeing objects in the sink (Marrelli & Krulish, 1999). If the area underneath the sink is left open (by removing cupboard doors), a person in a wheelchair can get closer to the sink. Pipes under the sink need to be covered with foam to prevent burns to insensate areas. Two sinks at different heights may accommodate ambulatory and wheelchair users. A spray attachment on the faucet can be used to fill pots so that it will not be necessary to carry a heavy filled pot. Some clients may benefit from foot-activated pedal valves and others by lever faucet handles. If the dishwasher can be raised 8 inches, the user will not have to bend so much to load and unload dishes. Push-button controls are preferable to a knob that is turned on all appliances. Safety off-switches on stoves, furnaces, and appliances is a good investment (Goodman & Bonder, 2014).

Bedroom

Bedrooms should have sufficient space for maneuvering around the bed and for access to other pieces of furniture in the room. The path to the bed should remain clear, uncluttered, and well-lit. Using motion-sensing lights or night lights is useful when moving in the dark. A bedrail, rope ladder made from 2-inch webbing, or trapeze bar may make bed mobility easier and provide support in transitional movements. Having both a phone and a light near the bed is a good practice (Trudeau, 2016).

Clothing racks in closets may need to be lowered so items can be reached from a wheelchair. Closet doors may need to be removed for easier access. The bed should be at a height that ensures a level transfer, which can be achieved by removing or shortening the legs of the bed or by adding extension blocks to raise the surface. Waterbeds, while helpful to prevent decubiti formation, are difficult surfaces for transfers.

Bathroom

For ease in maneuverability, a bathroom should have a diameter of 60 inches or a 5-foot square for turning. In tight areas such as bathrooms, open cupboards under the countertops and sinks enable a greater turning area. Often, bathroom doors are narrower and ideal dimensions are nonexistent.

Ideally, the toilet should be in a corner opposite from the door. Multilevel sinks, cabinets, and countertops can accommodate all users, and adapted toilet seats and pedestal sinks provide easier access to the sink for wheelchair users (be sure to wrap exposed pipes with foam to prevent burns). If there is sufficient room in the bathroom, a stool can be placed near the sink and counter so that people with decreased endurance can sit while grooming.

Falls often occur in the bathroom due to inappropriate toilet height, absence of grab bars, or lack of nonslip mats in the tub (Oss, Rivers, Heighton, Macri, & Reid, 2012). Toilets should be 17 to 19 inches high for a level transfer, and standard toilets are 14 to 15 inches from the floor. Elevated toilets or commode chairs can raise the toilet height. Often, the toilet is located next to the bathtub, so tub transfers using a tub seat are difficult because there is minimal space to swing the legs into the tub.

Grab bars are useful in the tub and near the toilet. Caution clients to not use towel racks in place of a grab bar. Grab bars can be wall-mounted or attached via suction, or pivoting grab bars can be moved out of the way, which is helpful in the confined spaces of a bathroom. Grab bars can also be a part of a commode seat, which may assist with movement in the small room. A center pole that goes from floor to ceiling can also be used as a way to provide support and takes up minimal space (Holm et al., 1998). Grab bars usually are 1.25 to 1.5 inches thick and can bear 250 pounds. For visually impaired people, grab bars can be installed in contrasting colors to the background.

Tub benches can be used successfully even if the bathroom dimensions are minimal. They have slats so that water will not collect on the chair and are adjustable in height to ensure a level transfer. Hydraulic bathtub chair lifts are available for people who prefer to take baths but are unable to transfer into the tub. Rubber suction-grip tub mats are a possible solution for slippery bathtubs. Shower doors can be removed and replaced with a plastic curtain hung with hooks over a spring-tension bar if shower doors prevent entry into the shower.

Handheld showers, used with the tub seat, allow a person to sit to bathe safely. The handheld shower head can replace the existing showerhead, can be provided as an additional showerhead, or can attach directly to the spigot. Handheld showers can also be mounted to a bar that can allow changes in position. It is best if there is an on/off switch on the handle and that the water shuts off automatically if dropped. Diverter valves can be added so that if other family members do not wish to use the handheld shower, they can use the regular showerhead. Anti-scald devices are available if the client has decreased sensation, and the temperature on the hot water heater can be adjusted to safe levels to prevent burns. A thermometer can also be used to test water temperature, which should be below 120°F. A tap overflow alarm will alert inattentive or visually impaired people when water levels are too high. An emergency call system is particularly helpful in the bathroom, where many falls and accidents occur. Roll-in showers are a nice option for individuals in wheelchairs. Coupled with a stable seat, a roll-in shower can be beneficial for those with poor balance and decreased endurance because there is no tub to step over.

Child Care Suggestions and Modifications

Child care presents several challenges to the disabled client. If the client is ambulatory but bending over is difficult, cribs can be raised by raising the crib legs, adjusting the mattress, or even by using two mattresses. For the client in a wheelchair, the typical drop-side crib can be adapted by cutting the middle of the crib side and attaching two hinges at each end with a latch in the center. Another alternative might be to make the crib side slide along horizontal rather than vertical channels. Bathing an infant may be easiest in a modified kitchen sink for both the wheelchair and ambulatory client. Although a plastic tub or small baby pool can be used to bathe a baby, emptying the tub may be difficult without assistance. Playpens are very useful in confining the child safely.

Raising the legs of a playpen or using a portable crib will minimize bending. Adapting a playpen so that a person in a wheelchair can use it with his or her children would be similar to adapting the crib. While the safest place to handle a baby is on the floor, a changing table at a height of 31 inches is appropriate for most wheelchair users. Carrying a baby can be done by using a bassinet on wheels or a reclining stroller if one is ambulatory. Cloth infant carriers can also be used, but be alert that the front styles require back muscle contraction against a load, while back styles compress the vertebrae. For those in a wheelchair, transporting the child on the lap with a seatbelt is appropriate.

Laundry Facilities

For clients who can ambulate, a top-loading washing machine is best, and a raised dryer would minimize bending. Having a waist-high table for folding clothes nearby would enable a smooth, efficient sequence. For clients in a wheelchair, a front-loading washer is preferred with a dryer with side-hinged doors (which is hard to find). If a top-loading washer is used, use of an overhead mirror will enable the person to load the machine. Transporting objects is made easier with a wheeled cart, lapboard, walker bag, or wheelchair pouches or by wearing an apron. Having a clip mounted on the wall will allow one end of a sheet to be held while folding. Mounting an ironing board on a wall at 28 to 32 inches may provide a more appropriate height for this activity. Sitting to sort and fold laundry conserves energy and is a safer method for people with decreased balance and poor endurance.

Safety and Security

The major areas of concern in the home are safety, means of mobility, and client characteristics. Safety includes awareness of sensory deficits, the cognitive abilities to make good decisions and pay attention during task performance, having sufficient physical strength and endurance to complete activities (including grasp), and the ability to use equipment.

Clients may be considered high risk when considering safety in the home for a variety of reasons. An older person living at home or with an elderly caregiver may put the client in a higher risk category. The physical environment must support basic requirements for safety and health, such as refrigeration availability, safe drinking water, adequate heat, and free from pest or infestations (e.g., fleas, bedbugs, lice), and provide adequate protection from the natural environment. If the client is in an abusive relationship (either the client or the caregiver), has a pattern of problematic interactions with others, refuses family help, or is geographically isolated from others, this can also put the client at more risk for unsuccessful community and home reentry. Preexisting or coexisting limitations and multiple pathologies make living at home less likely or more difficult.

The home may have limited adaptability, such as only having one bathroom that is located on the second floor. The client may have used a wood stove but is now on oxygen, or the client used outdoor toilets but is now in a wheelchair. These are examples of limited environmental adaptability. Financial constraints can also limit the type and extent of changes made to the physical environment.

A visit to the client's home allows the therapist to see what tasks the client can do safely, what modifications or adaptations are needed, how much assistance or supervision is required, and what tasks the client cannot do safely. This is particularly valuable because it is the client's own home and the client can demonstrate skills learned in the clinic in the actual environment to which he or she will return. Items in the home that are safety hazards include frayed cords, sharp kitchen implements, use of machinery, repetitive trauma, fires, and exposure to toxic substances. Often, a home visit will identify potential safety hazards that may be overlooked by the family because they see the objects daily and may not see the danger as clearly.

General principles to consider when looking at the client's home are to allow enough space for ease of mobility (whether using a cane, walker, or wheelchair), but not an excessive amount of space, which may be fatiguing. Limiting the travel between tasks completed sequentially will also conserve energy, as well as limiting changes in levels.

Often, a client will turn an existing room (often a dining room) into a downstairs bedroom if there is a full bath on the same level to eliminate the need to travel on different levels of the home. Awareness of lighting, noise, and safety features (e.g., door peep holes at the level of the user) is important as well.

When looking at the home overall for accessibility, it may be easy to overlook how the client can control the environment and safety features. The client needs to be able to control the lights, open and close the draperies or blinds, and adjust the thermostat. Adaptations may need to be made to burglar alarms or to emergency alarm or alert systems. When evaluating the accessibility of the home, be sure to consider two ways to enter the home and have an evacuation route planned in case of emergency. Clients using a respirator or who are on oxygen need to have a back-up plan in place should there be a power failure. A caregiver or aide will need to perform regular maintenance at the home, including changing smoke alarm batteries periodically and checking breaker boxes. Even if the client is unable to use a fire extinguisher, one should be in the kitchen and other areas of the house.

It is important to reinforce the use of smoke and carbon dioxide detectors, which can be wired into the electrical circuits of the home. This would eliminate the need for batteries. Smoke detectors should be on every level of the home. The pitch of the alarm should be low enough to be heard easily by the elderly.

Cordless utensils are excellent devices that diminish the possibility of entanglement in the cord or inadvertently cutting the cord. Appliances that turn off automatically are excellent choices, especially if the client has decreased attention or short-term memory deficits. Devices that turn on automatically (e.g., outside lights with timers, coffee pots) are also good choices.

Portable, cellular, or cordless phones are very helpful because a person in a wheelchair may be unable to reach a wall-mounted telephone in an emergency. Checking the location of light switches, thermostats, and door locks may reveal that these are inaccessible for some clients. Buzzers, intercom systems, or environmental control units are commercially available as a means of contacting others in the home or in independently controlling the environment.

Community Accessibility

Many IADL (e.g., driving and community mobility, religious and spiritual activities, shopping), work, education, play and leisure, and social participation include involvement with family, friends, and others in the community. Livable communities support full participation in meaningful activities for all people (AOTA, 2016a). Because of our knowledge about aging and health conditions, analysis of task characteristics, and ability to evaluate the environment, occupational therapists can work to eliminate barriers in the environment that limit full participation. Healthy People 2020 (U.S. Department of Health and Human Services, 2012), Centers for Disease Control and Prevention (CDC; 2016), the World Health Organization (2017), as well as the AOTA (2016a) accentuate the importance of livable communities to improve health and quality of life. Loss of community mobility has a negative impact on individuals' health and social participation (Edwards, Lunsman, Perkins, Rebok, & Roth, 2009; Frank, Saelens, Powell, & Chapman, 2007).

Mulry and Piersol (2014) described a community program that used education, peer interaction, meaningful occupations, and self-reflection to increase social participation. The program, Let's Go, aimed to prevent negative health effects of social isolation. In 2017, Mulry, Papetti, De Martinis, and Ravinsky examined the outcomes of the Let's Go program, and their findings support occupation-based health programming in the community for marginalized older adults.

Community mobility includes more than the physical capability to navigate in the outdoor, public arena, although wheelchair users confront far more significant barriers within the community and outdoor environment than experienced at home or in the workplace (Arthanat, Nochajski, Lenker, Bauer, & Wu, 2009). The Usability Scale for Assistive Technology—Wheeled Mobility measures seven aspects of contextual mobility: home usability, workplace/school usability, community usability, outdoor usability, ease of use, seating, and safety (Arthanat et al., 2009). Able Road Map is an app that connects users with accessible businesses and facilities.

Programs like Let's Go can have a preventative effect on health problems by promoting wellness and participation, can increase confidence and autonomy, and can decrease isolation (Mulry et al., 2017). Community mobility includes identification of what transportation options are available and effective, the frequency of access to needed services (e.g., medical care), shopping and leisure interests, and the quality of life afforded by community mobility (Stav, 2014). Getting around in the community is possible for the disabled via public and private transportation systems. Information about these options and modifications that can be made to private automobiles and driver's training for the disabled is a valuable resource to share with the client and family.

Parking spaces for the disabled should be clearly marked, located near entrances, and a minimum of 12 feet wide with a 5-foot area serving as a drop-off zone for side-exit vans. The parking space should be connected by an accessible route to an accessible entrance to pathways or buildings. Curb cuts should be textured and have a minimal lip with the street. There should be no more than a 2-degree cross slope, be no more than a 5-degree rise, and have 5-foot level surface at the top and bottom for turning. Pathways should be 36 inches wide with a firm, smooth, nonslip, and continuous surface.

Entrances

Getting into public buildings can be accomplished either by ramps or by negotiating steps. Helping a client in a wheelchair navigate over curbs and stairs is a valuable skill to teach a caregiver. To assist with ascending a curb, the easiest and safest method is to ascend the curb with the chair facing forward or toward the curb. This gives the greatest control of the chair and requires the least effort by the caregiver (Pierson, 1994). This technique is discussed in detail in the following section on caregiver education.

Entrances to buildings should have a 36-inch clear opening (32 inches with the door open) or power-operated door. The door threshold should be 0.5 inches or less, although fire doors are exempt from these requirements. Doors in a series need adequate space between the doors for door swing. Turnstiles and revolving doors are not considered accessible. Directional signs should be posted to indicate accessible entrances and should be 54 to 66 inches off the ground or floor level for easy visibility.

Interiors

Building interiors need to be 48 inches wide and free of obstructions, such as furniture, water fountains, plants, or fire extinguishers. Hard, nonslip surfaces or low-pile carpet are recommended for most types of disabilities. The building interior should not require the person to leave the building or negotiate stairs. Elevator controls should be no more than 60 inches high with doors at least 32 inches wide. Elevator controls should have visual, auditory, and tactile indicators.

Do not forget items like telephone height, light switch location, smoke alarms, elevator call button accessibility, thermostat, and water fountain heights when evaluating accessibility. Remember, too, that accessibility applies not only to those in wheelchairs, but also for ambulators and people with low vision, decreased endurance, and many other limitations.

Restaurants and Theaters

Fast food restaurants and bars may present different challenges for the mobility-impaired client. High counters make ordering and managing food items more difficult. Getting beverages from refrigerated storage or from soda machines is not always possible without assistance. Built-in booths for seating may be challenging for transfers, and high stools and tables cannot be used by those in wheelchairs and with poor balance.

Theaters also have high counters, and a person in a wheelchair might not be seen beneath the level of the counter and may be overlooked in the crowded, noisy cinema lobby.

Shopping

Shopping can be challenging for the mobility impaired. A person in a wheelchair cannot push a cart, so he or she needs to use a basket, which limits the amount the person can buy at any one time and may necessitate more frequent shopping. Reachers may be very useful because many items may be out of reach. Store aisles are often narrow and crowded with items, making movement through the store more difficult. Clothing stores provide accessible changing rooms, but trying on clothing in the store is difficult due to benches that are too narrow or not long enough to permit laying down to don/doff the items.

Grocery stores present a wide variety of colors, sights, sounds, and smells that can easily overload those people with sensory or perceptual deficits. Shiny, highly waxed floors also provide challenges. The wide array of options requires that many purchase decisions be made, which may be very difficult for those with impaired cognition. Getting groceries from the cart to the car is easily remedied by having grocery employees assist with this task, but the problem recurs when unloading groceries from the car at home. Grocery stores now have online ordering where all items are gathered and bagged, requiring only that the items be loaded into the car. Apps are available from many national store chains such as Harris Teeter, Publix, Walmart, Meijer, Kroger, and Giant Eagle.

Other Services

Getting a haircut or going to a dentist usually occurs by sitting in a special chair that can be raised or lowered to a height that is comfortable for the professional to complete the task. The problem is that some people may be unable to transfer to these chairs, and the haircut or dental work needs to be done with the person in the wheelchair.

ATMs are designed for drivers in cars, and counters inside of banks are designed for people who are standing. Again, the height of the counter or location of the ATM may be limiting for people in a wheelchair. Drive-through banking is designed primarily for cars and may be too low for people in vans.

Driving

Driving and community mobility are considered IADL necessary to support daily life in the home and community (AOTA, 2016b). Driving represents independence, self-reliance, and the ability to travel where and when a person wants (Suen & Sen, 2004), thereby supporting social participation, access to health services and the community, and a sense of identity (Chihuri et al., 2015; Oxley & Whelan, 2008; Satariano et al., 2012). Driving cessation, especially in the elderly, was reported to be associated with declines in general health and physical, social, and cognitive functions; depression; decreased community participation; and increased risks of admission to long-term care facilities and mortality (Chihuri et al., 2015; Classen et al., 2010; Fairhall et al., 2014; Fonda, Wallace, & Herzog, 2001; Freeman, Gange, Muñoz, & West, 2006; Golisz, 2014a; Ragland, Satariano, & MacLeod, 2005; Satariano et al., 2012). In a study of participants over age 65 years, a significant difference was found between drivers' and non-drivers' quality of life (*P* value = .000, $P < .05$) with drivers having higher scores (M = 16.19, standard deviation [SD] = 2.29) than those who had ceased driving (M = 9.56, SD = 2.94; Sason, Dietrich, Patel, & Oliveira, 2017).

In a qualitative study by Sanchez et al. (2016), there were five themes that emerged about the varied roles of occupational therapy and driving rehabilitation. These roles included the occupational therapist as an educator, advocate, evaluator, driving trainer, and a role in driving cessation. Occupational therapy practitioners provide services in this area of occupation as generalists and as specialists. The goal is to enhance community mobility across the lifespan and at all levels of ability (AOTA, 2016b).

As a generalist, occupational therapists evaluate the ability to safely engage in driving and community mobility with an understanding of state regulations regarding criteria for safe driving, which varies from one state to another. Referral to driving rehabilitation specialists (DRSs) may be necessary for clients who would benefit from specialized driving and community mobility services.

These specialists have acquired skilled and focused approaches using adaptive equipment, advocacy and recommendations for system modifications, and execution of on-road assessment and intervention (AOTA, 2016b). These DRSs may be credentialed through the AOTA Board and Specialty Certification program (http://tinyurl.com/jt8vp67) and may use the credentials SCDCM or SCDCM–A (specialty certified in driving and community mobility as an occupational therapist or occupational therapy assistant). DRSs may also be certified through the Association for Driver Rehabilitation Specialists (http://www.aded.net) and can obtain CDRS (certified driver rehabilitation specialist) certification. Occupational therapists with these advanced credentials provide enhanced professional capacity for driving and community mobility (Korner-Bitensky, Menon, von Zweck, & Van Benthem, 2010). AOTA developed a guide titled *Spectrum of Driver Services: Right Services for the Right People at the Right Time* (Lane et al., 2014) to differentiate services, training, credentials and outcomes for mobility specialists, available at http://www.aota.org/-/media/Corporate/Files/Practice/Aging/Driving/Spectrum-of-Driving-Services-2014.pdf. In addition, AOTA also provides resources such as the Practitioner Toolkit, tips for developing a driving program, screening and assessment tools, evidence-based research, and certification information (https://www.aota.org/Practice/Productive-Aging/Driving/Practitioners.aspx). Collaboration between the general practice occupational therapist and DRSs is essential for efficient, effective driving assessment and rehabilitation (Dickerson, 2013).

Driving Assessments

Assessments of driving can be conducted in the clinic or on the road. When conducted together, these are referred to as *comprehensive driver evaluations* (AOTA, 2017). The results of these assessments will lead to recommendations about approaches and any adaptive equipment to improve driving safety. If the evaluation results indicate that the client is not safe to continue driving, recommendations about alternative mobility options will be explained to the client and his or her family.

Clinic Based. Clinic-based assessments tend to focus on the physical, visual, and mental abilities required for safe driving. This typically includes an assessment of reaction time, needed for stopping fast enough to avoid a crash; basic visual acuity; and decision making. While a single measuring tool for cognition, vision, perception, or physical ability individually is not sufficient to determine fitness to drive, some tools have stronger predictive evidence than others, and using different, focused tools together seems to be effective for specific medical conditions (Dickerson, Meuel, Ridenour, & Cooper, 2014). More than 80% of the DRSs reported testing visual acuity, ROM, muscle strength, Trail Making A & B, Motor-Free visual perceptual test—Revised, Mini-Mental Status Examination, Montreal cognitive assessment, and Clock-Drawing test (Dickerson, 2013; Dickerson et al., 2014; Gibbons et al., 2017).

Assessments specific to assessing driving fitness have also been developed, including Useful Field of View (Ball, Owsley, Sloane, Roenker, & Bruni, 1993), Driving Health Inventory (Staplin, Lococo, Gish, & Decina, 2003), and Cognitive Behavioral Driver's Inventory (Duquette et al., 2010). Assessment tools for specific diagnostic categories for driving fitness have also been developed, such as the Stroke Drivers Screening Assessment (Nouri & Lincoln, 1992) and the use of Useful Field of View, caregiver report, and Rapid Pace Walk for clients with Parkinson's disease (Classen et al., 2011). Web-based (The Fitness To Drive Screening, https://www.aota.org/Practice/Productive-Aging/Driving/Practitioners/Screen/FTDS.aspx), computer-based (AAA Roadwise Review: A Tool to Help Seniors Drive Safely Longer), and workbook (Driving Decisions Workbook) resources are also available for the driver and/or caregivers to complete to detect risks associated with driving.

The OT-Driver Off Road Assessment Battery, a clinical assessment of fitness to drive, can be administered by occupational therapists and clinical DRSs. This assessment can be used as a screening tool for clients needing comprehensive driver evaluations, to screen young adults with disabilities to determine driving readiness and to evaluate a driver's skills for on-road testing (AOTA, 2017).

The battery includes the following (AOTA, 2017):

- Section A. Initial interview (driver history and projected needs)
- Section B. Medical history
- Section C. Medication screen
- Section D. Sensory assessment, including:
  - Visual acuity (Snellen chart or equivalent)
  - Visual confrontation test
  - Motor sequences screen–selected test of proprioception–lower limb
- Section E. Physical assessment, including:
  - Berg balance scale
  - The Motricity index
  - Simulated accelerator–brake test
  - Right heel pivot test
- Section F. Cognitive assessment, including:
  - Occupational therapy drive home maze test
  - Road law and road craft test
  - Mini Mental Status Examination (not included, needs to be obtained separately)
- Section G. Summary of issues identified during the assessment
- Section H. Further assessments that are only administered if clinically indicated, including:
  - Bells test
  - Range of Movement–Goniometry
  - Muscle strength scale
  - Whispered voice test

- Tardieu scale of muscle tone
- Short form McGill pain questionnaire and visual analogue scale and pain diagram

The OT-Driver Off Road Assessment Battery takes about 90 minutes to administer and can be viewed at https://www.aota.org/Practice/Productive-Aging/Driving/Practitioners/Screen/OT-DORA.aspx.

There is no single screening or assessment tool to use in determining fitness to drive. Dickerson and colleagues (2014) determined that more research is needed before individual screening and assessment tools can accurately predict older adults' fitness to drive. Also, while simulators have been used to evaluate the fitness to drive (Bédard, Parkkari, Weaver, Riendeau, & Dahlquist, 2010), there is little evidence that simulations can be used validly and reliability to make a final determination of driving ability (Bédard et al., 2010; Clay et al., 2005; Dickerson et al., 2014; Lee, Cameron, & Lee, 2003; Lee, Lee, Cameron, & Li-Tsang, 2003). Training in the use of technical simulators is important since simulator sickness occurs frequently with older adults (Dickerson, 2013).

Behind the Wheel. Behind-the-wheel or on-road testing takes place in a vehicle with safety equipment (e.g., an instructor's brake) and is considered the gold standard assessment to evaluate fitness to drive (Dickerson, 2013; Dickerson et al., 2014; Langford et al., 2008; Weaver, Walter, & Bédard, 2014; Wheatley & Di Stefano, 2008). Behind-the-wheel testing can be done by occupational therapists with specialized training. While assessments, such as the Performance Analysis of Driving Ability (Patomella & Bundy, 2015) and Record of Driving Errors (Barco, Carr, Rutkoski, Xiong, & Roe, 2015), have been developed to assess behind-the-wheel driving skills, more assessments and guidelines need to be developed (Dickerson, 2013).

Driving Interventions

Interventions in driving programs can include all the approaches outlined in the *Occupational Therapy Practice Framework* (AOTA, 2014). Advocating for transportation equity, consulting with automobile manufacturers, and training paratransit staff are examples of health promotion. Remediation for cognitive limitations, providing caregiver education, or restoring motor skills are examples of establish/restore approaches. A maintenance approach could include walking wellness programs, including maintenance of bike and walking routes. Adaptive equipment and environmental and vehicle modification are examples of the compensation/adaptation approach and, finally, prevention strategies might include review of policies and legislation or recommendations for restricted driving (AOTA, 2016b).

In a systematic review of driving interventions, five themes emerged. These included the following (Golisz, 2014b):

1. Educational interventions including family education
2. Cognitive-perceptual training
3. Interventions addressing physical fitness
4. Simulator training
5. Behind-the-wheel training

Educational interventions that combined in-class sessions with on-road training improved driving knowledge and performance and reduced unsafe actions. In-class educational sessions alone improved drivers' knowledge but did not significantly change driving habits. There is insufficient evidence to support that in-class education and on-road training or physical fitness training can reduce crashes. Moderate evidence supports that the Useful Field of View training can lower at-fault crashes, delay driving cessation, and improve performance in clients with stroke and right hemisphere lesions. Physical retraining can moderately to substantially improve the driving skills of older drivers or maintain driving performance. Fitness programs that simultaneously challenge cognitive-perceptual skills may prolong driving skills (Golisz, 2014b). Using simulators for training drivers has been shown to have moderate to substantial improvements for on-road driving performance. Overall, there was low to moderate positive effects for interventions used by occupational therapy practitioners to improve older driver performance (National Guideline Clearinghouse, 2015).

Technological devices to train drivers or modify automobiles are being developed. A DriveCam monitoring video device records driving behaviors and can provide video feedback to older drivers (Ott, Davis, & Bixby, 2017). VISION COACH Interactive Light Board (Perceptual Testing, Inc.) and the Functional Object Detection Advanced driving simulator provide immediate feedback and train clients with visual scanning deficits (Brooks et al., 2017). High-tech automobile modifications such as collision avoidance systems, speed limitation systems, and adaptive cruise control have demonstrated good benefit to drivers, while there is insufficient evidence that the use of blind spot detection, lane departure warnings, and other countermeasures are effective to improve driving safety and performance (National Guideline Clearinghouse, 2015).

Health Promotion and Disability Prevention

The practice of occupational therapy includes many aspects of primary health care, including lifestyle modification, health promotion, and prevention of disease and disability (Benthall, 2016; Metzler, Hartmann, & Lowenthal, 2012). The interactions between people, environments, and activities are complex and dynamic, and occupational therapy practitioners understand the importance of habits and routines and habits that promote healthy behaviors (AOTA, 2015b). The *Occupational Therapy Practice Framework* (AOTA, 2014) identifies two IADL that directly relate to health promotion and disability prevention: safety and emergency maintenance involves knowing preventive procedures to maintain a safe environment and the ability to imitate emergency actions to reduce threats; health management and maintenance includes performing routines to enhance health and wellness.

Health promotion focuses on preventing or reducing illness, disease, accidents and injuries and improving the overall health of people and their caregivers (Reitz & Scaffa, 2013). Occupational therapy has three critical roles in health promotion and prevention: to promote healthy lifestyles, to emphasize occupation as an essential element of health promotion strategies, and to provide interventions not only with individuals, but also with populations (Reitz & Scaffa, 2013). Many health promotion occupational therapy programs involve teaching clients and caregivers safer ways to perform daily activities and may include fall prevention programs for the elderly, workplace injury and wellness programs, stress and anger management programs, backpack safety, self-management programs for those with chronic diseases, and caregiver education to prevent injury and/or burnout (AOTA, 2015b).

Much of caregiver training is directed toward safety and preventing further disability or injury for both the caregiver and client. Safety education can be considered a subcategory of adapted methods, and, since it may require the application of abstract concepts, this may be a consideration for clients with cognitively impairments (Dutton, 2008). Disability and safety prevention includes a wide variety of topics, including prevention of deformities, accidents, dependency, the need for institutional care, invalidism, vocational misfits, and misunderstanding and mistreatment (West, 1969).

Caregiver and client education addresses prevention at different levels. For the client, education is at a tertiary level because they already have activity limitations, impairments, or participation restrictions. The goal of education at this level is to maximize function and minimize the detrimental effects of illness or injury in order to promote full participation, independent living, and self-sufficiency (Reitz & Scaffa, 2013). Disability prevention at this level is often related to secondary consequences that may occur because of a physical limitation. For example, clients who have sustained spinal cord injuries are taught skin protection and inspection techniques because insensate skin may develop decubiti ulcers. Clients with unilateral neglect are taught to visually scan the environment to prevent injury due to lack of awareness of objects, in specific visual areas. Avoidance of potentially deforming positions is often recommended for clients with rheumatoid arthritis. Adults with severe mental illness can go to drop-in centers to increase social participation. This is teaching that is done to prevent further disabilities or to arrest the progression of specific conditions.

For the caregiver, education is at a secondary prevention level because he or she may be considered at risk for developing disability due to caregiving responsibilities. Secondary prevention involves the screening and early detection and intervention after a condition has occurred to prevent or disrupt the disabling process (Reitz & Scaffa, 2013). At-risk populations may include clients just returning home from a recent hospitalization, children born to addicted mothers, or those in whom new behaviors may conflict with strong values or ingrained habituation (Harlowe, 2006). Caregivers are given information that will enable safer ways or use different objects to perform tasks. These methods might include work simplification, energy conservation, and joint protection techniques as well as instruction and practice in using correct body mechanics.

Primary prevention occurs in those people who do not have limitations or impairments. The purpose of primary prevention is to identify, reduce, or eliminate risk factors that can result in injury or disease (Reitz & Scaffa, 2013). Education about consistent use of seat belts, anger and stress management, proper child seat restraints, wearing a helmet on bicycles and motorcycles, programs to reduce bullying, backpack awareness training, fall prevention programs, and the hazards of smoking are all directed toward helping people in society at large avoid the onset of unhealthy conditions, diseases, or injuries before a critical event occurs. Primary prevention efforts are directed toward helping people realize the "linkages between occupational behavior and risks for injury" (Harlowe, 2006).

Effective prevention efforts need to include not only an evaluation of capacities of the individual and context, but also an understanding of the client's beliefs about health risks. The importance and value that the client places on the risk factor may be related to his or her ability to carry out the recommendations. Other factors influencing the success of caregiver and client education are the cost-benefit analysis of using the recommendations in daily activities, one's belief in self-efficacy, and a belief that the recommendations or resources will be helpful (Harlowe, 2006).

The caregiver provides a pivotal role in the family, and it is important to appreciate the complex demands placed on the caregiver as he or she balances the needs of the client with his or her own needs and the needs of the other family members. Often, caregivers work outside of the home and have many issues to deal with concurrently, so it is reasonable to expect to repeat information more than once. Teaching caregivers and clients includes helping them transfer what they have learned in therapy so that they can apply it at home and in family contexts. Provision of resources and additional support in the community is a useful strategy, particularly for people with degenerative or progressive illnesses or who need ongoing support beyond the provision of the occupational therapy services (Flinn & Radomski, 2008).

Family, client, and caregiver education involves teaching the family or caregiver the ways in which the disorder or injury affects the client's performance in work, play, and self-care. The client needs to learn how to care for him- or herself or to instruct others about his or her care needs.

Often, the ramifications of a chronic disability are not realized by the family who, like the client, are adjusting to the medical and psychosocial aspects of the injury while being only minimally aware of the changes that will be needed in daily activities. The client with chronic disabilities needs to relearn how to move, dress, and perform daily tasks with an altered body and capabilities. The client and the family need help coping with the changes, and the family needs help in learning how to help the client. Provide resources to the client and his or her family to help with the psychological adjustment to the altered physical capacities and refer them to other professionals or support groups if additional counseling is needed.

Teaching family members the specific ways to provide assistance in dressing, transfers, positioning, as well as provision of the appropriate level and type of cueing is important for successful return to home and for safety. Recommending adaptive equipment or assistive technology and available resources to aid the family/caregiver in providing assistance is an important aspect of caregiver training. Home programs are taught to the family so that functional gains can be continued or maintained. The family needs to clearly understand the level of assistance or supervision that is required during activities.

Present information to the client and caregiver in a variety of formats to appeal to varied learning styles. Handouts that provide both written instructions and pictures are helpful references. Be sure to include your contact information, local organizations, and websites that may relate to the information provided. Demonstration of techniques need to be done with clear, concise directions and presented in the same way each time. Have the client/family member repeat after the demonstration to demonstrate competence and safety. Providing videotapes and audiotapes is also a useful way to convey information that can be used after the client is discharged. Resource catalogs with recommendations for adaptive equipment marked will make equipment procurement simpler. Online resources and YouTube videos can be helpful, as are any applicable apps.

The following sections will start with body mechanics and joint protection techniques. These concepts should be part of teaching the client and family how to perform all tasks safely. Education regarding mobility and transfers are the next two sections, which provide information for caregivers as to how to ensure that these tasks are done safely.

Body Mechanics

Occupational therapists often assume a dual responsibility in health care settings: teaching families good body mechanics and teaching other health care workers methods to avoid injury (Darragh, Huddleston, & King, 2009). Body mechanics should be taught to the family to ensure safe movement of the client and to prevent injuries to the caregiver. Body mechanics should also be consistently practiced by the therapist for the same reasons. Consistent use of good body mechanics ensures that the back is well protected while producing movements that are efficient and safe (Houglum & Bertoti, 2012). Back pain occurs in caregivers and therapists because of muscle and ligament strains due to improper lifting or trauma, muscular imbalance, and poor posture coupled with sedentary habits and overeating.

Before attempting to move or lift something, be sure that you or the client/caregiver are strong enough to handle the demands of the task. Pause and think before moving or lifting an object, and plan the path and method prior to beginning. Test the load prior to lifting. Ask for assistance whenever you need it, and do not attempt to lift or move an object that is beyond your capacity. Move at a steady pace and do not rush.

Sliding, pushing, pulling, or rolling objects rather than lifting uses better body mechanics as well as conserves energy and simplifies the work. If sliding an object, rock back on the heels and keep the back straight. Generally, push before pulling and pull before lifting (Fasoli, 2014). Working in a horizontal plane will eliminate or lessen the effects of gravity on the movement of objects. Gravity can be an assist when objects are moved toward the floor. Movements done in an arc also require less force to overcome object inertia and produce movement. Figure 13-6 illustrates the use of good body mechanics when getting an object out of the refrigerator or lifting a garbage can.

Figure 13-6. Illustration of good body mechanics.

Use these mechanical principles to your advantage when moving objects. Lifting with the legs and not the back is crucial and is done by bending the knees, using the strongest muscles to their best advantage. Start with a wide BOS and position yourself near the item/person being moved. Keep the back straight and head and trunk in midline, stabilize the lumbar spine by moving the pelvis into neutral position, and lift in one smooth motion. Avoid twisting or overstretching during the movement. A general rule cited by Gench, Hinson, and Harvey (1995) is, "if the head is kept erect while lifting, pushing and pulling, muscular involvement will tend to keep hips low and force the larger, stronger muscles of hip and knee to carry out the task" (p. 184). Use the hip flexor and extensor muscles, and bend the hip and knees rather than bending forward at the waist. By moving into a squat position, the hips can rotate laterally and flex as the tibia moves forward over the foot and the knees flex to lower the item. When standing, better body mechanics can be achieved by positioning one foot ahead of the other and by bending the knees slightly (Gench et al., 1995). Incorporate pelvic tilt during static sitting or standing to unload the facet joints, aid in pelvic awareness, and decrease muscular tension in low back (Trombly, Radomski, Trexel, & Burnett-Smith, 2002). Keep the back in proper alignment with the ear over the shoulder, the shoulder over the hips, and the hips over the knees. Keep a wide BOS, with feet at least hip distance apart. This will provide a stable BOS over your center of gravity (COG).

Keep objects and people close to your body when moving them. In essence, you are using short lever arms for better control. By doing this, you are avoiding twisting the trunk, and the movement requires less muscular force. Pivot the body as a whole by moving the feet rather than twisting the torso, which can cause stress to ligaments and muscles in the back. Use good pacing and do not rush the movement (Sidebar 13-6).

Sidebar 13-6 Good Body Mechanics Principles

Keep objects/people close to body.

Keep wide BOS.

Push before pulling and pull before lifting.

Lift with legs (not back) by bending knees to squat and then stand.

Use good pacing and lift smoothly.

Pivot whole body en bloc by moving feet.

Maintain your COG close to the object/person's COG.

Use short lever arms for better control.

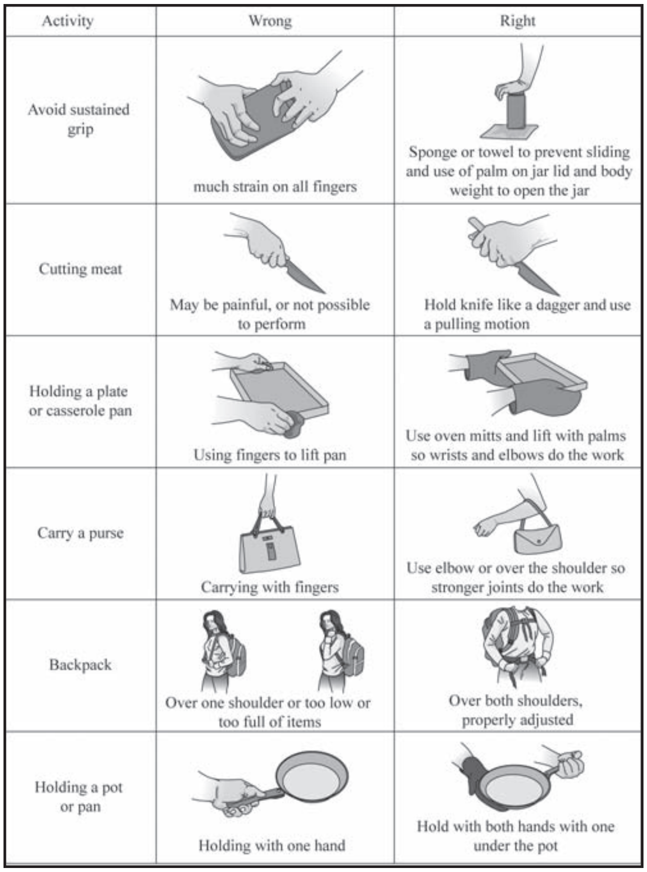


Figure 13-7. Illustrations of joint protection methods.

Joint Protection Techniques

Preventing further disability may involve ensuring joint protection. Instruction to the family and client about joint protection techniques is useful for many clients, especially those with fragile joints, as in rheumatoid arthritis. Joint protection techniques involve seven different principles.

The first is to encourage the client to avoid positions of possible deformity. Usually, this would be static, flexed positions. Examples would be to avoid leaning the head on the back of the hand or to avoid pushing up in a chair with the back of the fingers bent at the knuckles. Instead, push up by leaning on the palm. Avoiding movements in an ulnar direction also would be an example of avoiding a position of possible deformity. Most objects and fasteners are designed for use by right-handed people, using ulnar movements. Consider opening a pickle jar lid: one turns the lid to the ulnar side. An alternative way to open the jar would be to press down on the jar with the palm and use the shoulder, not wrist, to open the lid. Using a knife with a pulling motion is another example. Avoid activities that require a tight grip by enlarging handles or gripping items between the palms of both hands. Avoid wringing out a washcloth; instead, press down to remove excess moisture.

The second major idea behind joint protection techniques is to avoid holding joints or using muscles in one position for a long time. Specific examples include the following:

- Do not stand too long.
- Use a book rest or prop it up.
- Substitute typing for writing.
- Avoid unnecessary jobs.
- Activities requiring repetitive actions should be done for short periods only (e.g., washing windows, vacuuming).

Using the strongest joints available helps to protect joints. This third principle is obvious in body mechanics principles that stress using the legs rather than the back to lift. Carrying the purse on the forearm rather than by the hand can decrease stress to joints, and even using the crook of the elbow to stabilize a bowl when stirring rather than using the hands can be protective of the joints. Figure 13-7 illustrates some joint protection suggestions.

This is related to the fourth joint protection principle, which is using each joint to its best mechanical advantage (Sidebar 13-7). Using both arms and legs to stand up and maintaining good posture while working at comfortable work heights enables joints to work at their best capacity.

Sidebar 13-7 Joint Protection Principles

Avoid positions of possible deformity.

Avoid holding joints or using muscles in one position for a long time.

Use the strongest joints available.

Do not start an activity you cannot stop.

Use each joint to its mechanical advantage.

Respect pain.

Take regular rest periods.

Being able to stop an activity is an important consideration in joint protection and is the fifth principle. Breaking a task into smaller parts might make this easier. For example, if planning a multicourse dinner, prepare different parts of the meal on different days. Prolonging an activity to the point of fatigue may exacerbate the inflammatory process in healing tissues.

Respecting pain, the sixth principle, is important for clients to learn to do because stopping an activity due to pain or avoiding painful activities may prevent further joint damage. As a general guide, if the client experiences pain 1 hour after an activity, the activity was too stressful. The client should conscientiously conserve energy and respect pain when it occurs.

The final joint protection principle is to plan rest periods throughout the day to give joints respite from activity demands. Clients should be encouraged to organize their days so that activities are sequenced based on alternating strenuous activities with rest, using knowledge of fatiguing situations and times of day as guides. Sufficient sleep at night (8 to 10 hours) and frequent small rests during the day would be beneficial. Stretch break software is available that prompts one to take breaks and is available at no cost (http://people.bu.edu/kjacobs).

Reliable and valid joint protection behavior assessments have been developed to assess how well these techniques are used by clients (Klompenhouwer, Lysack, Dijkers, & Hammond, 2000). There is some support that an educational-behavioral approach is useful in teaching joint protection techniques to clients and families (Hammond & Freeman, 2004), and use of these techniques results in significantly less pain and disability and increased social and health status (Masiero et al., 2007).

Medication Management

Medication management is an important part of many people's daily lives. Assessment of the client's hand dexterity, vision, functional cognition, motivation, health literacy, and numeracy is necessary as these factors may affect the person's ability to manage medications independently (Cole, 2011; Rogers, Bai, Lavin, & Anderson, 2016; Siebert & Schwartz, 2017). Occupational therapists may also use interventions that utilize cognitive or cognitive-behavioral intervention strategies, which may be useful for those clients with limited access, poor comprehension about the dosage and use of medication, tendencies to forget to take medications, cultural beliefs, and low health literacy (Aspden et al., 2015; Horne, Weinman, & Hankins, 1999; Okuyan, Sancar, & Izzettin, 2013). These interventions include multiple components that may include intense education, counselling (including motivational interviewing and/or cognitive-behavioral interventions), daily treatment support, and support from family or peers (Nieuwlaat et al., 2014; Schwartz & Smith, 2016).

A variety of apps are available to help clients with medication management. Many alert the client to take medications at specified times (e.g., Pill time, Med Safe and Pill Reminder, My Med Schedule, My Med List), while other apps are useful in pill identification (e.g., Pill Identifier, Pill Identification from WebMD, Pill Identifier from Healthline, Pill Identifier from RX, Pill Identified from CVS, Pill Identifier from Medscape, NIH Pillbox). The MediSafe app includes a variety of medication management features such as education, health tips, medication discounts, biofeedback, reminders regarding prescription refills, and family/friend notifications if medication is not taken on time.

Disability Prevention for the Therapist

Disability prevention applies to therapists as well. Incorporating good body mechanics and joint protection techniques as well as energy conservation and work simplification ideas are as important for the therapist as for the client and caregiver. Sit when possible when working, and when you do stand, stand straight with good posture. Optimally standing on a gel-filled mat will decrease discomfort and facilitate posture changes necessary to avoid static positioning. Raising one foot on a low stool will help to support the lower back for prolonged standing. While not always possible in busy clinics, take a brief break every 20 minutes or change what you are doing (Fecko, Errico, & Jacobs, 2004).

Work-related musculoskeletal injuries and disorders include moderate to severe work-related pain and injury affecting the lower back, neck, shoulder, wrist, and hand (King, Huddleston, & Darragh, 2009). Because the work of occupational therapy often involves heavy lifting, awkward postures, or repetitive motions, therapists are at risk for work-related musculoskeletal injuries and disorders. Therapists have injury incidence rates that are higher than other professions, such as construction, manufacturing, and agriculture (Darragh et al., 2009; King et al., 2009). This led Darragh and colleagues (2009) to conclude that "work-related injuries and disorders among occupational and physical therapists pose a significant population health problem" (p. 359). Good body mechanics alone will not protect therapists from injury, so inclusion of mechanical lift devices and other minimal-lift equipment can help prevent injury (Darragh et al., 2009).

Safe Mobility and Transfers

Mobility training and transfers are essential skills to teach the family. If possible, the client should also be taught how to instruct others in his or her own care if unable to perform the tasks independently. Taking responsibility for oneself is an important aspect that may facilitate coping and acceptance of the disability.

Assisting a person with moving from a supine position to sitting involves helping the person roll to the unaffected or stronger side. The client can then slide the feet off the bed, or the caregiver can assist with this. Keeping the client's head and shoulder forward, assist the client in pushing up to sit. Ensure that sitting balance is achieved before removing support. During this process, the caregiver should keep his or her back as straight as possible, bend with the knees, and avoid excessive trunk torsion.

Assisting someone with transfers can be done by one person. For a logroll transfer, start with a locked wheelchair facing the foot of bed, and be sure that the seat is located near the client's hips. Remove the armrest and place a pillow over the wheel to facilitate the transfer and minimize skin breakdown. The client is rolled onto his or her side with the back toward the chair. The client's hips are near the chair seat at the edge of the bed, with arms and legs flexed to distribute the weight. Move the hips onto the chair seat, keeping the trunk and upper body on the bed. Next, the upper trunk is moved to an upright position in the chair and, finally, the feet are placed on the footrests (Radomski & Latham, 2014).

Assisted swivel trapeze transfers can be done by having the client hook an extended wrist around the bar and pulling him or her to a sitting position. With forearms across the bar, the client would then contract his or her elbow flexors while the helper holds onto the legs, pulls off the bed, and swings the lower body over to the chair (Radomski & Latham, 2014).

If there is weakness in all four extremities, then the assisted depression or sliding board transfer would be a good choice. Assistance is provided by helping to place the transfer board, then by holding onto the client's waist, waistband, or transfer belt to guard against loss of balance. Do not hold onto the belt loops of pants because these rarely remain secure when pulled on strenuously. Further assistance can be provided in helping the person slide across the transfer board and then maneuvering and positioning the person's feet.

If the client can partially bear weight or has loss of function on one side of the body, an assisted pivot transfer can be used. Assistance can be provided by giving physical and/or verbal cues; by helping the client scoot forward in the chair; by holding the client by a transfer belt, belt loop, or waistband during the transfer; by stabilizing the client in standing; by maneuvering the client's feet during the pivot and when sitting; and by easing the client into the chair.

It may be necessary to assist in repositioning the client once in the wheelchair. The helper stands behind the wheelchair, which is locked and tipped back to the point of balance.

Gently shake the chair, which assists gravity in sliding the client's hips back into the seat. A precaution is if the client has spasticity, which would necessitate a different method. In that case, have the client flex the elbows so the forearms go across the body. The helper puts his or her arms in between the client's folded arms and the chest wall, under the axilla from behind to grasp each forearm just distal to the forearm. The helper applies an upward force to reposition the client (Radomski & Latham, 2014).

Management of wheelchair parts is important to review with the family prior to initiation of transfer skills. Regardless of whether the client can manipulate the wheelchair parts without assistance, the client should be able to instruct others on how to set up the wheelchair prior to and after transfers.

Assisting a wheelchair with navigation of curbs can be done either facing toward or away from the curb. This is shown in Figure 13-8. The helper approaches the curb with the front of the wheelchair and depresses the foot projection on the back of the frame. Next, the helper will push down on push handles and the tipping lever to push casters over the curb. The client can assist by leaning forward and pushing on the tire rims as the wheelchair is elevated. Roll the wheelchair forward so that all four wheels are on the elevated surface. To ascend a curb backward, the rear wheels are placed close to the edge of the curb. The helper stands behind the chair and tips the chair so that the casters are elevated. Pull the push handles so that the rear wheels come over the curb. Turn the wheelchair 90 degrees, and gently place the casters down.

Helping a client in a wheelchair descend a curb backward is the easiest, safest method and requires the least effort by the caregiver. The helper approaches the curb backward with the back wheels of the wheelchair eased down first. The helper can use his or her hip or thigh to slow the downward movement. Turn the wheelchair 90 degrees, and then ease the casters down. Descending a curb in a forward position is done by tipping the wheelchair back to a point of balance with the COG over the rear axle. Then, push the large wheels down gently over the curb (Turner et al., 1996).

Two people are needed to assist a client in a wheelchair going up stairs. Approach the stairs backward with one helper behind the wheelchair. This person tips the wheelchair backward into a balanced position. The second person is in front and holds onto the legrest upright (onto the frame, not removable parts). The second person helps to maintain the point of balance while pulling the wheelchair up each step, while the person at the foot assists with lifting and maintaining the point of balance (Pierson, 1994). Going down the stairs, the stairs are approached in a forward position. The wheelchair is tipped into a balanced positions, and the process listed here is reversed.

Placing a wheelchair into a car is also a skill that can be taught to the caregivers. The wheelchair can either fit into the trunk or into the back seat of the car, especially if a two-door car is used and the client is loading the wheelchair into the car.

Assisting a person using a walker to ascend a curb is achieved by having the client step close to the curb with the walker and then lifting the walker up. With the stronger leg leading, the client then steps up. The caregiver is behind the client or to the side, holding onto a gait belt, waistband of the pants, or the client's elbow. Going down a curb is the reverse process: approach close to the curb, lower the walker, and step down with the weaker leg first. The same method would also apply to crutch users.

Proper Use of Equipment

Teaching the family and caregiver how to use any pieces of adaptive equipment, devices, or orthotics is important for continued and proper use of these items. Education about adapted techniques used in dressing, feeding, and daily living skills as well as adaptations for work and play need to be clearly explained and demonstrated to the family.

Preventing further structural damage is often achieved by orthotic devices or positioning in bed or in the wheelchair. It is important for both the client and the family to know how to apply the devices, minimize potential harm (e.g., skin breakdown, duration of use), and achieve maximal benefit from the devices. Devices may be used to protect a specific vulnerable body part during activities, to relieve pain, or to promote rest for healing structures.

Wrist cock-up splints are useful for clients following a stroke, and arm troughs are placed on wheelchairs to position a dependent extremity. Other examples are seen in prosthetic devices for clients with amputations or with the use of an ankle-foot orthosis or knee-ankle-foot orthosis. These devices not only position the parts, but they also protect the parts from further structural damage. Foot drop splints and orthoses maintain functional positions and prevent foot drop deformities, which increase the risk of falls and limit ambulation.

Slings are often used following an upper extremity injury or after a stroke, but their use for subluxed joints is controversial. The use of a sling for the glenohumeral joint, which would position the scapula on the rib cage with the glenoid fossa facing upward, forward, and outward, would position the joint to compensate for the lack of rotator cuff and superior capsule support. However, no slings assist in realigning the scapula on the rib cage in this way (Gillen, 2015). Slings do not reduce subluxation (Zorowitz, Idank, Ikai, Hughes, & Johnston, 1995). Slings may lift the head of the humerus to the level of the glenoid fossa, but scapular and trunk alignments do not occur in slings that are currently available (Gillen, 2015). Slings can be used to provide support to prevent overstretching of soft tissue, decrease traction forces, and prevent neurovascular injury (Zorowitz et al., 1995). Issues of comfort, cosmetic appeal, and easy donning/doffing are important to consider in recommending a sling. Slings, troughs, and lap trays can be used to support the glenohumeral joint, but care should be taken that their use does not interfere with extremity function.

Positioning a client with loss of movement on one side of the body provides support for weakened parts, which maintains normal symmetry with additional goals of inhibition of abnormal tone, provision of normal sensory input, and increased awareness of the affected side (NDT goals). In supine, pillows are placed under the knees to maintain knee flexion, and a folded sheet is placed under the pelvis on the affected side to maintain symmetrical pelvic alignment. A rolled towel under the head will maintain the head in midline with slight flexion. Specific positioning suggestions may vary by diagnosis.

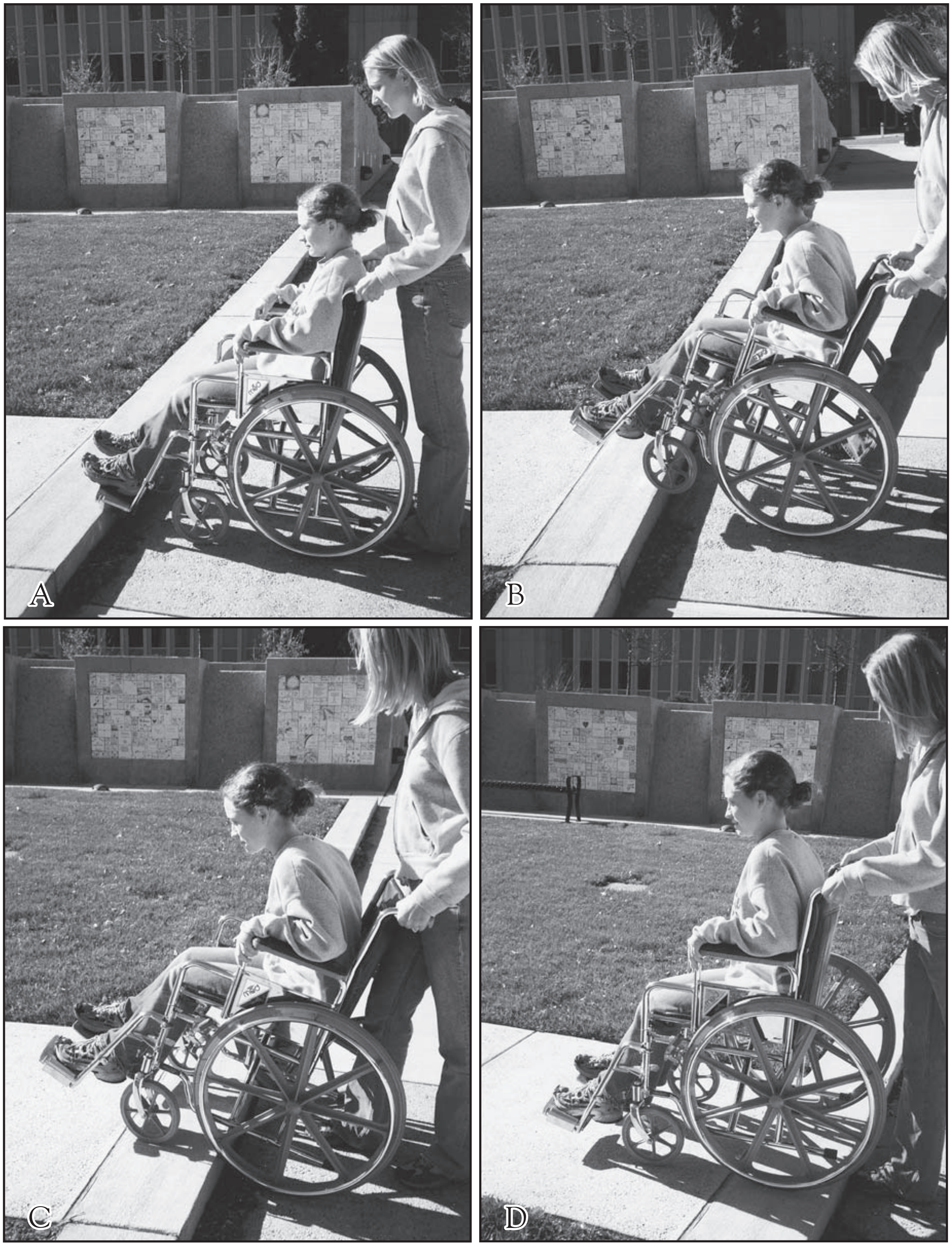


Figure 13-8. (A) Approach the curb with the casters facing the curb. (B) Assistant pushes on the handles and tilts the wheelchair back, while the client leans forward if possible. (C) Assistant rolls the wheelchair and pushes the casters over the curb. (D) Assistant rolls the wheelchair and pushes the back wheels over the curb.

Scar prevention devices, which use compression, may slow collagen synthesis. Devices such as pressure dressings, elastomer molds, transparent face masks, and pressure garments apply a uniform pressure gradient to promote healing and minimize heterotrophic scar formation. Caregivers need to learn how to apply these garments and need to be instructed in care to maintain hygiene.

Somatosensory Losses

Clients with somatosensory losses will need to be aware of the areas that are insensate to prevent skin breakdown or damage. Pressure relief is a very important area of disability prevention for clients with lack of sensation. Clients are taught methods to inspect their skin daily. Pressure relief techniques, such as push-ups in the wheelchair or leaning to one side in a wheelchair, are essential to teach to clients with spinal cord injury to prevent decubiti ulcers (pressure sores). Clients are taught to relieve pressure at regular intervals, are able to differentiate pressure marks from pressure sores, and are provided with seating devices and special mattresses to minimize skin breakdown due to prolonged pressure.

Awareness of areas lacking sensation is important in compensatory practices. For example, a person with no thermal sensation will need to use alternative methods to prevent burns to the hand when checking water temperature. Decreasing the temperature of the hot water heater and using a thermometer are easily implemented protective adaptations. Clients are taught to compensate for decreased sensation by relying more on vision.

Fall Prevention

Falls in the home occur for many different reasons or combinations of factors.

The risk factors include client-related factors (physical, behavioral, or attitudinal), environmental, or a combination of both. Client-related factors are varied. A client with decreased vision due to cataracts, macular degeneration, glaucoma, homonymous hemianopsia, or low vision will need environmental adaptations, such as contrasting colors on steps and greater illumination.

Clients may have lower extremity dysfunction or weakness due to arthritis, peripheral neuropathies, stroke, Parkinson's disease, or foot disorders. Lower extremity weakness is a common contributor to increased incidence of falls. Clients with gait and balance disorders are at risk for falls, and people with bladder dysfunction (nocturia, incontinence, frequency of urination) may rush to the bathroom and fall. Fluctuations in blood pressure and cardiovascular disorders (orthostatic hypotension, arrhythmia, syncope) and certain medications (diuretics, antihypertensive, sedatives, psychotropic, non-steroidal anti-inflammatory drugs) may also be risk factors for falls. Emotional and cognitive deficits also make falling more probable (dementia, depression, anxiety, fear of falling, denial of physical and functional limitations, refusal to use assistive device).

Environmental factors that may cause falls include using unsafe objects like a wheeled cart for support rather than a walker or by using objects in an incorrect way. Furniture in poor repair is a danger, as are loose scatter rugs. Carpets that are thick or not secured at the edges could cause falls. Poor lighting is also a variable to be considered when attempting to prevent falls. This is especially true in congested areas, halls, and entranceways. Lighting intensity may be increased (especially in bathrooms and stairways) by using fluorescent lights, and adding tinted windows or Mylar shades to reduce glare may improve lighting throughout the home. Improper footwear is another culprit in falls, and shoes with low heel height and high surface contact area reduce the risk for falling. Tripping hazards, such as excessive clutter or electrical cords, also are extrinsic causes of falls in the home.

Falls in the bathroom are common and serious due to the small space, wet surfaces, lack of maneuverability, and hard surfaces. Common adaptations may include slip-resistant surfaces or nonslip adhesive strips. Additionally, falls are not restricted only to the elderly. For children, playground equipment is a potential source of falls, and many playgrounds are now being built to reduce the fall impact by being covered with shredded rubber or mulch rather than concrete.

The risk of falling increases with age and is associated with morbidity and mortality in the older population. Falling is also linked to decreased social participation, decreased quality of life, depression, decreased independence, and early admission to long-term care facilities. Occupational therapists can work with individuals to reduce falls by facilitating safe performance of daily tasks, modifying the home, and changing behaviors. Fear of falling, both a risk factor for falls and a consequence of falling, can lead a person to limit activities and tasks, which can result in decreased physical functioning, inactivity, and sedentary lifestyle that further increase the risk of falling (Filiatrault et al., 2013; Peterson, Finlayson, Elliott, Painter, & Clemson, 2012). Fall-related injuries may result in increased emergency department visits and hospitalizations. Reducing falls is important in health, social, and economic terms and is an important public health objective (Panel on Prevention of Falls in Older Persons, 2011). Occupational therapists can contribute to fall prevention on a larger scale through consultation to staff of community centers, nursing homes, and assisted living facilities (AOTA, 2010a).

Fall Risk Assessment

Since falls occur due to many reasons, the assessment of fall risk involves a multidimensional process with an interdisciplinary team and usually includes a focused history, physical examination, functional assessment, and environmental assessment (Panel on Prevention of Falls in Older Persons, 2011). The Clinical Practice Guideline: Prevention of Falls in Older Persons (available at https://onlinelibrary.wiley.com/doi/abs/10.1046/j.1532-5415.2001.49115.x), developed by the American Geriatrics Society and British Geriatrics Society, provides recommendations for assessment of fall risk and evidence to support interventions across settings and disciplines (Peterson et al., 2012).

A physician conducts a physical examination, and nursing personnel may conduct continence protocol including toileting schedules and bladder training and management. Other members of the interdisciplinary team complete the remaining sections. A functional assessment would often include balance tests (e.g., Tinetti Gait and Balance Tool or Berg Balance Scale), transfer assessment, and vestibular function. Often, a mini-mental status assessment is done as well as screens for recall and judgement (safety awareness). The client will be asked about any pain (chronic or acute) and any medications taken to alleviate pain. The environmental assessment would entail information about the room layout, observing for any environmental hazards, use of any assistive devices, and lighting and, optimally, would include an observation of the client in his or her home performing daily tasks. Going to the home to assess environmental hazards, providing information about modifications, and facilitating changes are an important part of an environmental assessment. Training in the use of adaptive and mobility aids and any new technology was found to be effective in reducing falls in older people's homes (Nikolaus & Bach, 2003).

Several studies have looked at how the fear of falling effects activity and participation. Fear of falling tools can be categorized into two domains: psychological and behavioral (Filiatrault et al., 2013). The psychological domain includes assessments of the fear of falling, falls efficacy, and balance confidence. Specific tools used to assess these factors are the Fall Efficacy Scale and, for balance confidence, the Activities-Specific Balance Confidence Scale. Schepens, Sen, Painter, and Murphy (2012) examined the relationship between one's confidence in the ability to perform activities without losing balance or falling (fall-related efficacy) and participation in desired occupations, and they found a strong positive relationship between fall-related efficacy and activity ($r = 5.53$; 95% confidence interval [.47, .58]).

In the behavioral domain, the tools typically measure activity restriction resulting from fear of falling. Tools such as the Survey of Activities and Fear of Falling in the Elderly or the Fear of Falling Avoidance Behavior Questionnaire would be relevant to this domain (Filiatrault et al., 2013). Painter et al. (2012) examined the relationship between fear of falling to depression, anxiety, activity level, and activity restriction and whether depression or anxiety predicted fear of falling, activity level, or restriction. There was a significant relationship between fear of falling and depression, anxiety, and activity level. There was also a significant relationship between depression and anxiety and between activity restriction and depression. The authors concluded that screening older adults for fear of falling, anxiety, and depression is important since these may be risk factors for falls and activity restrictions. Cognitive-behavioral interventions, designed to limit fear of falling and promote social participation among community-dwelling seniors, was found to result in a 31% reduction of falls (Clemson et al., 2004) as compared to usual care alone (Filiatraut et al., 2013; Waite, 2014; Weatherall, 2004).

Fall Prevention Programs

Fall prevention can occur at all three levels of the disability prevention continuum. Primary prevention of falls would consist of controlling environmental hazards, educating people about fall risks, and making a clear link between behavior and falls (Harlowe, 2006). Primary prevention programs in older adults without impairments have resulted in fewer declines in physical health and improved physical and social functioning, vitality, mental health, and life satisfaction (Clark et al., 1997; Jackson, Carlson, Mandel, Zemke, & Clark, 1998). Interdisciplinary fall risk screens in the community is feasible and can lead to environmental and behavioral changes to reduce falls in the elderly (Elliott et al., 2012).

Secondary prevention training might include a home safety assessment for clients at risk and would include an assessment of attitudes and knowledge about fall risks to ascertain if new behaviors may conflict with strong values and ingrained habituation (Harlowe, 2006). Tertiary prevention efforts are for those clients who have experienced falls on a recurrent basis. Comprehensive programs would provide assessment and information to the family and client about environmental safety, risk-taking behavior, assertiveness training, self-efficacy, attitudes about risks, and physical fitness. A complete medical history and fall history would be gathered during an interview with the client and his or her family. Detailed descriptions about the client's level of physical activity and alcohol use would be important, and a complete and updated list of current medications would also be part of the medical information gathered. Physical assessment would include assessment of strength, ROM, coordination, balance problems, gait or mobility deficits, and visual impairments.

The interaction of the person, environment, and occupation must be included in the assessment and in the intervention. Discover what activities the client is doing or wants to do, and match the client and environmental characteristics to the person's capacities. Use the person's outcome expectations and efficacy expectations to determine intervention (Ceranski & Haertlein, 2002). In a study by Cumming and colleagues (2001), 65% of the clients and families were at least partially compliant with 50% or more of the recommendations for home modification for fall prevention. The only factor that differentiated adherers from nonadherers was a belief that home modifications prevent falls and that the clients and families saw no association between home modification and the self-perceived risk of falls or history of falls (Cumming et al., 2001). The clients and family need to believe that the modifications will be beneficial and that they need the changes for full participation in activities. In another study, participants in a falls prevention program were very knowledgeable about fall risks, but there was little change in behavior and attitudes (Buri, 1997).

This may require a change in beliefs about levels of activity participation and changes in physical abilities. Strategies that worked before may no longer work, necessitating learning new ways of performing common tasks. Sensory information and coping strategies need to be reinterpreted and revised. Changing efficacy and activity participation will require repetition of tasks in sequence to change habit patterns. Feedback, encouragement, and support from family and near-peer role models may help the client to believe he or she can develop the skills needed for safety in the home (Bandura, 1977; Ceranski & Haertlein, 2002).

Wahl, Fänge, Oswald, Gitlin, and Iwarsson (2009) stress that interventions for high-risk subgroups are urgently needed (e.g., people living with dementia, intellectual disability, multiple sclerosis, Parkinson's disease, stroke; people transitioning to or residing in long-term care facilities; hospital inpatients) since these groups experience falls at a much higher rate than the general population. Occupational therapists in collaboration with State Fall Prevention Coalitions through the National Council on Aging (NCOA) can participate in annual Falls Awareness Day events (https://www.aota.org/Practice/Productive-Aging/Falls/Falls-Day.aspx) and in delivering evidence-based programs (Peterson et al., 2012).

The CDC Compendium of Effective Fall Interventions categorized fall interventions into four categories: exercise-based, multifaceted, home modification, and clinical interventions (Stevens & Burns, 2015). The Clinical interventions focused primarily on medication withdrawal, vitamin D, podiatry, and cataract studies and programs. Of greater relevance to occupational therapists are the studies and programs in the other three categories.

Exercise-Based Interventions

Since lower extremity weakness, impaired balance, and sensory impairment are risk factors for falls, many programs include an exercise component as part of a multifactorial intervention for fall prevention. Interventions to improve gait, balance and strength, flexibility, and tai chi are effective in preventing falls. It is strongly recommended by review of relevant evidence that exercise should be included in intervention for fall prevention in community-dwelling older adults and is an effective intervention to reduce falls (Filiatrault et al., 2013; Panel on Prevention of Falls in Older Persons, 2011). There is fair evidence to suggest that exercise programs can be performed in groups or individuals, and both are effective in preventing falls (Filiatrault et al., 2013; Panel on Prevention of Falls in Older Persons, 2011).

Current data support exercise programs only for community-dwelling older persons, in contrast to the earlier guidelines, which recommended long-term exercise and balance training for all older people who have had recurrent falls (Panel on Prevention of Falls in Older Persons, 2011). The benefit of the exercise to preventing falls must be clearly understood to reduce falls.

In a study by Campbell and colleagues (2005), a home safety program and an exercise program were used with older adults with visual impairments. Falls and injury were reduced primarily due to the safety education elements of the intervention and not due to the exercise, possibly due to low adherence (Campbell et al., 2005). This may be due to the lack of association between the benefit of exercise in decreasing falls or due to the lack of congruence with valued occupations.

The CDC has taken the initiative to disseminate several exercise programs aimed at fall prevention that include the Tai Chi: Moving for Better Balance Program, Otago Exercise Programme, as well as Stepping On. Tai Chi: Moving for Better Balance was developed by researchers at the Oregon Research Institute and has demonstrated effectiveness in decreasing the number of falls, risk of falling, and fear of falling and improving balance in the elderly. In two randomized controlled trials, the efficacy of the program in improving functional balance, strength, and flexibility and, consequently, reducing fear of falling and the risk of falls in sample populations of healthy community-dwelling older adults was demonstrated (Peterson, 2011). Materials and products are available at http://www.taichimovingforbetterbalance.org/. The Otago Exercise Programme was developed as an individualized home safety and exercise program for older people with low vision. A meta-analysis of the home-based trials showed an overall fall reduction and a fall-related injury reduction of 35% (Peterson, 2011). Other exercise programs are listed in Table 13-19.

Multifaceted Interventions

It is widely accepted that fall prevention programs need to be multifactorial and multidisciplinary. Multicomponent, multifaceted, and interdisciplinary programs reduce functional difficulties, fear of falling, fall incidence, fall burden, anxiety about falls, and home hazards, and they enhance self-efficacy and adapted coping in older adults with chronic conditions (Chang et al., 2004; Chase, Mann, Wasek, & Arbesman, 2012; Close et al., 1999; Davison et al., 2005; Gitlin et al., 2006; Leland, Elliot, O'Malley, & Murphy, 2012; Siebert et al., 2014; Stark & Keglovits, 2014; Tolley & Atwal, 2003). Chase and colleagues (2012) conducted a systematic review of the effect of fall prevention programs and home modifications on the number of falls, as well as performance of older adults living within the community. The review strongly suggested that multifactorial programs help to reduce falls and difficulties with ADL and IADL. Multifactorial programs included, but were not limited to, home modifications, education on health and safety, medication management, vision management, gait and balance training, and exercise.

Matter of Balance is a cognitive-behavioral, multifaceted group intervention that aims to reduce the fear of falling, stop the fear of falling cycle, and increase activity levels among community-dwelling older adults. Developed by an interdisciplinary team, the program discusses concerns, attitudes, and beliefs about falls and includes engaging in exercise and learning to use cognitive restructuring techniques. Results of a randomized controlled trial demonstrated that 97% of the participants were more comfortable talking about their fear of falling and in increasing activity levels after the program, and 99% continued to exercise after the program completion (NCOA, 2017).

Another example of a multifaceted program is CAPABLE, designed to decrease fall risk, improve safe mobility, and improve the ability to safely accomplish daily functional tasks. The interdisciplinary team consists of occupational therapy, nursing, and a handyman. In a study of program effectiveness, 79% of participants improved their self-care over the course of 5 months, self-care tasks were less difficult, and the decreases in depressive symptoms were similar to that of antidepressant medication (Szanton et al., 2014). The Secure Step Fall Prevention Program, for use in the home, includes environmental assessments and recommendations for modifications with clients and also handymen or remodelers to make the environment barrier-free, as in the CAPABLE program. The program also has cognitive-behavioral facets that include fall prevention education, guided imagery, and balance tasks to improve self-efficacy and promote health and wellness (Siddiqui, 2016). Two other multifaceted programs, FallScape (http://fallscape.org/) and Fallstalk, are individual programs for anyone who has experienced a fall and can be used to develop personalized interactive media and programs.

Home Modification Interventions

Home modifications can be provided both as a single component or as part of a multifaceted falls prevention program. Home modifications were identified as a best practice to help reduce the number of falls experienced by older adults living in the community, and there is strong support for home modifications provided by occupational therapists to reduce falls (Chase et al., 2012; Leland et al., 2012; Stark & Keglovits, 2014). Clemson, Mackenzie, Ballinger, Close, and Cumming (2008) developed a rating system based on best practice recommendations for environmental interventions that address fall prevention. High-quality interventions include 75% of the following criteria:

> (a) a comprehensive evaluation process of hazard identification and priority setting taking into account both personal risk and environmental audit, (b) the use of an assessment tool validated for the broad range of potential fall hazards, (c) inclusion of formal or observational evaluation of the functional capacity (physical capacity, behavior, functional vision,

Table 13-19

Fall Prevention Programs

Program	Study
Exercise-Based Interventions	
Stay Safe, Stay Alive	Barnett, Smith, Lord, Williams, & Baumand (2003) *https://academic.oup.com/ageing/article/32/4/407/40031/Community-based-group-exercise-improves-balance*
The Otago Exercise Programme	Campbell et al. (1997) *http://www.bmj.com/content/315/7115/1065* Robertson, Campbell, Gardner, & Devlin (2002) *http://onlinelibrary.wiley.com/doi/10.1046/j.1532-5415.2002.50218.x/full*
Lifestyle-integrated Functional Exercise	Clemson et al. (2010) *https://www.ncbi.nlm.nih.gov/pubmed/20854564/*
Erlangen Fitness Intervention	Freiberger, Menz, Abu-Omar, & Rütten (2007) *https://www.ncbi.nlm.nih.gov/pubmed/17536207*
Senior Fitness and Prevention	Kemmler, von Stengel, Engelke, Häberle, & Kalender (2010) *https://jamanetwork.com/journals/jamainternalmedicine/fullarticle/774236*
Adapted Physical Activity Program	Kovacs, Prókai, Mészáros, & Gondos (2013) *https://www.researchgate.net/publication/236042597_Adapted_physical_activity_is_beneficial_on_balance_functional_mobility_quality_of_life_and_fall_risk_in_community-dwelling_older_women_A_randomized_single-blinded_controlled_trial*
Tai Chi: Moving for Better Balance	Li et al. (2005) *https://academic.oup.com/biomedgerontology/article/60/2/187/563288/Tai-Chi-and-Fall-Reductions-in-Older-Adults-A*
Australian Group Exercise Program	Lord et al. (2003) *http://onlinelibrary.wiley.com/doi/10.1046/j.1532-5415.2003.51551.x/abstract*
Yaktrax Walker	McKiernan (2005) *http://onlinelibrary.wiley.com/doi/10.1111/j.1532-5415.2005.53302.x/abstract*
Veterans Affairs Group Exercise Program	Rubenstein et al. (2000) *https://academic.oup.com/biomedgerontology/article/55/6/M317/2948064/Effects-of-a-Group-Exercise-Program-on-Strength*
Falls Management Exercise Intervention	Skelton, Dinan, Campbell, & Rutherford (2005) *https://academic.oup.com/ageing/article/34/6/636/40192/Tailored-group-exercise-Falls-Management-Exercise*
Music-Based Multitask Exercise Program	Trombetti et al. (2011) *https://jamanetwork.com/journals/jamainternalmedicine/fullarticle/226932*
Central Sydney Tai Chi Trial	Voukelatos, Cumming, Lord, & Rissel (2007) *https://www.ncbi.nlm.nih.gov/pubmed/17661956*
Simplified Tai Chi	Wolf et al. (1996) *http://onlinelibrary.wiley.com/doi/10.1111/j.1532-5415.1996.tb01432.x/abstract*
EnhanceFitness Program	Greenwood-Hickman, Rosenberg, Phelan, & Fitzpatrick (2015) *http://dx.doi.org/10.5888/pcd12.140574*
Stay Alive and Independent for Life (SAFE)	Shumway-Cook et al. (2007) *https://www.ncbi.nlm.nih.gov/pubmed/18166695*

(continued)

Table 13-19 (continued)

FALL PREVENTION PROGRAMS

PROGRAM	STUDY
Multifaceted Interventions	
Stepping On http://www.steppingon.com/	Clemson et al. (2004) *https://wihealthyaging.org/_data/files/Clemson_JAGS_2004_-_Falls.pdf*
Prevention of Falls in the Elderly Trial	Close et al. (1999) *http://www.sciencedirect.com/science/article/pii/S0140673698061194*
Accident and Emergency Fallers	Davison et al. (2005) *https://academic.oup.com/ageing/article/34/2/162/40462/Clients-with-recurrent-falls-attending-Accident*
The NoFalls Intervention	Day et al. (2002) *http://www.bmj.com/content/325/7356/128*
The SAFE Health Behavior and Exercise Intervention	Hornbrook et al. (1994) *https://www.ncbi.nlm.nih.gov/pubmed/8150304*
Multifactorial Fall Prevention Program	Salminen, Vahlberg, Salonoja, Aarnio, & Kivelä (2009) *http://onlinelibrary.wiley.com/doi/10.1111/j.1532-5415.2009.02176.x/abstract*
The Winchester Falls Project	Spice et al. (2009) *https://academic.oup.com/ageing/article/38/1/33/40520/The-Winchester-falls-project-a-randomised#*
A Matter of Balance	Tennstedt et al. (1998) *https://academic.oup.com/psychsocgerontology/article/53B/6/P384/618638/A-Randomized-Controlled-Trial-of-a-Group#*
Yale Frailty and Injuries: Cooperative Studies of Intervention Techniques	Tinetti et al. (1994) *https://academic.microsoft.com/#detail/2322424896?FORM=DACADP*
Secure Step Fall Prevention Program	Siddiqui (2016) *https://www.aota.org/Publications-News/otp/Archive/2016/2-22-16-productive-aging/fall-prevention.aspx*
CAPABLE	Szanton et al. (2014) *https://doi.org/10.1016/j.cct.2014.03.005*
A Multifactoral Program	Wagner et al. (1994) *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1615188/*
Home Modification Interventions	
The VIP Trial	Campbell et al. (2005) *http://www.bmj.com/content/331/7520/817*
Home Visits by an Occupational Therapist	Cumming et al. (1999) *http://onlinelibrary.wiley.com/doi/10.1111/j.1532-5415.1999.tb01556.x/full*
Falls-Home Intervention Team Program	Nikolaus & Bach (2003) *https://www.ncbi.nlm.nih.gov/pubmed/12588572*

habits) of the person within the context of their environment, and (d) provision of adequate follow-up by the health professional and support for adaptations and modifications. (Clemson et al., 2008, p. 957)

General modifications indicated earlier include consideration of lighting (e.g., sufficient light, reduction of glare, motion-detected lighting, lighting inside and out), reducing clutter (including stairways), and securing or removing throw rugs (Solet, 2014; Trudeau, 2016). The VIP Trial (Campbell et al., 2005) was conducted by an occupational therapist with older people with poor vision in their homes. The program included a home hazard assessment, home modifications and recommendations for behavior changes, and a home exercise program (strength and balance exercises). The Home Visits by an Occupational Therapist (Cumming et al., 1999) study also identified environmental hazards and unsafe behaviors, recommending home modifications and behavior changes. In this study, the use of an experienced occupational therapist who had the skills to care for older adults was critical. The Falls-HIT Program (Nikolaus & Bach, 2003) provided home visits to frail community-dwelling older adults at risk of falling. The home visit was conducted by an occupational therapist and either a nurse or physical therapist, and the rest of the team included a social worker and a secretary. The participants met team members prior to discharge from the hospital, and typically three home visits were needed to provide recommendations for home modifications and teach the participant how to use safety devices and adapted equipment (Stevens & Burns, 2015).

Additional information about falls, fall prevention, and available toolkits can be found at the NCOA website (https://www.ncoa.org/?s=falls+programcompendium&ncoaresourcetopic=falls-prevention&es=on&les=0). The AOTA offers a fall prevention toolkit developed by the AOTA and the Academy of Geriatric Physical Therapy intended for use by professionals in fall prevention presentations to older adults in the community. The contents include:

- A brief guide to assist you in using the PowerPoint presentation
- A PowerPoint presentation with sample narration notes under each slide

The AOTA also has a handout, Tips for Living Life to Its Fullest: Fall Prevention for Older Adults (https://www.aota.org/~/media/Corporate/Files/AboutOT/consumers/Adults/Falls/Fall%20Prevention%20Tip%20Sheet), and additional Falls Prevention Resources (www.aota.org/Practice/Productive-Aging/Falls). The AOTA/CDC jointly collaborated on a Falls Prevention Project (www.aota.org/Practice/Productive-Aging/Falls/CDC). The AOTA has three modules in an online course for assessment of falls among community-dwelling adults, assessment of falls among adults in the hospital setting, and fall prevention intervention strategies for community-dwelling adults.

Sternal Precautions

After heart surgery, sternal precautions are usually required. Activities where there is pushing or pulling with the arms, which includes using the arms to push oneself out of bed or a chair, should be avoided. No one should pull on the client's arms during activities or transfers because this applies too much pressure on the sternal area. Precautions for cardiac clients would include monitoring heart rate and blood pressure and often rely on metabolic equivalent levels for selected activities. If the heart rate goes up more than 20 beats per minute from the resting pulse, above 120 beats per minute, or below 60 beats per minute, a physician should be consulted. If resting systolic blood pressure goes above 150 or below 90 and/or if diastolic blood pressure goes above 90 or below 50, consult a physician. Normal blood pressure is 120/80.

Cognitive Impairment

For clients with cognitive impairments, limiting client choices and monitoring the client for safety are roles that the caregiver may assume. Limiting clothing options by limiting the clothing available and removing extra clothing from closets and drawers can allow the client to make decisions but limits the decisions that are necessary. This strategy can be applied to other tasks, such as meal preparation, housekeeping tasks, or leisure activities. Monitor the comfort of the client throughout the day, including how well the clothing fits, the temperature of the room, and medication routines. Help with organization by decreasing clutter and arranging the items for tasks in sequences (e.g., arrange clothing to be donned; Holm et al., 1998). The client may not be able to perform all parts of the task, so the caregiver may initiate the task and the client complete it. Provide only the level of assistance that is needed.

Having the client wear a nonremovable bracelet with identifying and contact information would be helpful if the person tends to wander off. Alarms can be installed if doors are opened. Keep hazardous materials and items out of reach, such as medications, alcohol, toxic cleaners, sharp objects, matches, and car keys. If safety around the stove is a concern, remove the knobs from appliances and unplug the microwave oven and coffee pot.

Visual Impairment

Caregiver training for family members with visual impairment would depend on the level of disability and vision loss. It may be a change in habit for the family members, such as closing drawers and opening doors, to increase safety for the visually impaired person or returning items to designated places and arranging food in a specific way to make it easier for the person. The help that the caregiver provides may be as simple as checking the appearance of the person to be sure clothing is clean, matched, and appropriate for the weather. Liu, Brost, Horton, Kenyon, and Mears (2011) conducted an evidence-based review suggesting that a multicomponent and intradisciplinary education program is the most effective intervention to maintain or improve performance in ADL or IADL within the home setting for older adults with low vision.

The team may include optometrists, occupational therapists, orientation and mobility specialists, social workers, and psychologists, and adding extra service to existing effective low-vision rehabilitation team services might not yield additional benefit (Liu, Brost, Horton, Kenyon, & Mears, 2013).

Shoulder Impairment

Clients who have recently had shoulder surgery or have unstable shoulder girdles should not be pulled up in bed or repositioned using their arms. During transfers, support these clients around their trunks rather than under the axilla to avoid structural damage or further instability. This advice is actually true for all clients. Safer transfer mechanisms have been described, and pulling on a client's shoulder girdle is not a recommended practice for any type of transfer.

Table 13-20 provides sample goal statements, the method to achieve the goal, and the principle guiding the intervention

Table 13-20

Changing the Context: Family and Caregiver Education Intervention and Documentation

GOAL

Client will (be independent/modified independent) and (require maximal/moderate/minimal/standby assist or verbal/physical cue) to perform (specify tasks) in (specify number of weeks/days) by using:

Method	Principle/Rationale	Example
Safety education that	Ensures good body mechanics	• Keep objects/people close to body • Keep wide BOS; feet wide apart • Slide/push/pull/roll objects/people rather than lifting • Lift with legs (not back) by bending knees to squat and then stand up • Use good pacing • Lift smoothly • Pivot whole body by moving feet instead of twisting torso • Maintain your COG close to the object/person's COG • Use short lever arms for better control
	Ensures joint protection	• Avoid positions of possible deformity • Avoid holding joints or using muscles in one position for a long time • Use the strongest joints available • Do not start an activity you cannot stop • Use each joint to its mechanical advantage • Respect pain • Regular rest periods
	Ensures safe transfers	• Get wheelchair as close as possible • Remove wheelchair parts if necessary • Equalize heights • Lock wheelchair brakes • Move client's hips forward to get close to edge of chair/bed • Place feet flat on floor and directly under knees before standing • Identify safe landing site for fall before standing up • Move smoothly
	Maintains joint ROM in the current range to prevent adhesion and mold collagen into orderly chains	• Functional patterns in activities and tasks related to interests such as overhead checkers, macramé, putting dishes into a cupboard, placing clothes in a side-loading dryer, making a bed • Movement in anatomical planes • Movement in muscle range of elongation • Movement in combined patterns of movement (e.g., proprioceptive neuromuscular facilitation) • Self-ROM exercises • ROM dance • Finger ladder • Shoulder wheel • Overhead pulleys • Suspension devices

(continued)

Table 13-20 (continued)

Changing the Context: Family and Caregiver Education Intervention and Documentation

Method	**Principle/Rationale**	**Example**
Safety education that	Ensures safety for somatosensory loss	• Inspect skin daily • Differentiate between a pressure mark and pressure area • Relieve pressure at regular intervals • Wear protective splints and orthotics • Use appropriate positioning • Move insensate body part carefully using visual feedback
	Ensures cardiac precautions	• Rest if heart rate goes up more than 20 beats per minute from resting pulse • Rest if heart rate goes above 120 beats per minute or below 60 beats per minute • Rest if systolic blood pressure goes above 150 or below 90 (normal = 120) • Rest if diastolic blood pressure goes above 90 or below 50 (normal = 80)
	Prevents scar hypertrophic formation using devices that apply compression, which may slow collagen synthesis	• Pressure dressings • Elastomer molds • Transparent face mask • Pressure garments
	Maintains strength by active use of currently intact muscles and joints, which prevents disuse atrophy and stiffness during periods of enforced rest	• Active movement in anatomical planes • Active movement in diagonal proprioceptive neuromuscular facilitation patterns • ADL • Wheelchair propulsion • Leisure activities • Work activities
	Ensures hip precautions are followed	• Avoid hip abduction (e.g., do not cross legs to roll in bed) • Avoid hip internal rotation (e.g., do not line up foot with shoe by twisting leg into internal rotation) • Avoid hip flexion past 90 degrees (e.g., stand up from chair by leaning back and sliding hips to edge of seat, then extend knee of operated leg, and push off from armrests) • Use elevated commode to maintain hip flexion 90 degrees or less • Do not cross ankles or legs when sitting, laying, or getting in/out of bed • When in bed, keep legs apart and toes pointed toward ceiling
	Ensures shoulder precautions are followed	• Never pull client up in bed using his or her arms; use a draw sheet • Do not support a client under the arms during transfers; support client around the trunk
	Ensures sternal precautions (after heart surgery) are followed	• Do not push/pull with arms • Do not use arms to push out of bed or pull on side rails • Do not allow others to pull on your arms

(continued)

Table 13-20 (continued)

CHANGING THE CONTEXT: FAMILY AND CAREGIVER EDUCATION INTERVENTION AND DOCUMENTATION

METHOD	PRINCIPLE/RATIONALE	EXAMPLE
Safety education that	Ensures safe mobility	• Educate regarding wheelchair parts and maneuverability • Hoyer lift • Two-person carry • Logroll transfer • Assisted swivel transfer • Assisted sliding board • Assisted pivot transfer • Assistance in repositioning • Assistance in ascending/descending curbs and stairs
Orthoses and devices or positioning that	Protects the upper extremity; prevents further structural damage by protecting a specific vulnerable body part during activities; or maintains joints and soft tissue in functional positions and prevents deformities	• Wheelchair arm trough • Lapboard • Cock-up splint for client with hemiplegia • Sling for upper extremity injury • Wheelchair arm trough • Foot drop splints and orthosis • Positioning for specific diagnosis

with several examples. A sample goal statement for family and client education might be, "Client's mother will demonstrate proper body mechanics and safe techniques consistently while assisting son with stand pivot transfer from bed to wheelchair" (Moyers, 1999).

SUMMARY

- The rehabilitation frame of reference is a compensatory and adaptation approach used when there is little or no expectation for change and where there are residual impairments. It may also be used when there is limited time for intervention and when the client or family prefers more immediate resolution of functional problems.
- This intervention approach focuses on the areas of occupation, which includes work, play, leisure, education, IADL, and social participation rather than on the underlying performance skills. This is known as a *top-down approach*, where intervention starts by identifying the environmental demands and resources with the client.
- Intervention methods include changing the task or changing the context.
- Changing the task can be accomplished by adapting how the task is done or by changing the task objects or using adaptive equipment.
- Changing the context would include environmental modification and training the client and caregivers.
- Disability prevention is accomplished by client and caregiver education. This is especially true of those who already have activity or participation limitations, as well as those who may be a member of an at-risk population.

Figures 13-1 is adapted from Law, M., Cooper, B., Strong, S., Stewart, D., Rgby, P., & Letts, L. (1996). The Person-Environment-Occupation (PEO) Model: A transactive approach to occupational performance. *Canadian Journal of Occupational Therapy, 63*(1), 9-23.

Figure 13-3 is adapted from Minor, M. A. D., & Minor, S. D. (2010). *Patient care skills*. Upper Saddle, NJ: Pearson.

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14

Occupational Adaptation Practice Model

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The Occupational Adaptation (OA) Practice Model was developed in response to the need for a foundational theory that would fundamentally assist occupational therapy research. It is clear that research and clinical practice have a synergistic relationship, with each one informing the other. The focus of the OA Practice Model is to link the conceptual beliefs of both occupation and adaptation. The OA Practice Model is a comprehensive theoretic model that provides a foundation of theory to describe this phenomenon and is also a framework to guide occupational therapy practice.

Since the emergence of OA in 1992, the OA Practice Model has been found to be broad enough to capture the interests of researchers and specific enough to direct a unique and individualized approach to occupational therapy interventions. The theory emerged as a process-based, non-hierarchical, and non–stage-specific explanation of an integrated phenomenon of occupation and adaptation (Schkade & Schultz, 1992). The model of OA is based on the client's ability to adapt as opposed to the acquisition of skills. The therapeutically directed and collaborative process is initiated with a thorough evaluation of the client's adaptive behavioral responses to the direction of natural energy and ultimate self-advocacy (Schkade & Schultz, 1992). This practice model focuses on the person's internal process of adaptation, his or her self-advocacy, and the need for mastery as motivating factors to functional performance.

The development of the OA Practice Model was in response to an overreliance on the medical practice model, resulting in an increasingly reductionistic practice of occupational therapy. Specifically, the use of the biomechanical frame of reference seemed at odds with the client-centered tenets and core values of occupational therapy and occupation-based interventions (OBIs) yet met the mechanical skill expectations of insurers, physicians, and clients (Bachman, 2016). Using biomechanical principles related to the physics of movement on gravitational and pathologic forces (Cole & Tufano, 2008), the focus of treatment is often on the immediate concerns of injury and healing to enhance the quality of movement that is pain free, efficient, and effective and based on the client's desire to return to previous occupations. Many practitioners in various areas of occupational therapy practice (e.g., hand therapy, outpatient orthopedics, skilled nursing facilities) have had difficulty defining their practice in occupational terminology and language. The OA Practice Model helps explain the phenomena of faciliatory adaptation to the pursuit of OBI.

Barriers to authentic occupation-based practice include reliance on predetermined treatment protocols that mostly focus on clinical symptoms instead of the whole person, environmental factors, or performance of relevant occupations; policy related to reimbursement from health insurance; limited resources such as space and materials; inadequate direct service delivery time devoted to getting to know the client well enough to identify appropriate activities, and/or to deliver occupation-based evaluations and interventions; and the complexity of measuring occupational performance vs. gains in body functions or performance skills (Colaianni & Provident, 2010; Mulligan, White, & Arthanat, 2014). Despite these barriers, OBI is more effective than exercise or other therapeutic activities in hand therapy (Colaianni & Provident, 2010; Daud et al., 2016; Guzelkucuk, Duman, Taskaynatan, & Dincer, 2007), neurological rehabilitation (Hsieh, Nelson, Smith, & Peterson, 1996), and burn injury rehabilitation (Melchert-McKearnan, Deitz, Engel, & White, 2000).

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The OA Practice Model does not exclude biomechanical or rehabilitation principles in intervention, nor does it disregard the necessity of functional skills; however, the primary focus of treatment is on the client's preferred occupational role and in restoring a healthy OA process. The therapist is involved in controlling and evaluating the results of the therapy process and affecting the adaptation outcome (Buddenberg & Schkade, 1998). A fundamental difference of the OA Practice Model is that OA is the focus of intervention with a direct link to future occupational functioning, rather than the acquisition of functional skills or quality of movement (Schultz & Schkade, 1992).

Conceptual Background

The OA Practice Model combines both occupation and adaptation into one construct. It is a conceptualization of a process that is fundamental to both human experience and the philosophical foundations of the occupational therapy profession (Mulligan et al., 2014). The OA Practice Model focuses on core occupational therapy concepts in which occupation provides the means by which human beings adapt to changing needs and conditions, and the desire to participate in occupation is the intrinsic motivational force leading to adaptation (Mulligan et al., 2014; Schkade & Schultz, 1992). Consistent with occupational therapy foundational tenets, the OA Practice Model believes that human beings have an occupational nature and can influence their health through occupation; human development is a continuous process of adaptation; biological, sociological, and psychological factors may interrupt and impair the adaptation process at any point in the life cycle; and appropriate occupation can facilitate the adaptive process (Schultz & Schkade, 1992, p. 918).

The OA Practice Model is client centered, where the therapist and client are active collaborators in prioritizing the client's goals, emphasizing the client's experience of self in relevant occupational contexts to facilitate the return to meaningful occupations. Client involvement in goal setting has been shown to lead to better functional outcomes (Laine & Davidoff, 1996; Ozer & Kroll, 2002), increased client involvement and participation in intervention (Wressle, Eeg-Olofsson, Marcusson, & Henriksson, 2002), and positive psychological benefits (Rosewilliam, Roskell, & Pandyan, 2011). The client is not only involved in goal setting, but also in assessing the outcome of intervention as he or she experiences it. The client is seen as the agent of change.

The OA Practice Model is a holistic approach that gives equal importance to the person, the occupational environment, and their interaction. These are considered the three adaptation elements of this approach.

The person is considered the internal factor of the OA Practice Model. The person operates through sensorimotor, cognitive, and psychosocial systems, which are a part of every occupational response. When there are occupational challenges, the person intends to produce a response that is adaptive and because of the desire for mastery. There are three subprocesses available to the person for adaptive responses: adaptive response generation, adaptive response evaluation, and adaptive response integration.

The adaptive response generation selection subprocess functions to select energy levels, modes, and behaviors. Adaptation energy is finite and idiosyncratic to each person and operates at two levels of awareness: primary, which is focused and depletes quickly, and lower-level energy, which is more creative and depletes less quickly. There are existing, modified, and new modes or patterns of adaptation. There are three classes of behavior for each person system (sensorimotor, cognitive, and psychosocial) that are part of the adaptation response. The first class is primitive or hyperstabilized behavior that may be seen in frozen postures or nonfluid movement (sensorimotor), in rigidity of thinking (cognitive), or in maladaptive defense mechanisms (psychosocial; Schkade & Schultz, 1992). Primitive behaviors are often seen when occupational challenges are beyond the person's capability as a temporary balance-restoring strategy (Schkade & Schultz, 1992). The second type is transitional or hypermobile behavior that provides variability, which has the potential to result in a successful adaptation response. Mature behavior, the third class of behaviors, is modulated and goal-directed. Each person uses all three types of behaviors depending on the occupational challenges. The adaptive response generation gestalt subprocess manifests as the occupational response once the plan is configured.

The adaptive response evaluation subprocess is the process that the person uses to assess how well the occupational response met the occupational challenges of the desire, demand, and press for mastery. The responses occur on a continuum from dysadaptation to OA, with homeostasis as a midpoint. Relative mastery, which is individualistic, is the extent to which the occupational response is efficient, effective, and satisfactory to self or society. The continuum of mastery reflects the adaptive response integration subprocess.

The occupational environment is the context in which occupations occur and is the external factor of the model (Schkade & Schultz, 1992). The physical (nonhuman), social (persons, attitudes, formal/informal social networks), and cultural (procedures, methods, rituals, values, constraints) subsystems call for an occupational response in response to the demand for mastery. The environment contributes significantly to the external role expectations of the individual, which profoundly affects the response to occupational challenges that is adaptive and masterful. Effective intervention with clients requires knowledge of the occupational environment in which the client functions (Schkade & McClung, 2001).

The interaction of the desire for mastery (person element) and the demand for mastery (occupational environment element) produces the press for mastery (interaction element; Schkade & McLung, 2001, p. 20).

Assumptions

Assumptions of the OA Practice Model were clearly indicated in the two articles by Schkade and Schultz when the OA Practice Model was introduced (Schkade & Schultz, 1992; Schultz & Schkade, 1992). The six assumptions are (Schultz, 2009, p. 463):

1. Competence in occupation is a lifelong process of adaptation to internal and external demands to perform.

2. Demands to perform occur naturally as part of the person's occupational roles and the context (person-occupational environment interactions) in which they occur.
3. Dysfunction occurs because the person's ability to adapt has been challenged to the point at which the demands for performance are not met satisfactorily.
4. The person's adaptive capacity can be overwhelmed by impairment, physical or emotional disability, and stressful life events.
5. The greater the level of dysfunction, the greater the demand for changes in the person's adaptive processes
6. Success in occupational performance is a direct result of the person's ability to adapt with sufficient mastery to satisfy the self and others.

OA is a normative process that allows our clients to respond masterfully and adaptively to the occupational challenges that they encounter. OA intervention provides necessary tools to enable the development and maintenance of competency in tasks associated with valued life roles. Carrying out life roles adaptively and masterfully provides a context in which competence in occupational functioning is expressed (Schultz & Schkade, 1992).

Function and Dysfunction Criteria

Personal adaptation is a constant process characterized by disorder, order, and reorganization. OA (i.e., function) is when the person has sufficient mastery and the ability to adapt to occupational challenges, resulting in successful occupational performance of life tasks associated with valued roles. Dysfunction occurs when the demand for performance exceeds the person's ability to adapt. These may include biological, sociological, and psychological factors that may interfere with the adaptation process. A person may be unable to produce appropriate adaptive responses due to impaired personal or environmental factors, leading to an imbalance between the desire for mastery and the demand for mastery. Occupation is a multidimensionality aspect of participation that is an ongoing and ever-changing phenomenon (Gray & Lewis, 2000). Traumatic injury causes changes in the functional kinematics and can lead to abrupt changes in roles and routines of everyday living that will require adjustment and reflection. Since more adaptive individuals are more functional, this is the focus of intervention.

Strengths and Limitations

The OA Practice Model offers a fresh perspective for occupational therapists who have worked within the medical model yet want to remain true to professional values of client-based, occupation-based, and holistic practice (Bachman, 2016; Jack & Estes, 2010; Schultz & Schkade, 1992). Research supports the effectiveness of occupational therapy intervention that is occupation based and focused on the client's interests and needs (Case-Smith, 2003; Colaianni & Provident, 2010; Doig, Fleming, Kuipers, & Cornwell, 2010; Dolecheck & Schkade, 1999; Guzelkucuk et al., 2007; Hétu, 2012; Jack & Estes, 2010). Jack and Estes (2010) state that the OA approach "provides the bridge between the application of clinical expertise, client-centered, occupation-based therapy and the time constraints placed by payer sources" (p. 82).

When the OA Practice Model has been used, treatment was associated with more efficient achievement of functional outcomes, clients were discharged to less restrictive environments, and there were higher rates of client satisfaction (Daud et al., 2016; Dorsey & Bradshaw, 2017; Gibson & Schkade, 1997; Jack & Estes, 2010; Jackson & Schkade, 2001).

The OA Practice Model offers a generic perspective so that the model can be used with any condition or setting. The OA Practice Model has been used with clients with musculoskeletal impairments (Bachman, 2016; Jack & Estes, 2010; Martin, 2007), cerebrovascular accident (Buddenberg & Schkade, 1998; Dolecheck & Schkade, 1999; Gibson & Schkade, 1997; Johnson & Schkade, 2001), children and adolescents with mental health issues (Bouteloup & Beltran, 2007), homeless persons (Johnson, 2006), community-dwelling elders (Miller et al., 2002), forensic psychiatry (Stelter & Whisner, 2007), and Level II fieldwork students (Coates & Crist, 2004; Garrett & Schkade, 1995).

Assessment Process

Data gathering is client centered, whereby the therapist is seeking client and significant others' input on concerns, goals, level of desired occupational performance (efficiency, effectiveness, and satisfaction), and approach to adaptation (Jack & Estes, 2010). The OA Practice Model data gathering begins with questions designed to learn about the client's occupational role and occupational environment and what the demands are of the individual's environment relative to his or her occupational role. This includes finding out about the primary role expectations (past, present, and future) and occupational performance that is most important to the client. Role expectations become the structure on which intervention is based. Discuss with the client current levels of relative mastery and the effect of preexisting problems on the person system factors (sensorimotor, cognitive, and psychosocial functioning). During the assessment process, identification of sources of dysfunction in the components of the OA Practice Model process and the effect on relative mastery is the objective. The role of the therapist is to use an in-depth knowledge base, provide skillful therapeutic use of self, understand OA, ask the appropriate questions, and engage the client in a collaborative relationship (Schkade & McClung, 2001). Data gathering, as done in the OA Practice Model, uses a client-centered, client-reported outcome, which changes the emphasis of assessment and intervention from client factors to those skills and tasks that support desired roles, occupations, and routines. Client-reported outcomes are vital as they can set the stage and climate for the intervention in the clinical process (Valdes et al., 2014). Collaboration with the client in the assessment process can be a powerful motivator within the client-therapist therapeutic process.

Intervention

Intervention planning is focused on helping the client achieve the highest level of internal OA and narrowing the gap between occupational functioning and role performance required by the person and the environment (Schkade & McClung, 2001; Schultz & Schkade, 1992). Planning intervention involves determining the most appropriate combination of occupational readiness and occupational activity needed to promote the adaptation process. Occupational readiness can include skill-based activities and interventions that focus on person system factors to prepare these systems to engage in occupation. These may include the use of preparatory techniques, instruction, or assistive devices initially, but should soon be followed with occupational activities. An example given by Jackson and Schkade (2001) for intervention with hip fracture included hip precaution education, activities of daily living (ADL), functional mobility, and environmental mobility, as is often included in the biomechanical intervention approach as occupational readiness tasks. Additionally, in the OA Practice Model, occupational activities were identified based on identified roles and tasks (Jackson & Schkade, 2001). The client is given the choice of tasks and activities. Occupational activities must require active participation by the client, have meaning to the client, and end with product (Schkade & McClung, 2001). Occupation is the tool to promote adaptation.

Even though functional skills may be improving, this does not mean that changes in OA are occurring (Schultz & Schkade, 1992). Indications of OA are evident in the improvement of relative mastery in terms of efficiency, effectiveness, and satisfaction. Improved adaptation can also be demonstrated in spontaneous generalization of adaptation to new situations and improved self-initiation of participation. Relative mastery is a client-centered concept since it measures performance from the client's perspective and is a reflection of the client's experience as an occupational being (Schultz & Schkade, 1992).

Since the client is the change agent, he or she evaluates progress in therapy in terms of efficiency, effectiveness, and satisfaction according to personal priorities. In many chronic conditions, clients report a loss of control over their lives. The client, as the agent of change, supports his or her self-management needs with a focus on habits and routines, which improves the client's approach to health (Brereton & Nolan, 2000) and leads to a better balance between expectations and the ability to engage in meaningful roles (Wood, Connelly, & Maly, 2010).

The therapist assesses progress with standard assessment tools and by assessing how effective the client is in using the ability to be adaptive (Schkade & McClung, 2001). The therapist determines which interventions are consistent with the client's adaptation needs to perform occupations with greater efficiency, effectiveness, and satisfaction. With collaborative goal setting and assessment of progress, not only does this enhance the therapeutic relationship that facilitates client adaptation, but the client takes ownership of the process (Jack & Estes, 2010).

Because OA assessment and intervention are a collaborative venture between the client and therapist, the therapeutic climate is extremely important to this model. The therapeutic climate is the "interdependent exchange wherein the therapist, as the primary facilitator, functions as the agent of the client's occupational environment and the client functions as the agent of his or her unique person systems" (Schultz & Schkade, 1992, p. 918). There is an emphasis on the therapeutic relationship that facilitates the client's adaptive responses. This relationship is essential to the occupational adaptive process of identifying the baseline relative mastery of existing performance to the dynamic adaptive capacity of desired occupations. Evidence suggests that client-centered OBIs can be valuable to improving the adaptation of recovery (Chan & Spencer, 2004; Daud et al., 2016). Through the therapeutic use of self and by asking questions, the therapist is the agent of change within the occupational environment. However, the client is the agent of change within the person system. This co-occupation reciprocating relationship identifies the client's meaningful activities and directs therapeutic strategies to improved functional outcomes.

OBIs are used to elicit an adaptive response from the client, and the activity does not have an inherent value, as the adaptation phenomena will translate to occupation in the relevant context. The person's enhanced ability to control elements of the body to the environment is the outcome of occupation and adaptation. Authentic occupation is realized when the client lives out the experience in life roles (Schkade & Schultz, 1992).

Phases of Occupation-Based Interventions

The process of adaption is an intangible product and may be described as occupation-based phases of intervention. Throughout a lifetime of physical development and complications, clients continue to strive to participate in their desired occupations. Altered aspects of health and abilities produce challenges to the expected occupational performance. According to the *Occupational Therapy Practice Framework* (American Occupational Therapy Association, 2014), to help clients achieve their desired outcomes, occupational therapy practitioners facilitate the interactions in which the person engages. There needs to be continued research that describes the intent and dimension of providing the just-right challenge strategy in clinical practice. The occupation-based phases provide language and descriptions of the process of adaptation that will communicate an understanding of the dynamic process of adaptation. Additionally, within OBIs, there is a merging of the dimensions of occupation: those of performing tasks that promote and improve skills (occupation-as-means) and occupation as an experience that allows a person to be independent in the tasks of living (occupation-as-end; Trombly, 1995).

The underlying premise in OBI is that the therapist interjects contemporary aspects of practice, those current challenges of being evidence based and philosophically congruent (Gustafsson, Molineux, & Bennett, 2014). From that premise, the next question asked is what does this concept of OBI entail for those people with existing, developing, or recent neuromusculoskeletal changes. The OBI phases provide a clear language to support occupation in process. This process has been especially difficult to document when there is limited clear and communicative language to describe the qualitative phenomena that occurs.

The phases describe the coexistence of occupation-as-means and occupation-as-end that keeps occupation as primary and directed to the core of treatment. The use of occupation-as-means utilizes the synergy of the person's operational capacity and meaningful activities to change impairment, ability, or capabilities (Gray & Lewis, 2000). Occupation-as-end is the adaptive option to promote new skills to achieve competence in function. The intuitive aspects of occupation used in therapy has been identified with descriptive categorical qualities or phases. Each of these phases describes the focus of occupation-based practice, fundamentally centered on the duality of addressing the person's biomechanics of movement and specific unique occupations.

Throughout a person's life, he or she has an innate desire to achieve health, well-being, and participation (American Occupational Therapy Association, 2014). The overarching goal of an OBI is to meet the person's need for mastery at all levels of impairment. Furthermore, the phases provide a profession-specific language that describes the processes of OBI in practice that can be applied to all stages of the human condition (sickness and health).

The distinct phases of OBI, as seen in Table 14-1, represent individual categories that relate to the objectives of the therapy in process. Each occupation phase is defined by the ability-body balance challenge, which is the occupational relationship of the demands of a given task with the available underlying body mechanisms. Independence in occupations is the goal, with emphasis on the quality of movement needed to perform a task. The phases are dimensions of performance in occupation that are unique and require adaptive and reflective ability in the execution of tasks. Education of clients is paramount to the understanding that directed occupation, utilizing their body movement in ways to help themselves, promotes self-development and adaptive ability. In movement-impaired clients, there is a need to correct the disequilibrium of function and facilitate living to fulfill potential (Wilcock, 1993). A body of knowledge and expertise in activity analysis and biomechanics are central to the process and essentially drive clinical decisions. Within the OBI phases, each is a multidimensional perspective of occupation that is not developmental or hierarchical. In some cases, a client may be in overlapping phases, as an activity has sub-actions and varied movement demands. Adaptation of tasks that meet the occupational challenge in the present moment is defined as performance of occupational mastery (Schkade & Schultz, 1992; Schultz & Schkade, 1992). The ability-body balance challenge promoted in OBI requires a therapeutic relationship that is grounded in the understanding of activity demands of movement during function, the dynamic body conditions, and the theory of the human need for occupation.

In determining which occupation-based phase the client is in, the therapist's mandate is to understand the objective and subjective aspects of a person's functional status. This approach requires an evaluation that uses appropriate outcome measures and interview skills to investigate the difficulties within desired occupations. The result of the occupational assessment is to identify pertinent roles and routines that define the person and the specific tasks that are important and those that are difficult to perform. An essential aspect of this design is to identify the person's desires and skills to the promotion of occupational competence. Constraints in intervention design begin by identifying what type of emphasis of "doing" a person seeks. Qualities of "doing" include the importance of the minimization of effort or the enhancement of the execution. The physical limitations will direct the therapist and client to the phase in which the type of activity adjustment will best be determined. The person's adaptability and motivation to adapt is vital to the process. Overall, a person's adaptability and the therapist skill to identify constraints and perspective in the present moment or to the promotion of that task are the phenomena of the prescribed interventions. Adaptation of tasks that meet the occupational challenge in the present moment is defined as the performance of occupational mastery and the goal to the promotion of independence (Schkade & Schultz, 1992).

In some cases, the need to limit the use of body parts is to protect and heal or to minimize painful responses due to movement, which requires compensatory adaptation. The client is directed to a version of forced disuse of the body part and action and, basically, the parameters of activity are redefined. This phase is called the *occupation restriction phase*. In the occupation restriction phase, there is a body part that is protected or unusable for reasons such as to promote rest and healing or to limit motion to reduce pain, or the part is absent due to a permanent loss. The occupation restriction phase is an adaptive intervention with an emphasis on "doing" to support desired aspects of independence through the use of positive adaptions. Compensations during movement and/or environment modifications are the evolving and ongoing occupation-as-end process. The individual's adaptability and desire to promote the self in activities is crucial, and the therapist's responsibility is to educate and facilitate the identified desires. The baseline level of function is to provide education of the purpose of the movement restriction (healing, chronicity, loss of part) and recognize the person's perceived need for meaningful activity and tasks (Chan & Spencer, 2004). The uniqueness of this phase is that the interventions are designed to provide the client with the insight about what motions are restricted, why there is forced disuse, and what changes are needed to promote adaptive compensatory occupations (Earley & Shannon, 2006).

Persons with conditions of changing pathology (either improving, regressing, or chronic) have functional limitations that can be described within a dimension of therapeutic activity (specifically, those subtasks that a person can be encouraged to perform that he or she unconsciously does not recognize). The combined physical abilities of strength, sensation, and range of motion contribute to the performance of subtasks. In the occupation augmentation phase, the subtasks can be identified and controlled to promote functional use. The newly identified existing yet not operating movement capacity is the intention of the OBI. By design, the therapeutic intervention is intended to increase the value and benefit to the whole of the possible movement. In the occupation augmentation phase, the person is educated about the allowable movements (torque, force, stress) and functional parameters that will engage specific body parts, such as soft tissue concerns of joint flexibility, muscle extensibility, and existing aspects of disuse. This phase uses both occupations-as-means and occupation-as-end to

Table 14-1

Occupation Phases in Occupation-Based Interventions

	Description	Definition	Examples of Performance Skills
Occupation Restriction	• Forced disuse for protection of healing body structures or for permanent loss	• Positive adaptation to facilitate relative mastery in desired occupations. Meaningful obligatory client-specific tasks are performed in a constrained manner imposed by the therapist, with an emphasis on ongoing occupation-as-end.	• The educated client completes morning dressing and hygiene using assistive devices, one-handed techniques, or use of uninvolved or noninjured body structures.
Occupation Augmentation	• Controlled adaptive functional loads that support pathology yet guide body structures to the promotion of functional use	• Complements corresponding capacity of client in specific meaningful activity. Occupation-as-means and occupation-as-end are both used due to the ever-changing capacities of body structures during occupation.	• The educated client completes functional tasks using involved body structures, understanding forces and movements allowed as a new tactical task (physiological and adaptive perspectives). Examples include tying shoes, buttoning, and holding a steering wheel.
Occupation Execution	• Forced use to promote occupation in the context/ environment	• Goal-directed subtasks of occupation as the solution to improved performance • Therapeutic activities are directed positive modification to body structures and/ or environment to facilitate efficiency of movement.	• The educated client reaches across a desk (distance allocated) for cell phone (shoulder stability for facilitative elbow extension). • The educated client places item in back pocket to perform a therapeutic reach (facilitate adhesive capsule with shoulder extension with internal rotation). • The educated client consciously places hand/fingers around toothbrush to initiate composite flexion in grasp (mobilize finger joint and flexor tendons).
Occupation Spontaneity	• Spontaneous, fluent, and efficient use of body parts in the entire activity • Generalizations occur from other occupation successes.	• Unconscious, unrestricted high-level activity of client's meaningful activity, at which there is observed mastery of occupational challenge.	• The educated client is able to independently clean kitchen floor (in four-point posture, the involved arm in extended flat hand position assisting trunk control during task). • The educated client is able to lean forward in extended reach to grab bar during tub transfer (fluent motoric efficiency and safety).

meet the dynamic and changing physical and adaptive abilities of the person in context. In the occupation augmentation phase, the OBIs are concerned with the present condition of the body parts and structures and the mechanical forces and stresses within the activity that will not compromise or cause injury. An example of this occurrence is seen in orthopedic cases of a healed fracture or joint dislocation when the movement restrictions have been removed. The conscious, directed use of positive modification in biomechanics is used to promote client factors that complement corresponding motor capacity during meaningful tasks.

The occupation execution phase occurs when the mechanics of motion are intrinsic to the design of the OBI. The specific motoric action is the solution to the body structure disorder. Muscle weakness, pain, or joint stiffness are examples of neuromusculoskeletal impairment that alter the mechanics of functional movement. In the concept of occupation-as-means, the activity prescribed is the intervention. Consequently, in this phase, the OBI goals are to improve specific performance by enhancing the properties or qualities of a movement. For example, a person with a nonfixed elbow flexion posture is observed to have a motoric pattern of using adaptive body

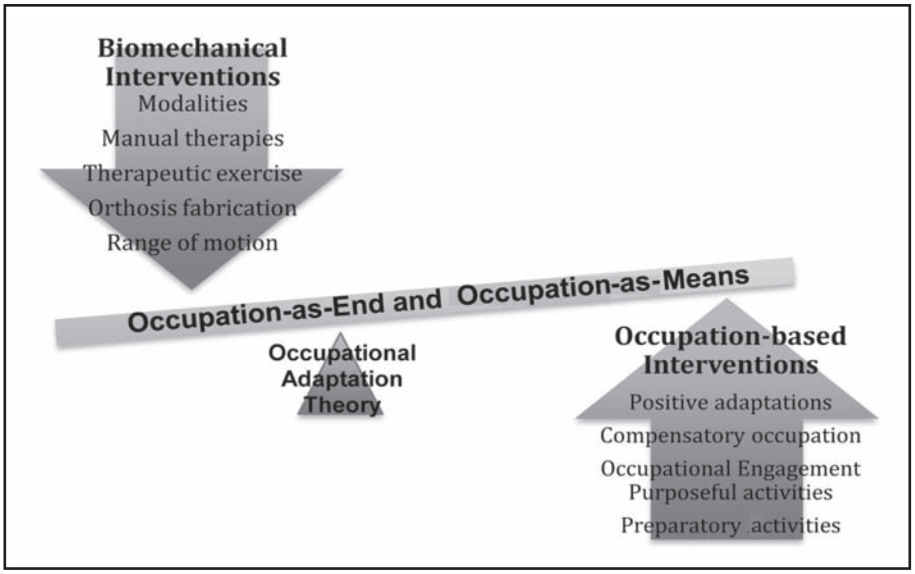

Figure 14-1. Diagrammatic representation of practice perspectives. Occupation-based and biomechanical interventions based on disorder (body functions, body structures) and the client's adaptability for desired purposeful activity.

movements (trunk and shoulder) during the functional arm reach. The therapist interjects the submotion that promotes the desired reach pattern. In the case of a limited range of elbow extension for arm reach, the person is taught to stabilize the trunk, retract, and hold the scapula in the downward rotated position. This position will limit compensatory movement of the upper girdle, that of elevation and scapular protraction. This conscious muscle activity is to facilitate the desired action and promote the execution of humeral motion, external rotation, and elbow extension. In the example, the OBI within the occupation execution phase is to educate the person about the desired movement and to promote continued recovery. For the activity of cell phone texting, the benefit of placing the device at a distance to the involved side requires engaging the desired therapeutic motion of controlled functional reach in elbow extension. The parameters of the occupation execution phase are created and designed by the therapist within the purposeful activity. The defined movement characteristics of the subtasks are demonstrated and performed within the task. Directed movement is the solution, and the activity requires the conscious engagement of the client. The promotion of a specific action (body structures to stabilize or mobilize) requires the deeper understanding of movement in function. The client demonstrates the desired motoric behavior to enhance recovery. Adaptation occurs by providing the challenge of an appropriate task with the emphasis on the body structure execution.

The occupation spontaneity phase is the unconscious, unrestricted, efficient, effective, and satisfied use of the body during activity. In this phase, spontaneous use of the whole body structure is fluent and pain free. OBIs are directed to the challenges of complex activity. The therapist using OBI sets the stage by the combined perspective of the identified biomechanical efficient movement goal as it intersects with occupation. This shift directs the treatment to a functional perspective. As the client is focused and engaged in the OBI, the functional and movement parameters meet the functional challenge. The successes obtained in one occupation are spontaneously generalized to others. For example, the occupation spontaneity phase is realized when trauma or illness that initially limited use for stabilizing the upper body is therapeutically engaged during car transfers, and this same action is then observed in other tasks. Functional equivalent tasks, such as placing the hand on the stair rail or when rising from the floor to a stand, become instinctively a part of the success to efficient occupation. The body meets the demand of activity using pain-free, fluid movements. The structures required for a balanced weightbearing position include upper quarter stabilization, elbow joint flexibility, and wrist extension, with the arm adjusting to the various surfaces in relative mastery to the achievement of an optimal performance within all desired occupations.

The use of multiple models and frameworks within practice benefits client-centered practice to meet the unique challenges of each person. The underlying issues of a therapeutic fit are based on the understanding of the dynamic exchange of noncompeting perspectives and to the contribution to an occupational equilibrium and stability, as illustrated in Figure 14-1. The balanced lever diagram illustrates one side with the biomechanical concerns of healing or injury. The opposite end of the level is that of occupation-based concepts that are dependent on client-centered adaptability. The fulcrum indicates the clinical decision making that is grounded in occupational therapy theory and framework. The diagram illustrates how the therapist utilizes different approaches to address the change or growth of client factors and the need for mastery at the level of impairment.

Evidence for Occupation-Based Interventions

Chan and Spencer (2004), in a mixed-methods study, sought to examine qualitative and quantitative measures of similarities and differences in the physical recovery and psychosocial adaptation of clients with a hand injury. The collected data from each participant demonstrated changing relationships within important categories of occupational relationships. A constant variable within this study is the therapist-client relationship. A compelling factor that influenced the adaptive process was the actual performance of early occupations, those that are imposed by restrictions of healing tissue, and the adaptation of the valued occupation. This process was unique to each individual and was directed by the client-centered treatment. The results indicated that OBI that addressed both physical recovery and psychosocial adaptation gave the injured person a sense of accomplishment with improving independence (Chan & Spencer, 2004). This study is an example of OBI intermixed with traditional biomechanical treatments and suggests the combination of therapeutic exercise and OBI within the rehabilitative experience of a hand-injured person to his or her daily life values (specifically to occupations of daily living and relationships).

A compelling study by Daud et al. (2016) measured the effect of directed occupations in home programing and OBI to assess improvement compared to exercise only. The study design, from a single-center, randomized controlled trial, used parallel groups, with the inclusion of 46 hand-injured adults, randomly selected into two groups. The experimental group received the OBI and therapeutic exercise, while the control group received therapeutic exercise only. The data were compared at baseline, after 6 weeks of supervised hand therapy, and after 4 weeks of home-based hand therapy. A linear mixed-model analysis was used to examine confounding effects that may have influenced therapeutic outcomes in t-tests. The parameters of performance measures were analyzed to determine treatment efficacy. Statistical significance of the P values ($P < .05$) using two-tailed t-test at the 6-week time measure were compared to the baseline to determine change due to intervention. The results indicated significant differences between the study groups, exercise only and exercises with OBI groups in total active motion, neuropathic pain, and the Canadian Occupational Performance Measure for performance and satisfaction. This study indicates a dual framework of biomechanics and OBIs in hand therapy based on the parametric of activity and participation that direct aspects of client occupation choice and therapist intention. This study illustrates the use of OBI and therapeutic exercise in tandem, those of the biomechanics and occupation approaches and not to the shifting of approaches; they were performed simultaneously as directed to individual client factors and the need for occupational mastery.

The theory of OA suggests that there is a dimension of occupation that is dynamic and relies on the self-advocacy of the client. The occupational approaches used in rehabilitation address the phases of adaption and are most likely directed by the dimension of occupation (as means and as end). These assertions, related to supportive literature and relevant evidence, validate the use of occupation-based principles within the profession and, specifically, to the subspecialty of hand therapy. Therefore, to extend the identity of occupation, the term *occupational efficiency* can operationally be applied to functional biomechanics. The dimensions of occupation can be narrowed to the individual's adaptation to injury or condition, yet at the level of performance. Occupation, at its highest level, is the transcendent concepts of participation and is measured by the client's satisfaction of the experience. At a lower level, the occupation as an element of the body part or body system as it relates to the experience of motion also is measured by the client's report of satisfaction. Occupational efficiency is the clients "doing" at the body system or body part level. An example of an elemental occupational skill is that of the ability to reach in context (i.e., reach into a base cabinet to obtain a bowl at arm's length). This requires shoulder stability with minimal elbow angle extension and hand in object orientation or beyond arm's reach (motor requirement of trunk displacement, shoulder protraction, and extended arm with hand object orientation). The occupational efficiency is the client's response to the experience. The movement analysis is the measure of target success that includes trajectory, smoothness, reach and return, and observed body faults. This is a combination of kinematic analysis of occupation in context.

The underlying knowledge of kinesiology, task analysis, and biophysiology of acute and chronic conditions could be called *occupational movement science*. These factors are paramount to the process of meeting an individual's occupational challenges. Occupational therapy intervention occurs with clients at all levels of impairment, in early stages of disease, and in advanced and chronic conditions. There is an inherent individual desire to be "doing" all that we can to the best level of ability that we can. This requires knowledge of kinesiology of efficient performance. When the time, energy, and resources are improved by improved motoric efficiency, the client's satisfaction with performance will improve. Success and satisfaction in activity and participation affects the overall health and well-being of all persons (Wilcock, 1993). In practice, for those clients who have acute or chronic conditions, the evaluation of body symptoms, body parts, and client factors set the stage for identifying and understanding of movement demands of the person. Then, the movement demands are interpreted in terms that describe the client's ability to respond in time, space, and material factors within his or her environment (Schkade & Schultz, 2003).

When a client presents with a condition of kinematic compromise, with either the need for protection or rest from the stress of intentional, functional forces or from the pain of that intention, the therapist guides the needed changes in functional behavior. The client identifies his or her individual adaptive capacity, and the therapist guides the occupational phase. The therapist understands the need for positive adaptations within the environment and the client's need for mastery to promote independence and well-being. Collaboration in client-centered practice directs the occupational phase to the biomechanical level of soft tissue capacity to the client's present adaptive functional capacity (see Table 14-1). The occupational phase is the client best fit of capacities: controlled stresses to body parts for the promotion of desired occupations. The therapist uses meaningful occupation and approved and controlled movement for a successful occupational experience. The underlying variable is the client's state of body kinematics and the need to protect or facilitate those processes. In OBIs, there is a merging of dimensions of occupation: those of performing tasks that promote and improve adaptive capacity (occupation-as-means) and the occupation as an experience that allows a person to be independent in the tasks of living (occupation-as-end; Trombly, 1995). Authentic occupation is realized when the client lives out the experience in life roles and routines (Schkade & Schultz, 1992).

Case Example

Hand therapy emerged from occupational therapy due to a need for professionals that have the skills of orthosis fabrication, precision measurements, and in-depth knowledge of hand and upper extremity function. The language, theory, and outcome measurements of occupational theory were difficult to apply in the outpatient hand therapy practice environment. The orthopedic medical occupational therapy practitioner shared biomechanical medical terminology that soon became the language that was employed to define occupation in the existing hand practice. The occupational therapy definition of occupation was not the same as that used by the orthopedic medical practitioner. The standard measures of intervention used by the hand specialist were those of client factor (body function and body structure) levels of measurement and with less emphasis placed on activities, participation, and environmental factors (Lesher, Mulcahey, Hershey, Stanton, & Tiedgen, 2017; Rose, Kasch, Aaron, & Stegink-Jansen, 2011). Traditionally, in hand therapy, the measurement of a client's physical status is that of specific neuromuscular and movement-related client factors: joint motions, capsular patterns, and tendon and nerve excursions. The body structures were quantified in correlation with the client's biomechanical and symptomatic responses. Occupational therapy hand therapists analyze the components of movement to their biomechanical and kinematic benefits to enhanced performance.

The client's awareness of these measures influenced the responses to questions asked by the therapist. How are you doing? If the response to the question is related to mere motion, such as the client reporting that he or she was able to bring the tip of the finger to the palm crease, then the emphasis of treatment is on components. Consequently, if the client reports turning a key in the car to start the ignition, then we know the focus of treatment is client centered and occupation based.

There are identified self-report outcome measures in practice that assess change over time and have attributes to those of activity and participation. Not until the past few decades have there been the quality measurements that support the philosophy of occupational performance (Chen, Palmon, & Amini, 2014; Law, Baum, & Dunn, 2005). If we are what we measure, then as the precision of our measurements improves, so will the quality of our therapeutic culture. Continued research is needed to discover the occupational dimensions of functional movement that can be measured by the subjective response of satisfaction of movement and the influence on improvement in participation.

Occupation-based models related to occupational therapy practice in movement dysfunction are often based on the OA Practice Model because it is the process of action and events that incorporate an occupational challenge of performance within the occupational role. The way in which each person performs is genuinely unique due to a person's desire for mastery in the presence of efficiency and that of time, energy, and resources (Schkade & Schultz, 2003). This model provides the flexibility of adaptation within the occupational phases. The therapist can overlap or shift to and from the OA Practice Model based on the client needs of biomechanical concerns of healing and controlling tissue responses (Jack & Estes, 2010). The use of the OA Practice Model enables the use of biomechanical principles and interventions as readiness components (e.g., healing, tissue response) while also being client centered and occupation based. In the specialized interventions of occupational therapy hand practitioners, the science of kinesiology in occupation, and the knowledge of movement requirements in pathology and dysfunction direct the process of OBIs.

The occupational therapist addresses both the need for healing of soft tissue in a protective sense and the need for positive adaptations to daily activity. Collaboration in client-centered practice directs the occupational phase to the biomechanical level of soft tissue capacity (see Table 14-1). Through the occupational profile, the therapist and client identify the occupational phase of the desired activity. The occupational phase is the description and terminology that describes the client's intersection of physical and functional capacities to the desired activity. The therapist's intention is to identify the baseline phase of activity that correlates with condition and the client's adaptive ability. The phase is to describe the type of occupation that is the adjusted skill challenge for the present condition and promotes the activity or task that is meaningful to the person.

The client has sustained a fracture to the shaft of his right-dominant fifth metacarpal. The fracture is 10 days old and stable. Roles and routines identified by the client include active participation in academic and social groups. The client's meaningful activities include using a keyboard, writing, and playing soccer. He lives with two other students in a small campus apartment. At this point of the bone healing stage, active motion out of orthosis is allowed, but the use of the hand is limited to light, fine-motor activity. Bone stresses that are needed for full composite grasp, lifting, weightbearing, and sustained manipulation are restricted for 4 weeks.

The client in an OBI is guided to engage in adapted meaningful tasks that correspond to the level of allowed functional forces. Initially, his healing capacity places him in the occupational restriction phase in some occupations, and others will be overlapping into occupational augmentation. The phase is dependent on the condition and how the condition influences or magnifies the limitations. In the acute fracture healing phase, the client is directed to perform activities using one-hand and to use assisted devices for writing and keyboard tasks. Due to the need to only limit the fourth and fifth metacarpal stresses (those that are incurred by forces applied by the intrinsic hypothenar and extrinsic wrist and digital flexors, specific to the ring and small finger metacarpal and carpometacarpal joint loads), the client is directed to use modified and motoric compensation for all ADL. This phase is the occupational restriction phase, as the client is directed to one-handed, positive adaptations of cup to mouth drinking using the uninvolved hand and using the keyboard with modified key strike. The fracture is protected by an orthosis with the thumb and index finger free for motion. Specific activity is identified, explored, and adapted in the therapy process.

In the occupational augmentation phase, the client demonstrates objective physiological evidence of bone status that allows active digit joint motion performance that is pain free with minimal swelling. The activity may be adapted to enable negligible forces. Following the reassessment and identification of activity demands, there is clinical observation during a designed intervention that is directed to the use of the radial aspect of his hand for light activity. The client is provided the education and training about how to adjust hand use to complete most ADL. For those activities that require forces outside of those allowed for his current condition (e.g., pushing a grocery cart, carrying a laundry basket or book bag), the use of a protective orthosis is recommended to enable modified occupational participation. In this example, the client presents an adaptive capacity that allows him to eat using a spoon and fork and pick up finger foods and bring them to the mouth. While brushing his teeth, the client is encouraged to place all of his fingers around the handle of the toothbrush, with greater grip possible from use of the thumb, index, and middle fingers. This process of directed adaptation is relative to the individual's occupational need and adaptive capacity.

When there is evidence of fracture healing (usually at 4 to 6 weeks after the date of injury, preferably confirmed by an x-ray), the client continues to identify occupations that are meaningful, those that are successfully performed, and those that are difficult. In the therapy process, the use of the hand and arm is attuned to the appropriate purposeful activities that are a match to the forces needed for that task.

In this example of the progression in bone healing, the client moves into the occupation execution phase to focused tasks of opening doors with whole hand grasp, placing and grasping the hand on the steering wheel, writing with the ring finger and small finger in full composite flexion, and beginning light bag-carry tasks. The client identifies the meaningful tasks; simultaneously, the therapist understands the contextual need for hand use and the kinematics of motion and forces that are required for both healing and function. Through the process of understanding the client's kinematic requirements and specific pathology, the therapist can provide guided and controlled interventions that are occupation focused and allow the person to respond masterfully to the demand. The promotion to new activities is not a reflection of an improved skill, but is the process of guided adaptation.

Summary

The OA Practice Model is one supporting theory that explains the phenomena of occupational engagement within the domain and process of occupational therapy, especially for those clients with neuromusculoskeletal disorders. The notion of shifting synergies between biomechanical concepts of motion and strength interventions to OBIs of adaptation is based on the client's need for self-advocacy, mastery, and the development of the best movement potential. The OA Practice Model is centered on the occupational profile and on self-report measures. These important interview and evaluative tools within the client-centered process guide and prioritize the interventions. The knowledge of kinesiology fundamentally directs functional movement to the intrinsic nature of how the essential task is being performed. The guided performance is directed to the present condition of available capacity and is a vital part of the therapeutic process. The introduction of OBI phases allows the therapist to use terminology to describe and document the adaptation and activity promotion in practice.

In a far-reaching purpose, the use of performance measures and the science of movement within occupation will promote the evolution of our profession from the broken biomechanical model of medicine to the holistic art and science of a helping profession. Importantly, this chapter provides a description, method, and terminology that summarize the phenomena of the adjusted challenge that occurs within an occupation-based practice. The OA Practice Model that influences occupation-based practice can fulfill the need of occupational therapists to foster and identify the changes in practice to that which best serves the client's functionality and well-being.

As research provides a greater understanding of the influence of satisfaction to meaningful performance and how this contributes to an understanding of motoric satisfaction, there may be a transition from the OA Practice Model to occupational movement science, which would be reliant on the use of satisfaction of movement measures. Occupational movement science, as the study of occupational performance at the intersection of client factors and occupation, is directed to the quality of motor proficiency that improves meaningful occupation. The model would include the qualitative and quantitative aspects that assess satisfaction in movement performance, called *occupational efficiency*.

In practice, we cannot bypass the components of functional kinematics and direct care to pure OBIs only. Top-down approaches to treatment can be neglectful of the concerns of the quality of movement. What the therapist sees and hears from the client with acute injury are the complaints of movement dysfunction that are described in their terms of weakness, pain, and coordination and are observed as gross or local postural dysfunctions or faults of movement. A client with a chronic condition and movement limitation has complaints related to anger, fear, helplessness, depression, anxiety, and sedentary activity. Recent studies looked at both quantitative and qualitative aspects of improved upper arm movement and correlated the outcomes of performance and satisfaction, using the client-reported outcome measures (Anderson, 2015; Wangdell & Fridén, 2012). As research continues to quantify and qualify the determinants of satisfaction in movement, especially those specific to meaningful occupations, the specialization of hand therapy will be fully realized, and occupational therapy will address function qualitatively and quantitatively in the context of occupation.

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15

Motor Control and Motor Learning

Sandra Rogers, PhD, OTR/L

A thorough study of kinesiology would not be complete without a discussion of motor control. Kinesiology is defined as the study of the mechanics of body movements, thereby demonstrating the linkage between the mechanics of movement and the control of body movements. A practitioner who has an understanding of kinesiology can appreciate all of the disciplines required for understanding human movement. On the mechanical side of human movement is an understanding of anatomy, muscle physiology, and physics (in particular, body mechanics), whereas the body movement or control side is based on neuroscience and understanding behavior (e.g., psychology and task analysis). Understanding the complementary role that biomechanics, motor control, and learning play in motor performance and recovery from injury is essential to all students of kinesiology and practitioners (Figure 15-1).

The organization and production of movement is a complex problem and relevant to many disciplines, so the study of motor control has been approached from a wide range of fields, including sport psychology, cognitive neuroscience, and biomechanics. Consequently, motor control has many applied aspects, in particular, those related to impaired control and coordination of movements in various neuromuscular disorders; effects of development, aging, and practice on motor control and coordination; and effects of motor rehabilitation. A thorough assessment of human movement and performance is needed to facilitate rehabilitation and management to maintain, rehabilitate, or enhance movement and performance. Thus, a discussion of how motor control and biomechanics are intertwined is useful when studying kinesiology.

Motor control is the ability of humans to use their central nervous system (CNS) to initiate and coordinate muscles, joints, and limbs to perform a motor behavior/skill. It is now generally accepted that all of the following are required to generate a desired movement pattern: integration of sensory information, calculation of the specific environmental demand, and the body's ability to determine an appropriate set of muscle forces and joint activations. This process of coordination requires the CNS and musculoskeletal system to solve a complex set of interactions and includes information processing, coordination, mechanics, physics, and cognition. Successful motor control is crucial to interacting with the world, not only determining action capabilities, but regulating balance and stability as well. See Table 15-1 for a comparison between these two broad disciplines.

The intention of the chapter is to emphasize the relationship of motor control to biomechanics and kinesiology (forming the foundation of movement), with an overview of motor control, motor control theories, and application to rehabilitation while referring readers to in-depth texts about motor control for comprehensive information.

Motor Control Theories

In the early part of the 20th century, Sherrington (1906) described a "reflex theory of movement model" that dominated neuroscience for many years. Sherrington theorized that all movements occur in response to a stimulus directed by spinal reflexes, and not by the CNS. An example of a spinal reflex is the commonly known patellar tendon reflex that causes a quick knee extension (jerk) without any direction from

Rybski, M. F.
Kinesiology for Occupational Therapy, Third Edition (pp. 451-463).

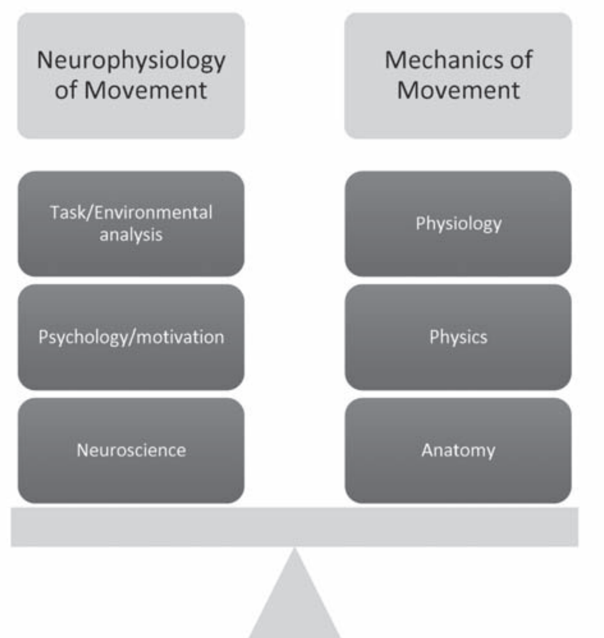

Figure 15-1. Balance between biomechanics and the neurophysiology of movement.

the brain. In addition, movement was believed to be developmental such that children proceed to a higher skill only after they master the lower-level, more primitive skill (e.g., rolling before sitting, kneeling before standing).

Gradually, a hierarchical or neuromaturation model replaced the reflex model through a burgeoning understanding of the plasticity and of sophistication in research methods to study the CNS. In these models, the CNS was thought to control movement, where the higher-level (brain) control of motor responses directed movement. These theories viewed the CNS as open-loop or feed-forward systems, where hierarchically stored motor programs rule so that tasks could be accomplished with a variety of musculoskeletal effectors. This open-loop system feeds the motor program forward and proposes the movements are selected, planned, and initiated from past motor experiences (Bertoti, 2004). These theories also reflected the understanding of neural plasticity and effectively sought to utilize plasticity following CNS injury. Motor control interventions were dominated by neuromaturation theories for a long time and have provided practitioners with numerous resources for understanding intervention. The differences between older neuromaturation theory and more contemporary motor control theory are highlighted in Table 15-2.

In the 1970s and 1980s, a series of discoveries gradually allowed researchers to see movement as emerging from the interaction of multiple subsystems, where no one system has hierarchical control of another but was instead distributed among many systems. Typically referred to as *systems theory*, *dynamic systems theory*, or *ecological theory*, these theories conceptualize movement regulation as a distributed process that results from the interaction of the multiple factors and systems working together to generate and control movement. In these theories, normal movement is thought to be possible because of the strategies of motion that emerge from the interaction of the various systems. Subsystems interact within a context of the environment and task demands to allow flexibility in responding to motor challenges and making further adaptations as motor demands are altered. Neuroplasticity following CNS damage was also essential in understanding and explaining how intervention would have an effect (Kandel, Schwartz, Jessell, Siegelbaum, & Hudspeth, 2012). The concept of neuroplasticity, and findings from current brain imaging research, has led to the further development of dynamical systems, systems theory, and ecological theory, which seems to better explain motor control. These theories propose that movement is a function of interactions among the neuromuscular system, environment, cognition (i.e., thought processes), and the task itself. The intent to move is a cognitive process enriched by motivation and it entices one to engage in a task. The task itself sets the tone for the system requirements (e.g., sensory, cognitive, neurological, musculoskeletal, emotional). The various systems interact with each other and play a role in movement.

Edward Taub showed, through a series of deafferentation experiments (i.e., cutting the sensory nerve fibers to eliminate sensory nerve impulses), that something other than reflexes is responsible for movement (Taub, Perrella, & Barro, 1973). Taub observed that, when the sensory roots of the spinal cord were severed in a lab monkey, rendering no sensory input to the limbs, the monkey could still use its limbs. With the advent of the ability to examine the relationship of the CNS to movement evolved, researchers learned more about the interplay among the nervous system, musculoskeletal system, motivation, and environment, and a new model for viewing movement emerged (Taub, Uswatte, & Morris, 2003). Thelen and Fogel (1989) examined the reaching skill development of infants and found that infants learn to reach in a vast array of potential movement trajectories so that movement emerged through the interaction and self-organization of many subsystems. This challenged the ideas that had emerged from hierarchical motor programs and gave support to viewing every task as unique to an individual and environmental demands (Thelen & Fogel, 1989). Movement is formed from interaction among many systems (e.g., sensory, musculoskeletal, cognitive, central nervous, environmental) and the demands and challenges inherent in a task. The connections between movement and multiple systems has been verified by functional magnetic resonance imaging studies and support that multiple levels of the central and peripheral nervous system are activated to create functional movement (Grafton & Hamilton, 2007; Krakauer, 2005; Nielsen, 2003; Takeuchi, Oouchida, & Izumi, 2012). The result is that we are able to generate specific movements with precise regulation and flexibility of control. Figure 15-2 illustrates the evolution of theories related to motor control.

Motor control theories involve the understanding of a number of related concepts, including biomechanical concepts (highlighted in Chapters 1 through 14 in this text), neurophysiological concepts (e.g., muscle tone, reflexes, programmed movement), degrees of freedom, and constraints of movement that affect the stability and efficacy of movement. Each of these areas will be addressed briefly next.

Table 15-1

COMPARISON OF MOTOR CONTROL AND BIOMECHANICS DISCIPLINES

	Motor Control	**Biomechanics**
Definition	Motor control refers to the "ability to regulate or direct the mechanisms essential to movement" (Shumway-Cook & Woollacott, 2017, p. 3). Scientists studying motor control examine the role of the CNS, techniques to quantify movement, and the nature of movement. Motor control, therefore, addresses posture, mobility, fine motor skills, and gross motor skills throughout the lifespan and includes knowledge of development and processing requirements. It is defined as the search for natural laws that describe how an animal's CNS interacts with its body and environment to produce coordinated, purposeful movement.	Biomechanics is the study of movement from a mechanical perspective.
Origins	This field borrows heavily from psychology, neuromuscular physiology, control theory, dynamical systems, optimization theory, biomechanics, information theory, computational neuroscience, and cognitive science.	The field includes cellular mechanics; muscle behavior; material properties of skin, tissue, and bone; macro-level analyses of joint motions; and gross behaviors such as locomotion, reaching, and prehension. The principles of rigid-body mechanics, fluid mechanics, continuum mechanics, dynamical systems, and optimization theory form the theoretical basis of biomechanics.
Measures	Motor control is typically studied at the muscular or behavioral level.	Typical measurements are forces and displacements of the components of the system under scrutiny.

Adapted from Latash, M. L. (2016). *Biomechanics and motor control: Defining central concepts*. San Diego, CA: Elsevier.

PHYSIOLOGY OF MOVEMENT

Brain Function

There are multiple areas in the brain and spinal cord that are responsible for the neurophysiological control of movement. These areas include the cerebral cortex, basal ganglia, cerebellum, thalamus, hypothalamus, brainstem, spinal cord, and their collective ascending and descending pathways. Depiction of motor control in a hierarchical model is helpful to conceptualize the structural interactions; however, this illustration is incomplete. As discussed earlier, contemporary motor control provides us with a much more dynamic view of the capabilities of the motor system, which depends equally on biomechanics, neurophysiology, environment, cognition, sensation, and task demands.

The spinal cord is the site of initial somatosensory processing and the reflex and voluntary control of posture and movement through motor neurons. Sensory afferents provide input to multiple levels within the nervous system, including spinal level neurons, brainstem, and subcortical and cortical levels of processing. After processing at these many levels, skeletal muscles are altered. We see an organized set of reflexes (discussed later in more detail) and coordination of basic patterns of movement (e.g., locomotion or itching behavior) directly at the spinal level.

The brainstem and cerebellar nuclei work together to coordinate postural and automatic movements. The brainstem contains nuclei that are essential to postural control and locomotion. These nuclei include the vestibular nuclei, red nucleus, and reticular nuclei. The other essential information is contained in ascending and descending pathways that are transmitting information about sensory and motor information from other parts of the nervous system. Thus, the brainstem is receiving somatosensory information about the skin, muscles, joints, and visual and vestibular systems. The motor output of the brainstem includes the control of eyes, head, and neck movements. The brainstem nuclei that control arousal and awareness of the environment are contained within the reticular formation, which contributes to cognitive processing. Cerebellum nuclei also receive input from both the spinal cord and the cerebral cortex and has its primary output via the nuclei at the level of the brainstem. The cerebellum serves as a comparator between the intended output and actual performance as the movement is unfolding. The cerebellum is also essential to motor learning and helps to modulate the force and timing of motor movements.

The cerebral cortex, subcortical structures, and thalamus are also essential to creating normal movement. The thalamus is the processing and relay station for most of the input from the spinal cord, cerebellum, and brainstem. The frontal cortex contains the premotor area, supplementary motor area, and motor cortex primarily responsible for programming

Table 15-2

Comparison of Hierarchical and Dynamical Systems Approaches

Hierarchical Neuromaturation Theory	Dynamical Systems Theory
Theoretical Assumptions	
• The CNS is hierarchically organized. Complex motor patterns are built on simpler movement patterns organized in sequence (i.e., parallel). • Movement develops in predictable ways (e.g., proximal to distal and cephalocaudal). • Effective movement is elicited by sensory input. Movement is linked to sensory processing movement activities and is, in turn, modified by sensory feedback. • Following damage, atypical movement patterns (immature patterns) predominate. Treatment focuses on the facilitation of typical developmental sequences. • Improvement following neurological insult is a result of predictable motor sequences (e.g., proximal to distal). • Incoordination of posture and movement combined with atypical qualities of muscle tone following neurological injury are responsible for functional limitations. • Goal-directed intervention leads to best functional outcomes; movement is organized around behavioral goals. • Open-loop and closed-loop controls are used to regulate movement. • Treatment is a problem-solving concept that is flexible to match the client's needs and is established in partnership with a client. • Learned motor skills need to be practiced in similar ways, and more efficient skills are improved with intention.	• Heterarchical functioning is expected and includes both personal and environmental systems. No one area of functioning supersedes another. The relationship between higher and lower centers is not one to one. • The CNS, perceptual skills, cognition, development, kinesthetics, and mechanical properties are all part of the multiple systems influencing motor behavior. • Emphasis is on the interaction of a person with his or her environment, where motor behavior (movement) emerges from multiple systems interacting within an environmental context. • Relationships between motor movements are related to behavioral goals and desires to move. Thus, intensive and variable practice improves motor behavior if there is a perceived functional need. • Changes in the system can alter the behavior. • Feedback and feed-forward control are used to achieve motor goals. • Progression following injury is expected to vary based on the unique capacities of the individual; thus, strategies, environment, and constraints differ, so progress will differ.
Evaluation	

• Muscle tone
• Reflexes
• Stereotypical movement
• Postural control
• Sensation
• Perception
• Stage of motor recovery
	• Task selection and analysis
	  ◦ Describe movement.
	  ◦ Identify preferred movements for optimal movement goals.
	  ◦ Identify variables that affect task completion.
	  ◦ Provide opportunities for practice with variation.
	• Client goals and occupational profile systematically analyze movement in environmental and developmental context.

(continued)

Table 15-2 (continued)

Comparison of Hierarchical and Dynamical Systems Approaches

Hierarchical Neuromaturation Theory	**Dynamical Systems Theory**
Intervention	
• Physical handling is a tool to be used in evaluation and treatment. • Feel the client's responses to postural and movement changes; movement is geared to evoke active responses. • Facilitate postural control first and then movement. • Provide boundaries for movements. • Inhibit or constrain abnormal movements that lead to further disability. • Facilitation techniques are carefully applied to establish or reestablish the postures and movements that will enhance the client's function. • Motor learning is a result of experience and practice in specific environments. • Client-set goals that are specific, meaningful, attainable, and moderately difficult have a greater effect on motor learning. • Instructional strategies are based on a task-oriented approach. • Practice is a prerequisite for motor learning.	• Client centered where the client is an active participant in directing treatment • Occupation-based focus in treatment that is meaningful to the client • Identify critical personal and environmental factors related to the task. • Practice and provide feedback. • Foster problem solving in clients. • Discover optimal movement patterns. • Develop flexibility, efficiency, and effectiveness in task performance. • Design the practice session to fit the type of task and learning strategies of the client. • Provide feedback that facilitates motor learning and experiment with solutions. • Optimize occupational performance given the constraints on the person and environment.

Adapted from Bertoti, D. B. (2004). *Functional neurorehabilitation through the life span*. Philadelphia, PA: F. A. Davis; Latash, M. L. (2016). *Biomechanics and motor control: Defining central concepts*. San Diego, CA: Elsevier; Magill, R. A., & Anderson, D. (Eds.). (2013). *Motor learning and control: Concepts and applications* (10th ed.). New York, NY: McGraw-Hill Higher Education; and Shumway-Cook, A., & Woollacott, M. (2017). *Motor control: Translating research into clinical practice* (5th ed.). Philadelphia, PA: Wolters Kluwer.

movements, generating a motor plan, sending commands to the spinal cord, and sharing information with the cerebellum and brainstem. The subcortical structures (e.g., basal ganglia) reciprocally receive input from the cortex and provide the motor cortex with planning motor strategies and inhibiting erroneous strategies (Kandel et al., 2012).

Neurons, Motor Units, and Sensation

Neurons, neuromuscular junctions, and motor units are the building blocks of movement. Daily tasks, from bathing, dressing, or eating, require complex coordination among these motor units. A motor unit is made up of a motor neuron and the skeletal muscle fibers innervated by that motor neuron's axonal terminals. Groups of motor units often work together to coordinate the contractions of a single muscle; all motor units within a muscle are considered a motor pool. Each motor unit will innervate all three types of muscle fibers (i.e., type I, IIa, and IIb fibers). These three different types of fibers are specialized to have unique functionalities. Type I fibers are described as high endurance but low force/power/speed production, type IIb are low endurance but high force/power/speed production, and type IIa are characterized as an intermediate combination endurance and power. All muscles have some combination of these three fiber types.

In practice, low-intensity tasks such as taking notes require smaller motor units with fewer muscle fibers used. These smaller motor units are also known as *low-threshold motor units*. They consist of type I fibers that contract much slower and thus provide less force. For more intense tasks, motor units containing type II muscle fibers are used. These fast-twitch

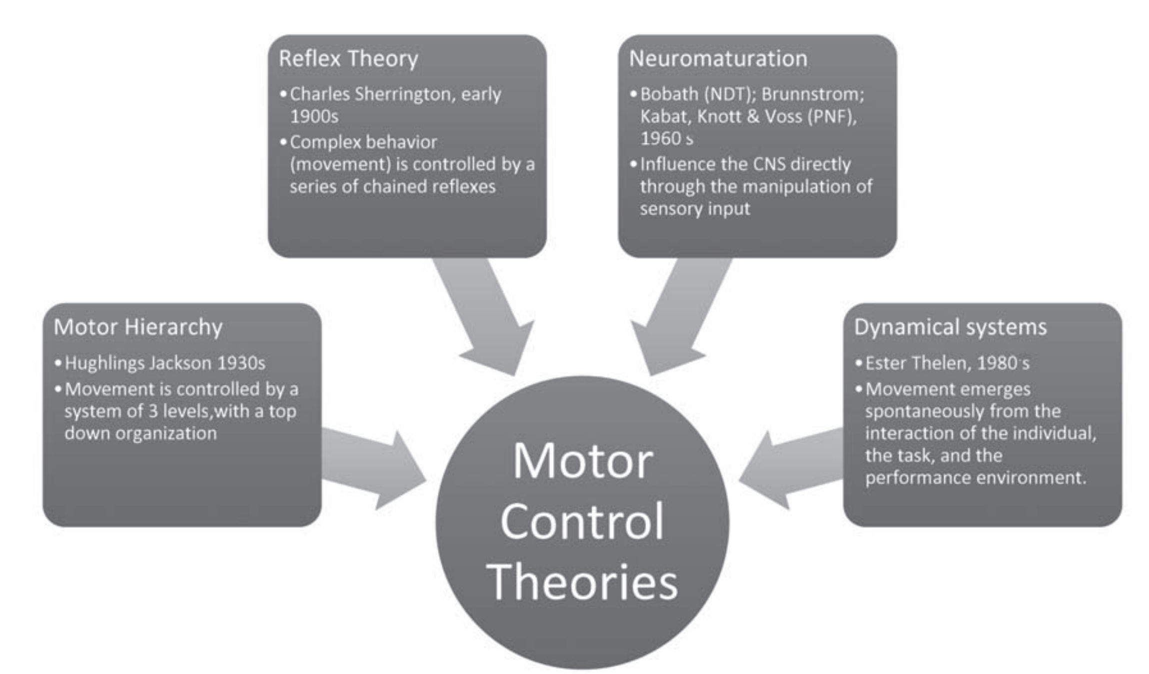

Figure 15-2. Comparison of hierarchical and dynamical systems approaches. NDT = neurodevelopmental treatment; PNF = proprioceptive neuromuscular facilitation.

motor units are known as *high-threshold motor units*. The major difference between low-threshold motor units (slow-twitch motor unit) and high-threshold motor units (fast-twitch motor unit) is that high-threshold motor units control more muscle fibers and contain larger muscle fibers in comparison to low-threshold motor units. During an activity of lifting heavy objects, such as carrying a 50-pound bag of soil, both low- and high-threshold motor units are recruited. The body will first recruit the type I motor units followed by recruitment of type IIa and IIb units as the task demands increase. The body might have recruited all of the available motor units to contract muscles to be used for carrying the heavy object over time (Bear, Connors, & Paradiso, 2015).

Sensory aspects of movement are conveyed by the muscle receptors (e.g., muscle spindles) that detect dynamic changes in muscle length and static muscle length to facilitate regulation of muscle length during movement. Spindle density is highest in muscles for fine motor function, eye, and neck. The muscle spindles and their afferent neurons coordinate the regulation of movement to provide an ongoing monitoring of static and dynamic movements. Gamma motor neurons regulate responses of the afferent neurons, which in turn register the length of the muscle spindles to ensure that the spindles are optimally ready to register any potential change in muscle length. This information is used at many different levels to contribute to our perception of movement as well as regulating the finite changes in movement (Lundy-Ekman, 2012). The information from the trunk and limb muscle afferents are used at the level of the spinal cord for spinal reflexes and automatic movements but also send information to the somatosensory cortex in the parietal lobe and cerebellum. This information provides perceptual awareness of where the body is in space and provides some tactile information (as they are joined with cutaneous receptors; Lundy-Ekman, 2012). Cross modal information is provided from the cutaneous (i.e., skin) receptors, and ascending fibers process fibers from both the muscle spindles and skin in the ascending dorsal-column medial lemniscal system and the fibers that ascend in the anterolateral (i.e., pain) system. The information reaches the somatosensory cortex, which is responsible for perceptual conscious awareness of sensation and spatial processing of movement (Shumway-Cook & Woollacott, 2017). Figure 15-3 demonstrates the interrelationship between all of these components.

Reflexes

The coordination of some motor components are hard-wired, consisting of fixed neuromuscular pathways referred to as *reflexes*. Reflexes are typically characterized as automatic and fixed motor responses and occur much more quickly than other responses (Bear et al., 2015). Reflexes play a fundamental role in stabilizing the motor system, providing almost immediate compensation for small perturbations and maintaining fixed execution patterns. Some reflex loops are routed solely through the spinal cord without receiving input from the brain, and thus do not require attention or conscious control. Others involve lower brain areas and can be influenced by prior instructions or intentions, but they remain independent of perceptual processing and neurological control. The simplest reflex is the monosynaptic reflex or short-loop reflex, such as the monosynaptic stretch response. There are five components in a reflex loop: a receptor (i.e., the muscle spindle embedded in the muscle), the afferent fiber (i.e., type Ia afferent neurons), a target (i.e., alpha motor neuron), an efferent fiber (i.e., type I fiber), and the neuromuscular junction. They are automatically activated by a stretch to the muscle spindle. In the spinal cord, the afferent fibers synapse directly onto alpha motor neurons that then regulate the contraction of the same muscle. As the

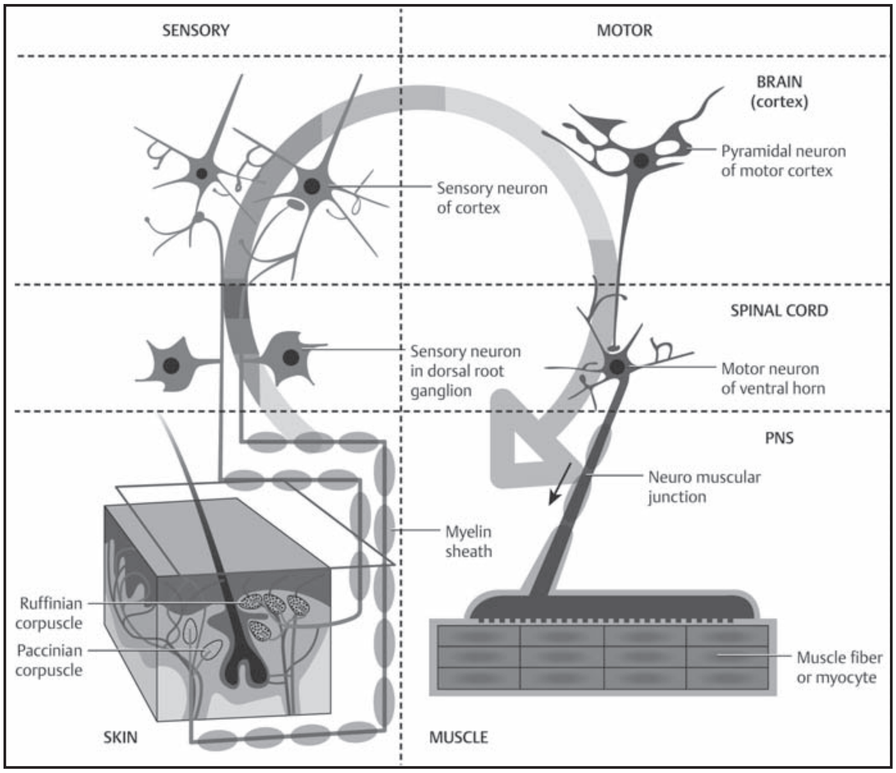

Figure 15-3. Nervous system organization.

name and description implies, a monosynaptic reflex depends on a single synaptic connection between an afferent sensory neuron and efferent motor neuron (Lundy-Ekman, 2012). In general, the actions of monosynaptic reflexes are fixed and cannot be controlled or influenced by intention or instruction. However, there is some evidence to suggest that the magnitude of these reflexes can be adjusted by context and experience. Polysynaptic reflexes or long-loop reflexes are reflex arcs that involve more than a single synaptic connection in the spinal cord and comprise the majority of reflex responses in the CNS. These loops may include cortical regions of the brain as well and are thus slower than their monosynaptic reflexes. Actions controlled by polysynaptic reflex loops are still faster than actions that require perceptual and somatosensory cortical processing. While the actions of short-loop reflexes are fixed, polysynaptic reflexes can be regulated by instruction or prior experience (Shumway-Cook & Woollacott, 2017). A common example of a long-loop reflex is the asymmetrical tonic neck reflex observed in infants (Lundy-Ekman, 2012).

Open- and Closed-Loop Systems of Motor Control

Interrelated to the neurophysiological theory discussion are the theories about how we control more sophisticated or coordinated movement and how the role of executive/central and environmental features differ in a dynamical control system. An open system is a feed-forward system that does not have any feedback loop (to some, this wording is slightly counterintuitive because the word *open* seems to imply that the system would be available for feedback) to control its output. In contrast, a closed system uses a feedback loop to control the operation of the system. In an open system, the output of the system is not fed back into the input to the system for control or operation; in a closed system, the output is fed back into the system to alter control.

Feed-forward (open-loop) control can be likened to learned anticipatory responses to known cues. For example, feed-forward control is exemplified by the normal anticipatory regulation of the heartbeat in advance of actual physical exertion. This differs from homeostatic control of autonomic states that uses a feedback (closed-loop) system that relies mainly on feedback in addition to the feed-forward elements of the system. Therefore, feedback regulation of the heartbeat provides further adaptive capabilities to the eventualities of physical exertion.

If a motor program contains all of the information needed to carry out the desired action, then the movement is presumed to operate under open-loop control. The features of open-loop control include the presence of the ballistic nature of the task (thus, feedback is too slow to be utilized to alter the movement) and the inclusion of all the necessary motor information for the motor program to carry out the desired movement. Feed-forward is triggered by the frontal cortex, which sends signals by way of the descending pathways to the lower extremities to activate for stability, holding, and support (Figure 15-4; Horak & Shupert, 1994).

If a person, while performing a motor task, is continually registering and evaluating the accuracy of the movement, then the movement is being controlled through closed-loop control. The two distinguishing features of closed-loop control are that this system uses feedback and that the motor program only contains the initial movement instructions. To continue the example of standing, after a standing position is achieved and held over time, the proximal muscles activate to sustain

Figure 15-4. Open-loop control of executed motor program. Features: Feedback is not available for use because of the ballistic nature of the task and the program for the motor movement is sent with all the necessary information to carry out the movement.

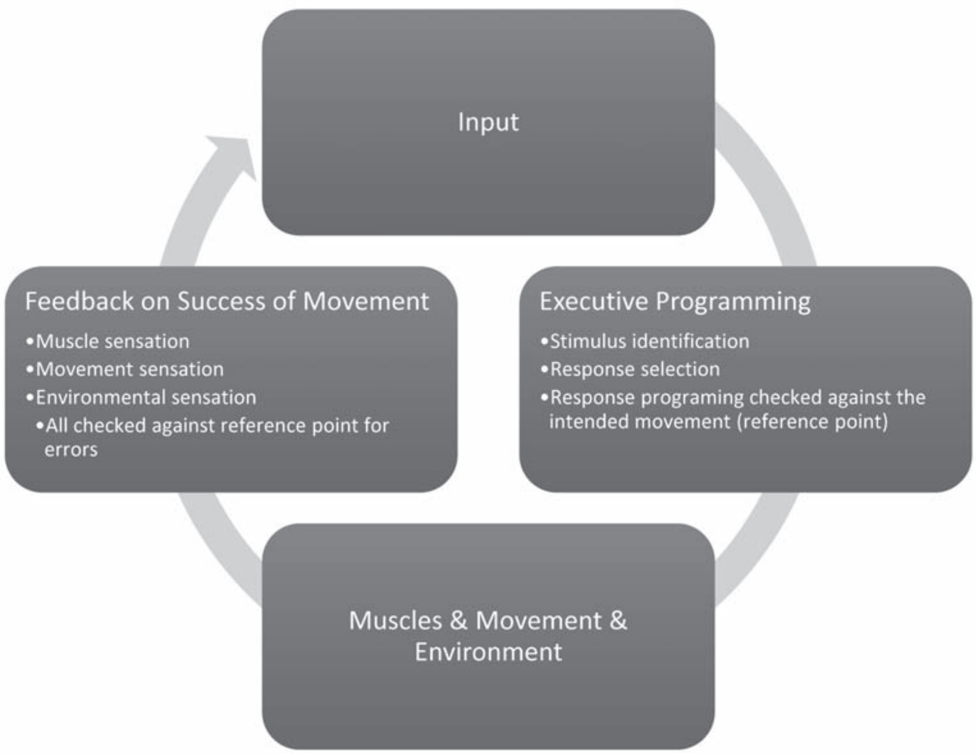

Figure 15-5. Closed motor loop of executed motor program. Features: Uses feedback to control movement and motor program only contains initial movement instructions.

this position. Proximal muscles activate as a result of feedback from the distal muscle groups. This phenomenon replaces the previously held neurodevelopmental construct that the body requires proximal control before it can develop control in the distal muscle groups (Figure 15-5; Horak & Shupert, 1994).

To illustrate this practically, feed-forward is that intangible abstract representation of sensation that gives us the awareness of what the movement pattern will feel like before we begin to move. For example, when one rides a bike, the sensation related to past experiences of riding a bike serve as a template for the movement. Feedback, on the other hand, is a compilation of the sensations collected as a result of completing movement and includes information on whether the movement was successful (e.g., riding the bike without falling) or unsuccessful (e.g., falling off the bike). After movement has occurred, adjustments or changes are performed based on the feedback. Active movements that are client generated and task oriented deepen the capacity for one to register the movement pattern in multiple areas of the CNS. Feedback may be stored in memory and called on for future use (Shumway-Cook & Woollacott, 2017).

Degrees of Freedom Redundancy

Degrees of freedom refer to the number of independent elements or components of the motor system and the number of ways each component can vary (sometimes called *redundancy*). From the initiation to the completion of the movement requires a resolution of degrees of freedom, or rather, the ability to control the body to produce the desired movement within any given situation (Bernstein, 1967). Since a large number of muscles (792 in the human body) are available to interact

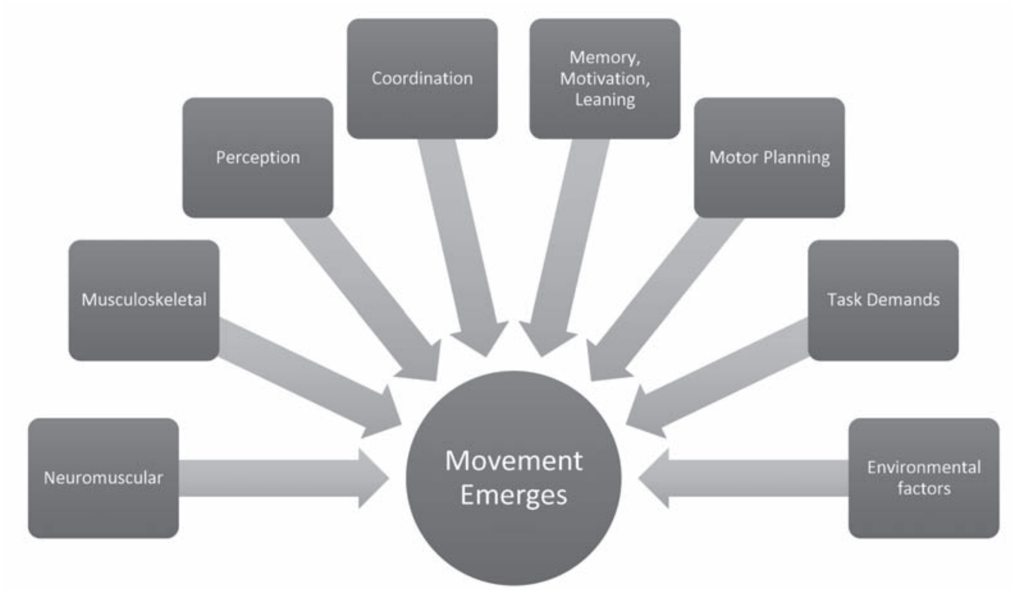

Figure 15-6. Degrees of freedom and redundancy. A challenge to achieve desired movement is to constrain all of the possible variables, including the personal characteristics of an individual, the task demands, and the environmental context. Therefore, we consider that the movement emerges as greater than the sum of all of the factors because, for any individual, these factors will be different.

with joints (100 available joints), and each of those joints have characteristics that define their range of movement, there are potentially hundreds of ways to resolve a simple motor task (Magill & Anderson, 2013). Motor control theories must take these numerous degrees of freedom or redundancy into account when explaining how the CNS combined with the task and environment resolve these motor challenges. The challenge is that, as the motor task becomes more complex, many aspects of the movement must be constrained to yield a specific motor result.

Redundancy refers to all of the ways that the body can possibly move given the degrees of freedom. While there is sufficient redundancy to accomplish motor tasks, there is a constant challenge of the sheer volume of options available. Therefore, the benefits and obstacles are used to explain the constraints that help to choose the most efficient movement pattern. Constraints are useful because they allow use of typical or frequent patterns that reduce the number of options (i.e., a benefit) possible for a given movement, but they can also interfere by constraining the potential options (i.e., obstacle) for movement. A beneficial constraint allows you to react more quickly, ideally using an effective and efficient movement pattern. An obstacle constraint limits you from selecting new options for moving or creating new movement patterns that are more efficient. Constraints are also introduced by mechanical principles (e.g., arthritis may reduce the ability of a joint to move) related to an individual's body composition (e.g., leg length). Figure 15-6 illustrates the number of factors that require attention by the motor system to generate movement and includes both skeletal and neurophysiology properties, properties demanded by the task, and demands made by the environment. Therefore, we consider that the movement emerges as greater than the sum of all of the factors because, for any individual, these factors will be different.

Constraints

Dynamical systems are composed of many interacting parts or degrees of freedom and are constantly pressured by constraints to alter a state of motor control or organization between component parts to achieve efficiency. Constraints are factors that shape or guide the organization of multicomponent motor control systems. Newell (1986) has provided the best account of how constraints influence coordination and control in human movement systems. His model categorizes constraints as *organismic* (exemplified in the current debate by the genetic profile and amount of task-specific practice of each individual athlete), *task* (related to the specific characteristics of each sport or physical activity; e.g., rules, boundaries, equipment), and *environmental* (exemplified by social and cultural influences on behavior; Newell, 1986). The numerous individual constraints are displayed in Figure 15-7, and the many paths practitioners may have to elicit change following CNS damage are highlighted. The simple implication of this approach is that the acquisition of expertise emerges under the interaction of the individual, task, and environmental constraints. Occupational therapists will recognize this description as we have long recognized the value of considering the triad of the individual, their environment, and the task that is required for individuals to participate in meaningful occupations. This dynamic system approach gives validity to therapists wishing to use cognitive, emotional, sensory, and motor strategies to facilitate motor efficiencies to engage their client in a desired occupation. A therapist using this approach recognizes that the whole brain and whole body are involved in participation and that no one system trumps another; therefore, choosing a meaningful task in which to engage is not simply commonsense, but well-established in the neuroscience of movement.

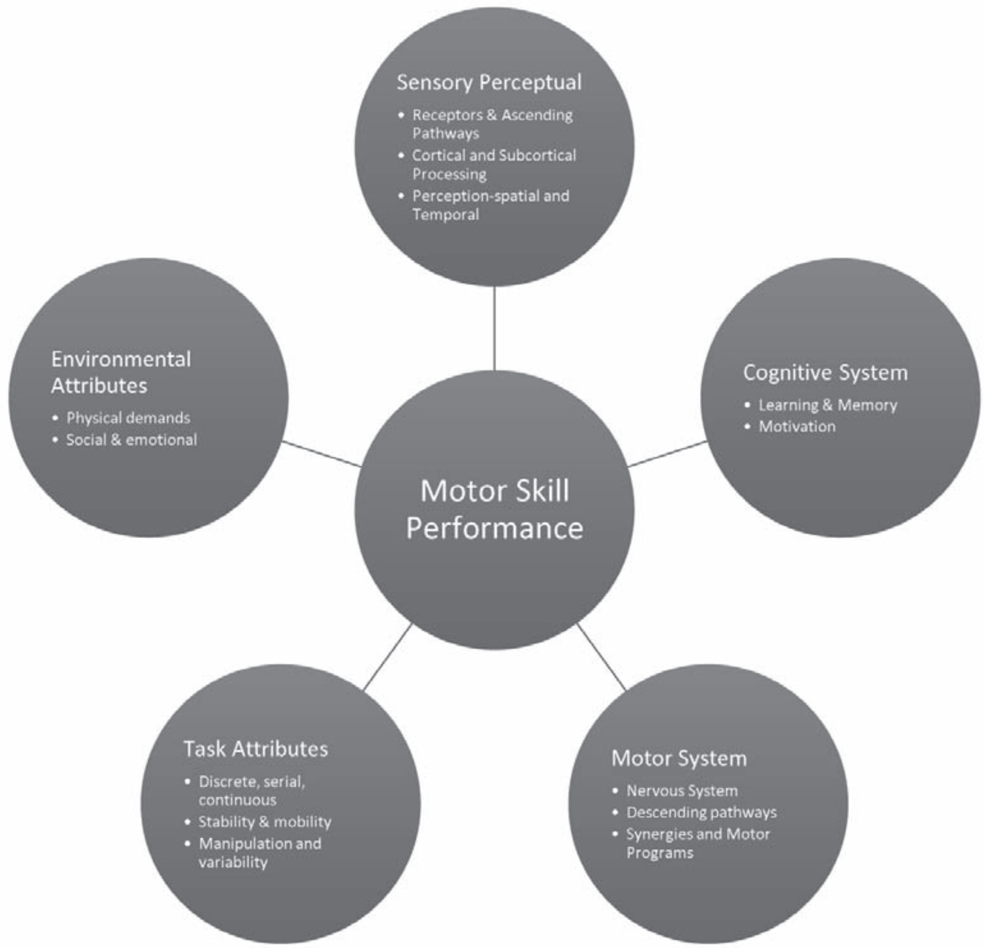

Figure 15-7. Intrinsic individual characteristics that influence movement.

Memory Constraints

Learning and memory are parts of the same process; learning is the acquisition of knowledge or an ability, whereas memory is the retention of that knowledge (i.e., explicit memory) or retention of the ability (i.e., procedural memory; Kandel et al., 2012). During any movement, the sensory system registers the influence of the experience and provides internal feedback from the motor output to the sensory system to establish a memory link of the movement. Implicit and explicit memory systems work together in learning motor tasks. Under normal circumstances, novel motor skills will require much more conscious effort (explicit memory). When the motor task is well-learned, it will become more automatic and unconscious (Shumway-Cook & Woollacott, 2017). The acquisition of information and abilities and the retention/memory of those skills underlie what we have come to know as neural plasticity. Understanding the learning and memory process helps us to understand motor control as it reflects neural plasticity and the ability to recover motor function when lost due to trauma or injury. The use of implicit or explicit learning and, thus, memory is a focus following CNS damage on the use of motor learning strategies to regain motor control (Lundy-Ekman, 2012).

Muscle Tone

"Muscle tone is characterized by a muscle's resistance to passive stretch" (Shumway-Cook & Woollacott, 2017, p. 110). Muscle tone abnormalities interfere with motor efficiency. Muscle tone ranges from hypertonicity or rigidity (high muscle tone) to hypotonicity (low muscle tone). Typically, muscle tone is considered on a continuum where hypertonicity is on one end of the continuum and hypotonicity is considered on the other. Early motor control approaches (e.g., neurodevelopmental) focused on decreasing the abnormal muscle tone to facilitate typical movement (Davis, 1996). It is believed that abnormal tone, particularly hypertonicity, within a muscle will reduce efficiency of motor control. Research has shown that other problems, such as paresis, abnormal reciprocal inhibition, as well as poor coordination of synergistic muscles, may have a greater impact on impaired performance than simply the abnormal tone (Shumway-Cook & Woollacott, 2017). Current motor control theories propose that practitioners focus intervention efforts on helping clients participate in activities despite any abnormal tone that may exist (Cole, 2015; Hsieh-ching et al., 2014; Takeuchi et al., 2012; Tsoi, Zhang, Wang, Tsang, & Lo, 2012).

Coordination (Synergies and Programs)

Coordination refers to the activation of specific muscles together (Shumway-Cook & Woollacott, 2017), as addressed previously in synergies and programs. The ability to selectively use a muscle or activate a group of muscles allows for specificity of movement or isolation of a particular movement. This is essential for creating synergies and motor programs that are efficient and effective at completing a motor task. When there is a loss of individualization of a set of muscles, the initiation of movement results in activation of a whole synergy of movement. These are referred to as *abnormal synergies* (Latash, 2016). These synergies are stereotypical patterns that cannot be adapted for the motor demand of a specific task. Research has shown that abnormal synergies result from increased recruitment of descending brainstem pathways in response to cortical damage. Many neurological impairments (e.g., stroke, traumatic brain injury, and cerebral palsy) result in abnormal synergies of the motor system, particularly resistant to improvement in the upper extremity. Retraining for skills in these areas may include identification of motivational tasks that allow for a variety of motor learning practice (e.g., massed, random practice) opportunities, sensory reeducation, bilateral hand training, mirror box training, and mental imagery and use of enhanced sensory properties (e.g., heavy or textural objects) when seeing to improve function (Hsieh-ching et al., 2014; Park, Chang, Kim, & Kim, 2015; Schack, Essig, Frank, & Koester, 2014; Wang et al., 2013; Wu, Trombley, Lin, & Tickle-Degnen, 1998, 2000).

Cognitive Constraints

Constraints related to cognition include attention, emotions, and motivation and may include factors such as fear of movement (e.g., postural insecurity, a fear of falling) and the ability to attend to appropriate cues in the environment during the performance of functional activities (Gillberg, 2003). These constraints are often affected following neurotrauma and present considerable challenges in promoting motor learning. Motor learning suggests that use of functional tasks that are perceived by the client as important can have a positive effect on motivation. Additionally, using feedback strategies effectively can also help to ameliorate attentional issues (i.e., inability to sustain attention to the task), and provide emotional support to more effectively reduce negative emotions (e.g., fear of pain; Muratori, Lamberg, Quinn, & Duff, 2014; Wulf & Lewthwaite, 2016). Additionally, focusing on the task qualities may also facilitate improved attention and motivation. For example, use of a familiar activity of daily living, like brushing teeth, reduces the amount of attention required, is typically motivating, and may carry fewer negative emotions (Preissner, 2010).

Synergies and Motor Programs

A motor synergy is a neural organization of a multielement system that organizes sharing of a task among a set of variables (e.g., musculoskeletal strength, endurance, coordination, grasping) and ensures variation among the variables in order to stabilize performance. The components of a synergy need not be physically connected, but instead are connected by their response to the particular motor task being executed. Synergies are learned, rather than being hardwired like reflexes, and are organized in a task-dependent manner; a synergy is structured for a specific action and not determined generally for the components themselves. Synergies are thought to have two components: sharing and covariation. They represent a bottom-up organization of the CNS and can be programmed as part of a motor program. Sharing requires that the execution of a distinct motor task will depend on the combined actions of all the components that make up the synergy. Often, there are more components involved than are strictly needed for the particular task (e.g., redundancy, limiting the number of required degrees of freedom), but the control of that motor task is distributed across all components. The classic example comes from a two-finger force production task, where participants are required to generate a fixed amount of force by pushing down on two force plates with two different fingers. In this task, participants generated a precise force output by combining the contributions of independent fingers. While the force produced by any single finger can vary, this variation is constrained by the action of the other such that the desired force is always generated.

Covariation, on the other hand, provides both flexibility and stability to motor tasks. The components of a motor synergy are expected to change their action to compensate for the errors and variability in other components that could affect the outcome of the motor task. This provides flexibility because it allows for multiple motor solutions to particular tasks, and it provides motor stability by preventing errors in individual motor components from affecting the task itself. Synergies simplify the computational difficulty of motor control (Cole, 2015; Hsieh-ching et al., 2014; Takeuchi et al., 2012). Coordinating the numerous degrees of freedom in the body is a challenging problem, both because of the tremendous complexity of the motor system and due to the different levels at which this organization can occur (neural, muscular, kinematic, spatial, etc.). Because the components of a synergy are coupled to improve functionality of a specific task, execution of motor tasks can be accomplished by activating the relevant synergy with a single neural signal. The need to control all of the relevant components independently is removed because organization emerges automatically as a consequence of the systematic covariation of components. Similar to how reflexes are physically connected and thus do not require control of individual components by the CNS, actions can be executed through synergies with minimal executive control because they are functionally connected.

While synergies represent coordination derived from peripheral interactions of motor components, motor programs are specific, prestructured motor activation patterns that are generated and executed by the CNS. They represent a top-down approach to motor coordination rather than the bottom-up approach offered by synergies. Motor programs are executed in a closed-loop manner, although sensory information is most likely used to regulate the current state of the organism and determine the appropriate goals. An important issue for coordinating the motor system is controlling the multiple degrees of freedom available to the motor system.

Multiple motor program solutions to a movement are possible because there are more motor components involved in the production of actions than are generally required by the physical constraints on that action. For example, the human arm has seven joints that determine the position of the hand in the world, but only three spatial dimensions are needed to specify any location in which the hand is placed. The excess of kinematic degrees of freedom means that there are multiple arm configurations that correspond to any particular location of the hand. Bernstein's (1967) research was primarily concerned with understanding how coordination was developed for skilled actions. Bernstein (1967) observed that the redundancy of the motor system made it possible to execute actions and movements in a multitude of different ways while achieving equivalent outcomes. This equivalency in motor action means that there is no one-to-one correspondence between the desired movements and the coordination of the motor system needed to execute those movements. Any desired movement or action has multiple sets of coordination components of neurons, muscles, and kinematics (Almhdawi, Bass, & Mathiowetz, 2014; Muratori et al., 2014).

Application to Practice

Research on motor control provides occupational therapy practitioners with support to conduct occupation-based intervention in the natural context that is meaningful to the client. Motivation, memory, and coordination are believed to heavily influence the recovery of motor control. The current model of motor control emphasizes the dynamical interaction among biomechanical, reflex, cognitive, sensory, and neurophysiological systems. Research supports the concept that inclusion of occupation-based and task-oriented interventions are likely to be most effective and efficient in improving motor recovery after damage (Gauthier et al., 2014; Morris & Taub, 2014; Taub, Uswatte, & Mark, 2014). Theories that help us understand that motor control develops from the interaction of a variety of systems (e.g., neuromuscular, skeletal, sensory, emotional, cognitive, environmental) and the task itself suggests that practitioners should design interventions that are dynamic and responsive to changes within one or many systems. Doing this requires continued evaluation and analysis of the many factors influencing movement. Furthermore, because dynamical systems theory proposes that movement is dependent on a variety of factors that constantly change and interact with each other, it is important to evaluate a variety of systems (e.g., neuromuscular, skeletal, cognitive, sensory, environmental) to fully understand movement, acknowledging that one change in one system can affect the others provides ways to explain performance following an injury (Hsieh-ching et al., 2014; Wang et al., 2013; Wu et al., 1998, 2000).

Summary

This chapter reviewed salient issues related to the performance of human movement and provided a discussion of how motor control and biomechanics are intertwined. In order to enable students of kinesiology to envision how biomechanics and kinesiology are applied to rehabilitation, this chapter provided more detail on the neuroscience of movement, motor control, and their application to rehabilitation. The components of movement were explored, including brain function, neurons, motor units, muscle tone, closed- and open-loop systems, and the constraints that exist on development of motor control.

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