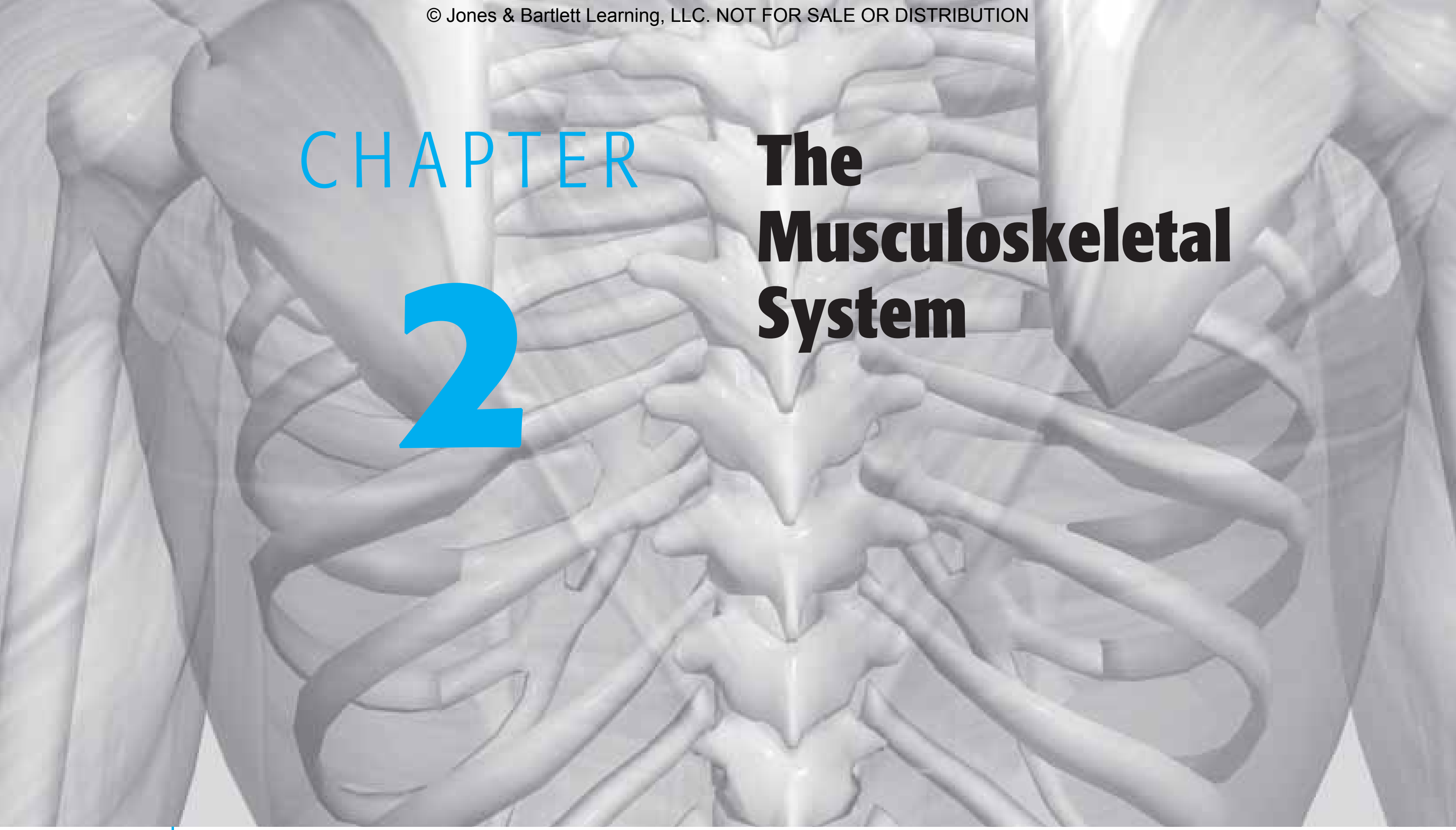

CHAPTER 2 The Musculoskeletal System

Chapter Objectives

At the completion of this chapter, the reader will be able to:

1. Describe the various structures of the musculoskeletal system.
2. Describe the types of connective tissue related to orthopaedics.
3. Outline the function of the various components of connective tissue, including collagen and elastin.
4. Describe the structural differences and similarities among fascia, tendons, and ligaments.
5. Describe the structure and function of a bone as it relates to physical therapy.
6. Outline the different types of cartilage tissue.
7. Describe the main constituents of a synovial joint.
8. Describe the main cellular components of skeletal muscle.
9. Outline the sequence of events involved in a muscle contraction.
10. Describe the major components of a musculoskeletal assessment.

Overview

A working knowledge of the musculoskeletal system forms the foundation of every orthopaedic assessment and intervention by a PTA. A basic tenet in the study of anatomy and biomechanics is that design relates to function, in that the function of a structure can often be determined by its design and vice versa. On the basis of design and function, the tissues of the body are classified into four basic kinds: epithelial, nervous, connective, and muscle tissue:[1]

- *Epithelial tissue* is found throughout the body in two forms: membranous and glandular. Membranous epithelium forms such structures as the outer layer of the skin, the inner lining of the body cavities and lumina, and the covering of visceral organs. Glandular epithelium is a specialized tissue that forms the secretory portion of glands.

- *Nervous tissue* (described in Chapter 3) helps coordinate movements via a complex motor control system of prestructured motor programs and a distributed network of reflex pathways mediated through the autonomic, peripheral, and central nervous systems.[2]
- *Connective tissue* is found throughout the body. It is divided into subtypes according to the matrix that binds the cells. Connective tissue provides structural and metabolic support to other tissues and organs of the body. It includes bone, cartilage, tendons, ligaments, fascia, and blood tissue. The properties of connective tissue are described in the next section of this chapter.
- *Muscle tissue* is responsible for the movement of circulatory materials through the body, the movement of one part of the body with respect to another, and locomotion. There are three types of muscle tissue: smooth, cardiac, and skeletal tissue. In this chapter, human skeletal muscle tissue is described.

Key Point Together, connective tissue and skeletal muscle tissue form the musculoskeletal system. The musculoskeletal system functions intimately with nervous tissue to produce coordinated movement and to provide adequate joint stabilization and feedback during sustained positions and purposeful movements, such as when climbing and dancing.

Connective Tissue

The anatomic and functional characteristics of the four types of connective tissue that predominate in the joints of the musculoskeletal system are summarized in **Table 2-1**.

The primary types of connective tissue cells are fibroblasts, which are the principal cells of connective tissue; macrophages, which function as phagocytes to clean up debris; and mast cells, which release chemicals associated with inflammation (see Chapter 5).[3] The connective tissue types are differentiated according to the extracellular matrix (ECM) that binds the cells.

Fibroblasts (Figure 2-1) produce collagen, elastin, and reticulin fibers. All connective tissues are made up of varying levels of collagen, elastin, and reticulin:

- Collagen fibers, the most common fibers in connective tissue proper, are long, straight, and unbranched. The collagens are a family of ECM proteins that play a dominant role in maintaining the structural integrity of various tissues and in providing tensile strength to tissues. The most common forms of collagen (types I–IV) are outlined in **Table 2-2**.[4]

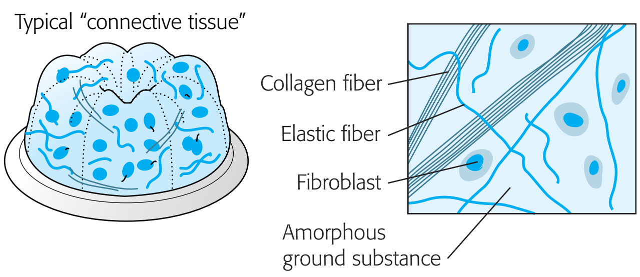

Figure 2-1 Typical connective tissue.

Key Point Collagen can be visualized as being like the little strands that run through packing tape.

- Elastic fibers contain the protein elastin and are branched and wavy. Elastin is synthesized and secreted from several cell types, including chondroblasts, myofibroblasts, and mesothelial and smooth muscle cells. As its name suggests, elastin provides elastic properties to the tissues in which it is situated.[5] Elastin fibers can stretch, but they normally return to their original shape when the tension is released. The presence of elastin determines the patterns of distention and recoil in most organs, including the skin and lungs, blood vessels, and connective tissue. These characteristics can be useful in preventing injury because they allow the tissues to deform a great deal before breaking.
- Reticular fibers are the least common of the three and are thinner than collagen fibers, forming a branching, interwoven network in various organs providing structural support.

Key Point Collagen and elastin fibers are embedded within a water-saturated matrix known as *ground substance*, which is composed primarily of glycosaminoglycans, water, and solutes. These materials allow many fibers of the body to exist in a fluid-filled environment that disperses millions of repetitive forces affecting the joints throughout a lifetime.[5]

Fascia

Fascia is an example of loose connective tissue. From the functional point of view, the body fascia may be regarded as a continuous laminated sheet of connective tissue that extends without interruption from the top of the head to the tips of the toes. It surrounds and permeates every other tissue and organ of the

TABLE 2-1 Types of Connective Tissue that Form the Structure of Joints

Joint Type	Anatomic Location	Fibers	Mechanical Specialization
Dense irregular connective tissue (CT)	Composes the external fibrous layer of the joint capsule Forms ligaments, fascia, tendons, and fibrous membranes	High type I collagen fiber content; low elastin fiber content	*Ligament:* Binds bones together and restrains unwanted movement at the joints; resists tension in several directions *Tendon:* Attaches muscle to bone *Fascia:* A layer of fibrous tissue that permeates the human body and that performs a number of functions, including enveloping and isolating the muscles of the body, providing structural support and protection
Articular cartilage	Covers the ends of articulating bones in synovial joints	High type II collagen fiber content; fibers help anchor cartilage to subchondral bone and restrain the ground substance	Resists and distributes compressive forces (joint loading) and shear forces (surface sliding); very low coefficient of friction—the ratio of the force of friction between two bodies and the force pressing them together The coefficient of friction depends on the materials used; for example, ice on steel has a low coefficient of friction, whereas rubber on pavement has a high coefficient of friction
Fibrocartilage	Composes the intervertebral discs and the disc within the pubic symphysis Forms the intraarticular discs (menisci) of the tibiofemoral, sternoclavicular, acromioclavicular, and distal radioulnar joints Forms the labrum of the glenoid fossa and the acetabulum	Multidirectional bundles of type I collagen	Provides some support and stabilization to joints; primary function is to provide "shock absorption" by resisting and distributing compressive and shear forces
Bone	Forms the internal levers of the musculoskeletal system	Specialized arrangement of type I collagen to form lamellae and osteons and to provide a framework for hard mineral salts (e.g., calcium crystals)	Resists deformation; strongest resistance is applied against compressive forces due to body weight and muscle force Provides a rigid lever to transmit muscle force to move and stabilize the body

body, including nerves, vessels, tendons, aponeuroses, ligaments, capsules, and the intrinsic components of muscle.[6,7] Theoretically, injury, inflammation, disease, surgery, and excess strain can cause the fascia to scar and harden. This can cause tension not only in adjacent, pain-sensitive structures but also in other areas of the body. This is because of the complete integration of fascia with all the other systems. Myofascial release (see Chapter 6) is a form of soft tissue therapy used to treat dysfunction and accompanying pain and restriction of motion by relaxing contracted muscles, increasing circulation, increasing venous and lymphatic drainage, and stimulating the stretch reflex of muscles and overlying fascia

Tendons

Tendons (Figure 2-2), a type of dense connective tissue, are cordlike structures that attach muscle to bone.[8] Tendons are made up of densely packed parallel-oriented bundles of fibers.[9] The thickness of each tendon varies and is proportional to the size of the muscle from which it originates. Tendons deform

TABLE 2-2 Major Types of Collagen

Type	Description/Location
I	Thick and rough Designed to resist elongation Found in bone, skin, ligament, and tendon
II	Thinner and less stiff than type I fibers Provide a framework for maintaining the general shape and consistency of structures such as hyaline cartilage and nucleus pulposus
III	A small and slender fiber of collagen Found in extensible connective tissues such as skin, lung, and the vascular system
IV	Overall arrangement causes the collagen to form in a sheet Found primarily in the basement membrane (a thin sheet of fibers that underlies the epithelium, which lines the cavities and surfaces of organs, or the endothelium, which lines the interior surface of blood vessels)

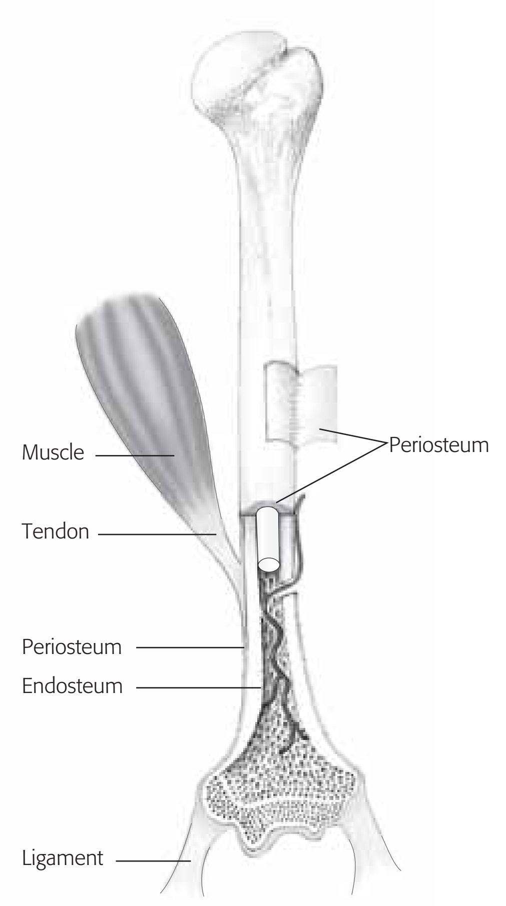

Figure 2-2 Tendon, ligament, bone, and muscle.

less than ligaments under an applied load and are able to transmit the load from muscle to bone.[10] However, tendons transmit forces from muscle to bone and are subject to great tensile stresses.

Key Point Although tendons withstand strong tensile forces well, they resist shear forces less well and provide little resistance to compression force (see Chapter 4).

As the tendon joins the muscle, it fans out into a much wider and thinner structure. The site where the muscle and tendon meet is called the *myotendinous junction (MTJ)*. Despite its viscoelastic mechanical characteristics, the MTJ is very vulnerable to tensile failure.[11,12] Indeed, the MTJ is the location of most common muscle strains caused by tensile forces in a normal muscle–tendon unit.[10,13]

Key Point A tendency for a tear near the MTJ has been reported in the biceps and triceps brachii, rotator cuff muscles, flexor pollicis longus, fibularis (peroneus) longus, medial head of the gastrocnemius, rectus femoris, adductor longus, iliopsoas, pectoralis major, semimembranosus, and the entire hamstring group.[14–16]

Ligaments

Skeletal ligaments, a type of dense connective tissue, connect bones across joints (refer to Figure 2-2). The gross structure of the ligaments varies with their location (intra-articular or extra-articular, capsular) and function.[9] The orientation of the collagen fibers has a less unidirectional organization in ligaments than it does in tendons, but this irregular crossing pattern still provides stiffness (resistance to deformation) and makes ligaments ideal for sustaining tensile loads from several different directions.[17,18]

Key Point Ligaments have a rich sensory innervation through specialized mechanoreceptors and free nerve endings that provide information about proprioception and pain, respectively.

Ligaments contribute to the stability of joint function by preventing excessive motion,[19] acting as guides to direct motion, and providing proprioceptive information for joint function (**Table 2-3** and **Table 2-4**).[20,21]

Key Point Immobilization and disuse dramatically compromise the structural material properties of ligaments (see Chapter 5), resulting in a significant decrease in the ability of the ligament to resist strain.[9]

Bone

Bone is a highly vascular and metabolically active form of connective tissue, composed of collagen, calcium phosphate, water, amorphous proteins, and cells. There are approximately 206 bones in the body.

There are three types of bone cells:

- *Osteocytes:* Control extracellular concentrations of calcium and phosphorus. Actively involved with the maintenance of the bony matrix.
- *Osteoclasts:* Responsible for bone resorption. An increased number of osteoclasts is characteristic of diseases with increased bone turnover.
- *Osteoblasts:* Responsible for bone formation.

TABLE 2-3 Major Ligaments of the Upper Quadrant

Joint	Ligament	Function
Shoulder complex	Coracoclavicular	Fixes the clavicle to the coracoid process
	Costoclavicular	Fixes the clavicle to the costal cartilage of the first rib
	Coracohumeral	Reinforces the upper portion of the joint capsule
	Glenohumeral	Reinforces the anterior and inferior aspect of the joint capsule
	Coracoacromial	Protects the superior aspect of the joint
Elbow and forearm	Annular	Maintains the relationship between the head of the radius and the humerus and ulna
	Ulnar (medial) collateral	Provides stability against valgus (medial) stress, particularly in the range of 20–130° of flexion and extension
	Radial (lateral) collateral	Provides stability against varus (lateral) stress and functions to maintain the ulnohumeral and radiohumeral joints in a reduced position when the elbow is loaded in supination
	Interosseous membrane of the forearm	Divides the forearm into anterior and posterior compartments, serves as a site of attachment for muscles of the forearm, and transfers forces from the radius to the ulna to the humerus
Wrist	Extrinsic palmar	Provides the majority of the wrist stability
	Intrinsic	Serves as rotational restraints, binding the proximal carpal row into a unit of rotational stability
	Interosseous	Binds the carpal bones together
	Triangular fibrocartilage complex (TFCC)	Suspends the distal radius and ulnar carpus from the distal ulna
		Provides a continuous gliding surface across the entire distal face of the radius and ulna for flexion-extension and translational movements
		Provides a flexible mechanism for stable rotational movements of the radiocarpal unit around the ulnar axis
		Cushions the forces transmitted through the ulnocarpal axis
Fingers	Volar and collateral interphalangeal	Prevents displacement of the interphalangeal joints

TABLE 2-4 Major Ligaments of the Spine and Lower Quadrant

Joint	Ligament	Function
Spine	Anterior longitudinal ligament	Functions as a minor assistant in limiting anterior translation and vertical separation of the vertebral body
	Posterior longitudinal ligament	Limits hyperextension of the spine
		Resists vertebral distraction of the vertebral body
		Resists posterior shearing of the vertebral body
		Acts to limit flexion over a number of segments
		Provides some protection against intervertebral disk protrusions
	Ligamentum flavum	Resists separation of the lamina during flexion
	Interspinous	Resists shear forces and separation of the spinous processes during flexion; prevents excessive rotation
	Intratransverse	Resists side bending of the spine and helps in preventing rotation
	Iliolumbar (lower lumbar)	Resists flexion, extension, axial rotation, and side bending of L5 on S1
	Nuchal (represents the supraspinal ligaments of the lower vertebrae)	Resists cervical flexion
Sacroiliac	Sacrospinous	Resists forward tilting of the sacrum on the hip bone during weight bearing of the vertebral column
	Sacrotuberous	Resists forward tilting (nutation) of the sacrum on the hip bone during weight bearing of the vertebral column
	Interosseous	Resists anterior and inferior movement of the sacrum
	Posterior (dorsal) sacroiliac	Resists backward tilting (counternutation) of the sacrum on the hip bone during weight bearing of the vertebral column
	Anterior (ventral) sacroiliac	Consists of numerous thin bands; a capsular ligament
Hip	Ligamentum teres	Transports nutrient vessels to the femoral head
	Iliofemoral (Y ligament)	Strongest of the hip ligaments; limits hip extension
	Ischiofemoral	Limits anterior displacement of the femoral head and internal rotation of the hip
	Pubofemoral	Limits hip extension and abduction of the hip
Knee	Medial collateral	Stabilizes medial aspect of tibiofemoral joint against valgus stress
	Lateral collateral	Stabilizes lateral aspect of tibiofemoral joint against varus stress
	Anterior cruciate	Resists anterior translation of the tibia and posterior translation of the femur
	Posterior cruciate	Resists posterior translation of the tibia and anterior translation of the femur
Ankle	Medial collaterals (deltoid)	Include the tibionavicular, calcaneotibial, anterior talotibial, and posterior talotibial ligaments; provide stability between the medial malleolus, navicular, talus, and calcaneus against eversion
	Lateral collaterals	Include the anterior talofibular, calcaneofibular, talocalcaneal, posterior talocalcaneal, and posterior talofibular ligaments; static stabilizers of the lateral ankle, especially against inversion
Foot	Long plantar	Provides indirect plantar support to the calcaneocuboid joint, by limiting the amount of flattening of the lateral longitudinal arch of the foot
	Bifurcate	Supports the medial and lateral aspects of the foot when weight bearing in a plantarflexed position
	Calcaneocuboid	Provides plantar support to the calcaneocuboid joint and possibly helps to limit flattening of the lateral longitudinal arch

Key Point The *periosteum* is a thin tough membrane that covers each long bone and helps secure the attachments of muscles and ligaments to bone. The *medullary canal* is the central hollow tube within the diaphysis of a long bone. It is important for storing bone marrow and provides a passageway for nutrient-carrying arteries (see "Blood Supply to Bone" later in this chapter).

Bone is the most rigid of the connective tissues. Despite its rigidity, bone is a dynamic tissue that undergoes constant metabolism and remodeling. The collagen of bone is produced in the same manner as that of ligaments and tendons, but by a different cell, the osteoblast.[22]

At the gross anatomical level, each bone has a distinct morphology (**Table 2-5**) comprising both cortical bone and cancellous bone.

- Cortical (compact) bone is relatively dense and found in the outer shell of the diaphysis of long bones. The osteon, or Haversian system, is the fundamental functional unit of much compact bone.
- Cancellous (trabecular) bone is porous and is typically found within the epiphyseal and metaphyseal regions of long bones as well as throughout the interior of short bones.[11]

Key Point The strength of a bone is related directly to its density. Compared to cortical bone, cancellous bone has a greater surface area but is less dense, softer, weaker, and less stiff, and therefore more prone to fracture.

The function of a bone is to provide support, enhance leverage, protect vital structures, provide attachments for both tendons and ligaments, and store minerals, particularly calcium.

Key Point Based on location, bones can be classified as follows (Figure 2-3):

- *Axial skeleton:* Bones of the skull, vertebral column, sternum, and ribs
- *Appendicular skeleton:* Bones of the pectoral girdle (including the scapula and clavicle), pelvic girdle, and limbs

Blood Supply to Bone

Bone has a rich vascular supply, receiving 10–20 percent of the cardiac output. The blood supply varies with different types of bones, but blood vessels are especially rich in areas that contain red bone marrow. The long bones are supplied by the following:

- *Diaphyseal nutrient artery:* The most important supply of arterial blood to a long bone

TABLE 2-5 General Structure of Bone

Site	Description
Epiphysis	The region between the growth plate or growth plate scar and the expanded end of bone, covered by articular cartilage The location of secondary ossification centers during development Forms bone ends
Physis (also known as epiphyseal plate)	The region that separates the epiphysis from the metaphysis The zone of endochondral ossification in an actively growing bone or the epiphyseal scar in a fully grown bone Vulnerable prior to growth spurt and mechanically weak
Metaphysis	The junctional region between the growth plate and the diaphysis Contains abundant cancellous (trabecular) bone, which heals rapidly, but the cortical bone thins here relative to the diaphysis Common site for many primary bone tumors and similar lesions (osteomyelitis)
Diaphysis	Forms shaft of bone Large surface for muscle origin Composed mainly of cortical (compact) bone The medullary canal contains marrow and a small amount of trabecular bone

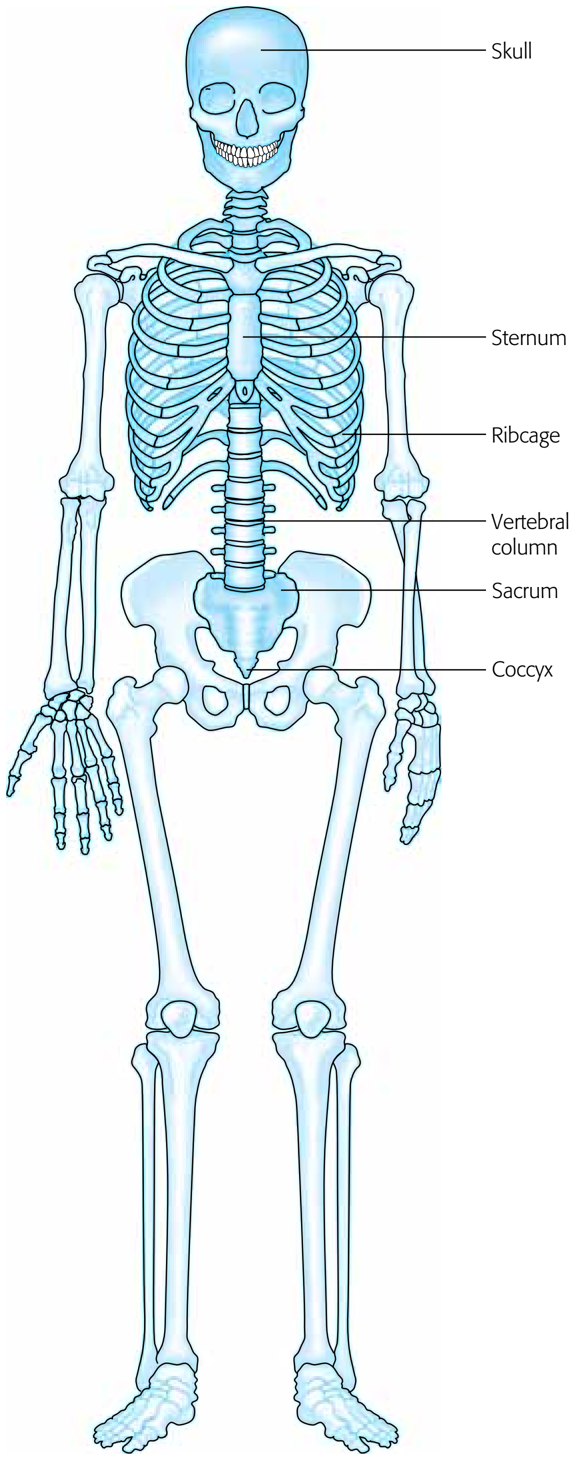

Figure 2-3 The axial (shaded) and appendicular skeleton.

- *Metaphyseal and epiphyseal arteries:* Supply the ends of bones
- *Periosteal arterioles:* Supply the outer layers of cortical bone

The large irregular, short, and flat bones receive a superficial blood supply from the periosteum, as well as frequently from large nutrient arteries that penetrate directly into the medullary bone.

Key Point Bone remodeling is a lifelong process that involves the replacement of old bone by new bone based on the functional demands of the mechanical loading according to Wolff's law (see Chapter 5).

Articular Cartilage

The development of bone is usually preceded by the formation of articular (hyaline) cartilage tissue, commonly called gristle. Articular cartilage is a highly organized viscoelastic material composed of cartilage cells called *chondrocytes*, water, and an ECM. The ECM contains proteoglycans, lipids, water, and dissolved electrolytes. Articular cartilage is devoid of any blood vessels, lymphatics, and nerves.[23,24] It covers the ends of long bones and, along with the synovial fluid that bathes it, provides a smooth, almost frictionless articulating surface.[25]

Key Point
- Articular cartilage is the most abundant cartilage within the body.
- Most of the bones of the body form first as articular cartilage and later become bone in a process called *endochondral ossification*.

Articular cartilage distributes the joint forces over a large contact area, dissipating the forces associated with the load. The normal thickness of articular cartilage is determined by the contact pressures across the joint—the higher the peak pressures, the thicker the cartilage.[9] This distribution of forces allows the articular cartilage to remain healthy and fully functional throughout decades of life.

Key Point The patella has the thickest articular cartilage in the body.

Articular cartilage may be grossly subdivided into four distinct zones with differing cellular morphology, biomechanical composition, collagen orientations, and structural properties (Figure 2-4).

Fibrocartilage

Fibrocartilage consists of a blend of white fibrous tissue and cartilaginous tissue. The white fibrous tissue provides flexibility and toughness, while the cartilage tissue provides elasticity.

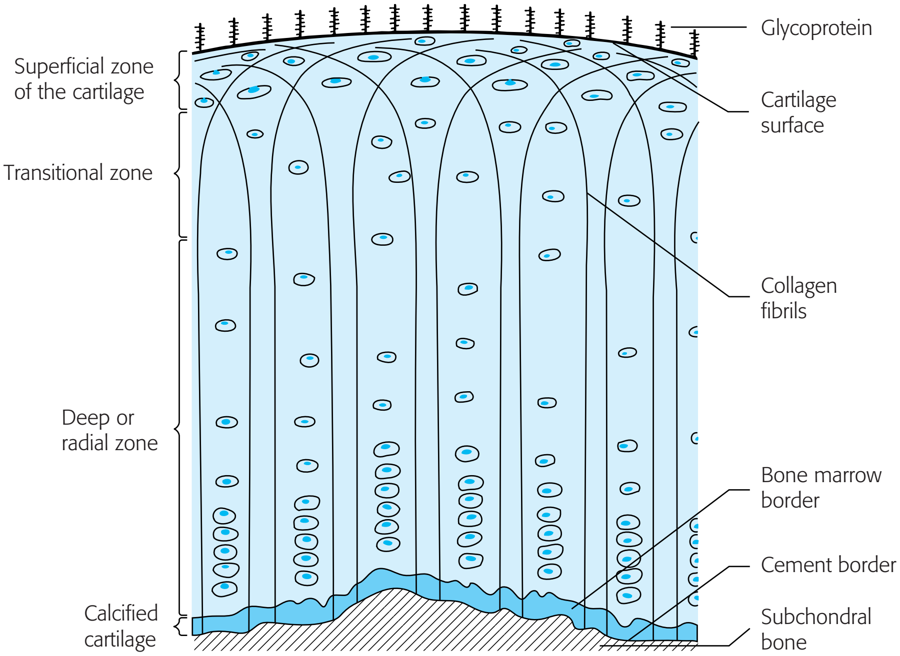

Figure 2-4 Articular layers of cartilage.

Meniscus

The meniscus is a specialized viscoelastic fibrocartilaginous structure capable of load transmission, shock absorption, stability, articular cartilage lubrication, and proprioception.[9] The collagen fibers of the menisci are arranged parallel to the peripheral border in the deeper areas, and are more radially oriented in the superficial region. The radially oriented fibers provide structural rigidity and the deep fibers resist tension. Menisci tend to be found in noncongruent joints, such as the knee. The pathology of the knee meniscus and implications for the PTA are described in Chapter 20.

Intervertebral Disc

An intervertebral disk (IVD) is located between adjacent vertebrae in the spine, and combined represent the largest avascular structure in the body.[24] In the human spinal column, the combined heights of the IVDs account for approximately 20–33 percent of the total length of the spinal column.[26] The human vertebral column is designed to provide structural stability while affording full mobility as well as protection of the spinal cord and axial neural tissues.[27] The presence of an IVD not only permits motion of the segment in any direction up to the point that the disk itself is stretched but also allows for a significant increase in the weight-bearing capabilities of the spine.[28] Vertebral disks have traditionally been described as being composed of three parts: the annulus fibrosus (AF), the vertebral end plate, and a central gelatinous mass, called the nucleus pulposus (NP).

Three main types of structural disruption are recognized: herniation, protrusion, and prolapse (see Chapter 15).

Joints

A joint represents the junction between two or more bones. Joints are regions where bones are capped and surrounded by connective tissues that hold the bones together and determine the type and degree of movement between them.[29] Joints may be classified as synovial, fibrous, or cartilaginous (Table 2-6).

● Key Point An amphiarthrosis, a type of joint formed primarily by fibrocartilage and hyaline cartilage, plays an important role in shock absorption. An example of an amphiarthrosis is the intervertebral body joints of the spine.

Every synovial joint contains at least one "mating pair" of articular surfaces—one convex and one concave. If only one pair exists, the joint is called simple; more than one pair is called compound. If a disk is present, the joint is termed complex. Synovial joints have five distinguishing

TABLE 2-6 Joint Types

Type	Characteristics	Examples
Synovial		
Diarthrosis	Fibroelastic joint capsule, which is filled with a lubricating substance called *synovial fluid*	Hip, knee, shoulder, and elbow joints
Fibrous		
Synarthrosis (eventual fusion is termed a synostosis)	United by bone tissue, ligament, or membrane Immovable joint	Sagittal suture of the skull
Syndesmosis	Joined together by a dense fibrous membrane Very little motion	The interosseous membrane between the tibia and fibula
Gomphosis	Bony surfaces connected like a peg in a hole (the periodontal membrane is the fibrous component)	The teeth and corresponding sockets are the only gomphosis joints in the body
Cartilaginous (amphiarthrosis)		
Synchondrosis	Joined by either hyaline or fibrocartilage May ossify to a synostosis once growth is completed	The epiphyseal plates of growing bones and the articulations between the first rib and the sternum
Symphysis	Generally located at the midline of the body Two bones covered with hyaline cartilage and connected by fibrocartilage	The symphysis pubis

characteristics: joint cavity, articular cartilage, synovial fluid, synovial membrane, and a fibrous capsule (Figure 2-5). Synovial joints can be broadly classified according to structure or analogy into the following categories:[1]

- *Spheroid:* As the name suggests, a spheroid joint is a freely moving joint in which a sphere on the head of one bone fits into a rounded cavity in the other bone. Spheroid (ball and socket) joints allow motions in three planes (refer to Chapter 4). Examples of a spheroid joint surface include the heads of the femur and humerus.
- *Trochoid:* The trochoid (pivot) joint is characterized by a pivot-like process turning within a ring, or a ring on a pivot, the ring being formed partly of bone, partly of ligament. Trochoid joints permit only rotation. Examples of a trochoid joint include the proximal radioulnar joint and the atlantoaxial joint.
- *Condyloid:* The condyloid joint is characterized by an ovoid articular surface, or condyle. One bone may articulate with another by one surface or by two, but never more than two. If two distinct surfaces are present, the joint is called condylar or bicondylar. The elliptical cavity of the joint is designed in such a manner as to permit the motions of flexion, extension, adduction, abduction, and circumduction, but no axial rotation (see Chapter 4). The wrist joint is an example of this form of articulation.
- *Ginglymoid:* A ginglymoid (hinge) is characterized by a spool-like surface and a concave surface. An example of a ginglymoid joint is the humeroulnar joint.
- *Ellipsoid:* Ellipsoid joints are similar to spheroid joints in that they allow the same type of movement, albeit to a lesser magnitude. The ellipsoid joint allows movement in two planes (flexion, extension; abduction, adduction) and is biaxial (refer to Chapter 4). Examples of this joint can be found at the radiocarpal articulation at the wrist and the metacarpophalangeal articulation in the phalanges.
- *Planar:* As its name suggests, a planar (gliding) joint is characterized by two flat

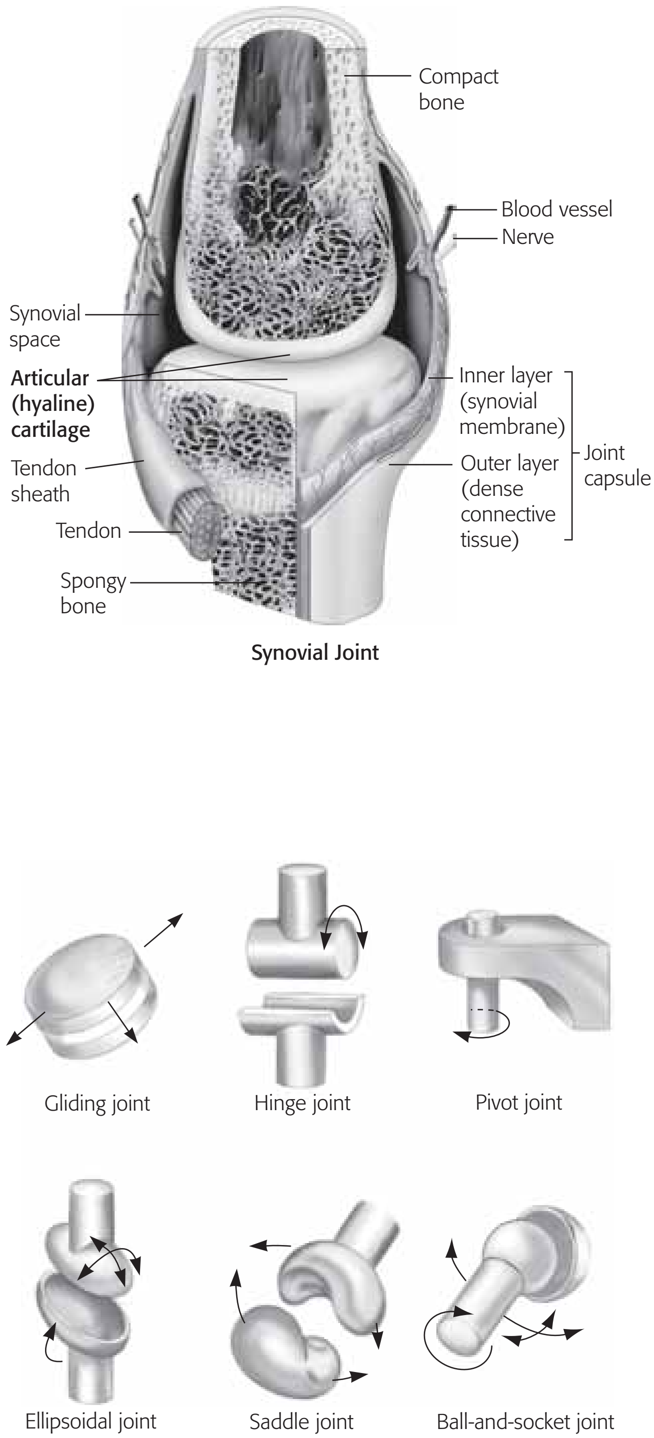

Figure 2-5 The synovial joint.

surfaces that slide over each other. Movement at this type of joint does not occur about an axis and is termed nonaxial. Examples of a planar joint include the intermetatarsal joints and some intercarpal joints.

- *Sellar:* The other major type of articular surface is the sellar (saddle) joint.[2] Sellar joints are characterized by a convex surface in one cross-sectional plane and a concave surface in the plane perpendicular to it. Examples of a sellar joint include the carpometacarpal joint of the thumb, the humeroulnar joint, and the calcaneocuboid joints.

Although the above-mentioned categories give a broad description of joint structure, this classification does not sufficiently describe the articulations or the movements that occur. In reality, no joint surface is planar or resembles a true geometric form. Instead, joint surfaces are either convex in all directions or concave in all directions, that is, they resemble either the outer or inner surface of a piece of eggshell.[2] Because the curve of an eggshell varies from point to point, these articular surfaces are called *ovoid*.

Joint Receptors

All synovial joints of the body are provided with an array of corpuscular receptor endings (mechanoreceptors) and noncorpuscular receptor endings (nociceptors) imbedded in articular, muscular, and cutaneous structures with varying characteristic behaviors and distributions depending on articular tissue (**Table 2-7**).

Synovial Fluid

Articular cartilage is subject to a great variety of loading conditions (see Chapter 4); therefore, joint lubrication through synovial fluid is necessary to minimize frictional resistance between the weight-bearing surfaces. Fortunately, synovial joints are blessed with a very superior lubricating system, which permits a remarkably frictionless interaction at the joint surfaces.

> **Key Point** In terms of design, a synovial joint imparts very little friction at the joint surfaces. By way of a comparison, a lubricated cartilaginous interface has a coefficient of friction* of 0.002[64]; ice moving on ice has a much higher coefficient of friction of 0.03.[30]

The composition of synovial fluid is nearly the same as that of blood plasma, but with a decreased total protein content and a higher concentration of hyaluronan.[31] Indeed, synovial fluid is essentially a dialysate of plasma to which hyaluronan has been added.[32] Hyaluronan is a glycosaminoglycan

*Coefficient of friction is a ratio of the force needed to make a body glide across a surface compared with the weight or force holding the two surfaces in contact. The higher the coefficient, the greater the force required and the greater heat generated.

TABLE 2-7 Characteristics of Mechanoreceptors and Nociceptors

Receptor Type	Type of Stimulus and Example	Receptor Type and Location
Mechanoreceptors	Pressure	
	Movement of hair in a hair follicle	Afferent nerve fiber (base of hair follicles)
	Light pressure	Meissner's corpuscle (skin)
	Deep pressure	Pacinian corpuscle (skin)
	Touch	Merkel's touch corpuscle (skin)
Nociceptors	Pain (stretch)	Free nerve endings (wall of gastrointestinal tract, skin)
Proprioceptors	Distension	Ruffini corpuscles (skin and capsules in joints and ligaments)
	Length changes	Muscle spindles (skeletal muscles)
	Tension changes	Golgi tendon organs (between muscles and tendons)
Thermoreceptors	Temperature changes	
	Cold	Krause's end bulbs (skin)
	Heat	Ruffini corpuscles (skin and capsules in joints and ligaments)

(GAG) that is continually synthesized and released into synovial fluid by specialized synoviocytes.[33] Hyaluronan is a critical constituent component of normal synovial fluid and an important contributor to joint homeostasis.[34]

Key Point Hyaluronan imparts anti-inflammatory and antinociceptive properties to normal synovial fluid and contributes to joint lubrication. It is also responsible for the viscoelastic properties of synovial fluid[31] and contributes to the lubrication of articular cartilage surfaces.[32,33]

The mechanical properties of synovial fluid permit it to act as both a cushion and a lubricant to the joint. Fluid lubrication results when a film of synovial fluid is established, and maintained, between the two surfaces as long as movement occurs.

Bursae

Closely associated with some synovial joints are flattened, saclike structures called *bursae* that are lined with a synovial membrane and filled with synovial fluid. The bursa produces small amounts of fluid, allowing for smooth and almost frictionless motion between contiguous muscles, tendons, bones, ligaments, and skin.[35–37] A tendon sheath is a modified bursa. Bursitis is defined as inflammation of a bursa, and it occurs when the synovial fluid becomes infected by bacteria or gets irritated because of too much movement. Symptoms of bursitis include inflammation, localized tenderness, warmth, edema, erythema of the skin (if superficial), and loss of function. Any signs of a pathologic or inflamed bursa should be reported to the supervising PT. The list of bursae that may become inflamed is quite extensive:

- Subacromial (subdeltoid) bursitis
- Olecranon bursitis
- Iliopsoas bursitis
- Trochanteric bursitis
- Ischial bursitis
- Prepatellar bursitis
- Infrapatellar bursitis
- Anserine bursitis

Skeletal Muscle Tissue

Skeletal muscle tissue consists of individual muscle cells or fibers (Figure 2-6). A single muscle cell is called a *muscle fiber* or *myofiber*. Individual muscle fibers are wrapped in a connective tissue envelope called *endomysium*. Bundles of myofibers, which form a whole muscle (fasciculus), are encased in the perimysium. The perimysium is continuous with the deep fascia. Groups of fasciculi are surrounded by a connective sheath called the epimysium. An electron microscope reveals that each of the myofibers consists of thousands of *myofibrils*, which extend throughout its length (Figure 2-7). Myofibrils are composed of sarcomeres arranged in series).[38]

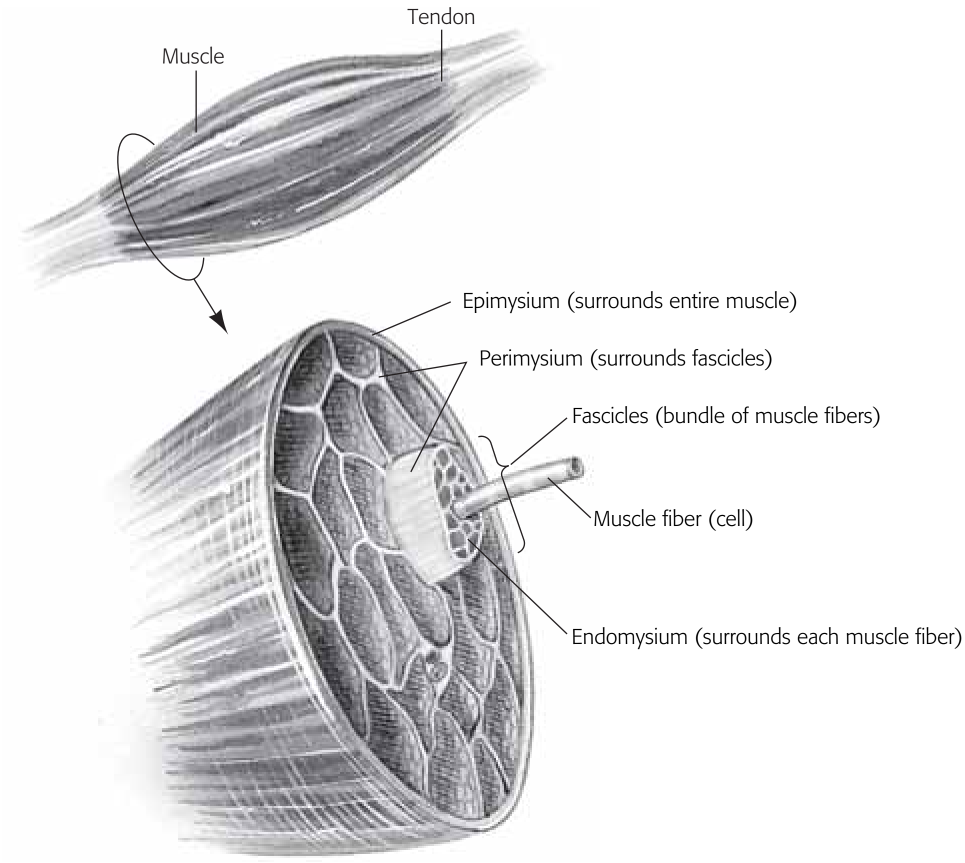

Figure 2-6 Muscle tissue.

Key Point There are approximately 430 skeletal muscles in the body, each of which can be considered anatomically as a separate organ.

Machinery of Movement

One of the most important roles of connective tissue is to mechanically transmit the forces generated by the skeletal muscle cells to provide movement. Each muscle cell contains many structural components called *myofilaments*, which run parallel to the myofibril axis. The myofilaments are made up of two protein filaments: actin (thin) and myosin (thick) (Figure 2-7). The most distinctive feature of skeletal muscle fibers is their striated (striped) appearance. This cross-striation is the result of an orderly arrangement within and between structures called sarcomeres and myofibrils.[39] The sarcomere is the contractile machinery of the muscle. The striations are produced by alternating dark (A) and light (I) bands that appear to span the width of the muscle fiber. The A bands are composed of myosin filaments, whereas the I bands are composed of actin filaments. The actin filaments of the I band overlap into the A band, giving the edges of the A band a darker appearance than the central region (H band), which contains only myosin. At the center of each I band is a thin, dark Z line (Figure 2-7). A *sarcomere* represents the distance between each Z line. Each muscle fiber is limited by a cell membrane called a *sarcolemma*. The protein *dystrophin* plays an essential role in the mechanical strength and stability of the sarcolemma.[40]

Key Point Dystrophin is lacking in patients with Duchenne muscular dystrophy.

When a muscle contracts, the distance between the Z lines decreases, the I band and H bands disappear, but the width of the A band remains unchanged.[39] This shortening of the sarcomeres is not produced by a shortening of the actin and myosin filaments, but by a sliding of actin filaments over the myosin filaments, which pulls the Z lines together.

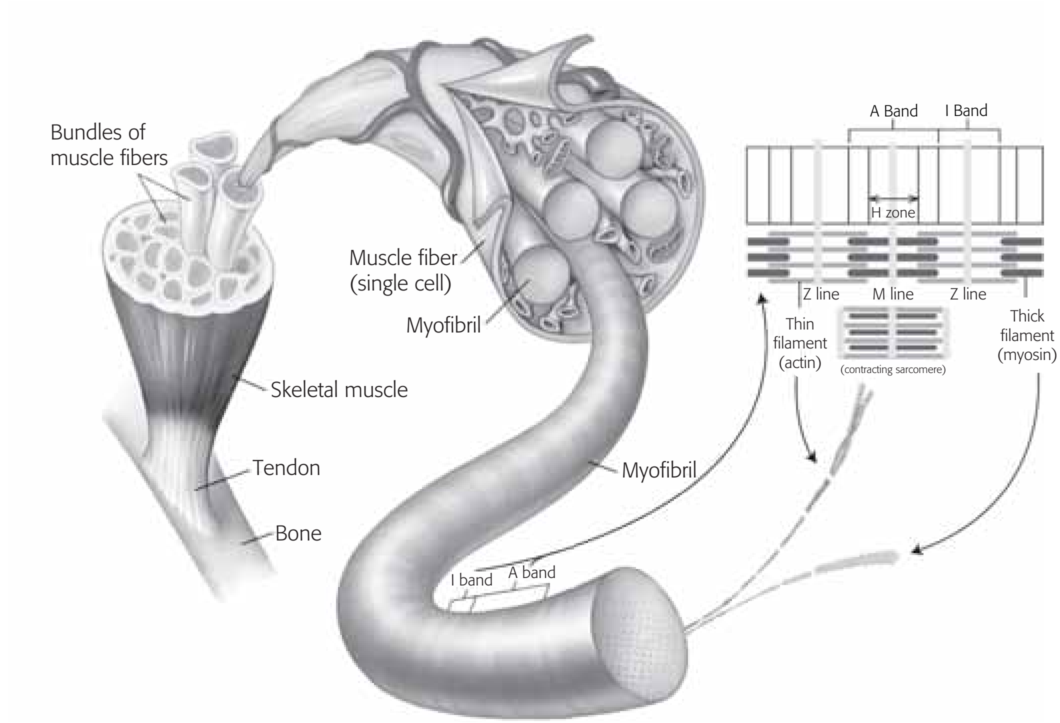

Figure 2-7 Contractile machinery.

Structures called *myosin cross-bridges* connect the actin and myosin filaments (refer to Figure 2-7). The myosin filaments contain two flexible, hinge-like regions, which allow the cross-bridges to attach and detach from the actin filament. During contraction, the cross-bridges attach and undergo power strokes, which provide the contractile force. During relaxation, the cross-bridges detach. This attaching and detaching is asynchronous, so that some are attaching while others are detaching. Thus, at each moment, some of the cross-bridges are pulling while others are releasing. The regulation of cross-bridge attachment and detachment is a function of two proteins found in the actin filaments: tropomyosin and troponin (Figure 2-8). Tropomyosin attaches directly to the actin filament, whereas troponin is attached to the tropomyosin rather than directly to the actin filament. Tropomyosin and troponin function as the switch for muscle contraction and relaxation. In a relaxed state, the tropomyosin physically blocks the cross-bridges from binding to the actin. For contraction to take place, the tropomyosin must be moved.

Each muscle fiber is innervated by a somatic motor neuron. One neuron, and the muscle fibers it innervates, constitutes a motor unit or functional unit of the muscle. Each motor neuron branches as it enters the muscle to innervate a number of muscle fibers. The area of contact between a nerve and a muscle fiber is known as the motor end plate or neuromuscular junction. The release of a chemical, acetylcholine, from the axon terminals at the neuromuscular junctions causes electrical activation of the skeletal muscle fibers. When an action potential propagates into the transverse tubule system (narrow membranous tunnels formed from and continuous with the sarcolemma), the voltage sensors on the transverse tubule membrane signal the release of Ca^{2+} from the terminal cisternae portion of the sarcoplasmic reticulum (a series of interconnected sacs and tubes that surround each myofibril).[39] The released Ca^{2+} then diffuses into the sarcomeres and binds to troponin, displacing the tropomyosin and allowing the actin to bind with the myosin cross-bridges. At the end of the contraction (the neural activity and action potentials cease), the sarcoplasmic reticulum actively accumulates Ca^{2+} and muscle relaxation occurs. The return of Ca^{2+} to the sarcoplasmic reticulum involves active transport, requiring the degradation of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) (see Chapter 8).[39]

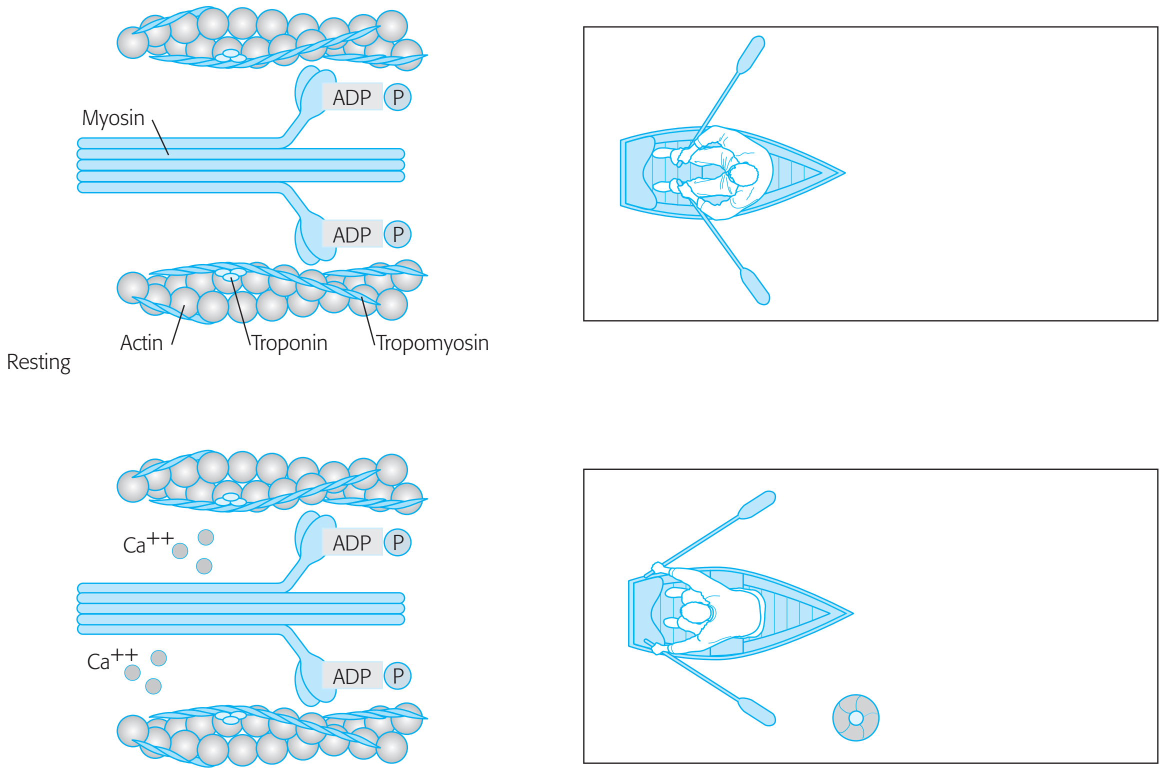

Figure 2-8 Troponin and tropomyosin.

● **Key Point** Because sarcoplasmic reticulum function is closely associated with both contraction and relaxation, changes in its ability to release or sequester Ca^{2+} markedly affect both the time course and magnitude of force output by the muscle fiber.[41]

Activation of varying numbers of motor neurons results in gradations in the strength of muscle contraction. The stronger the electrical impulse, the stronger the muscle twitch. Whenever a somatic motor neuron is activated, all of the muscle fibers that it innervates are stimulated and contract with *all-or-none* twitches. Although the muscle fibers produce all-or-none contractions, muscles are capable of a wide variety of responses, ranging from activities requiring a high level of precision to activities requiring high tension.

● **Key Point** The graded contractions of whole muscles occur because the number of fibers participating in the contraction varies. An increase in the force of movement is achieved by recruiting more cells into cooperative action.

When rapid successive impulses activate a muscle fiber already in tension, *summation* occurs, and tension is progressively elevated until a maximum value for that fiber is reached.[42] A fiber repetitively activated so that its maximum tension level is maintained for a time is in *tetanus*. If the state of tetanus is sustained, fatigue causes a gradual decline in the level of tension produced.

Muscle Fiber Types

The basic function of a muscle is to contract. On the basis of their contractile properties, two different types of muscle fibers have been recognized within skeletal muscle: type I (slow-twitch red oxidative) and type II (fast-twitch white glycolytic). Type II fibers can be broken down further into three distinct subsets: type II, A; type II, AB; and type II, B[43] (**Table 2-8**).

Slow-twitch fibers have a high capacity for oxygen uptake. They are, therefore, suitable for activities of long duration or endurance, including the maintenance of posture. Fast-twitch fibers have a low capacity for oxygen uptake, and are therefore suited to quick, explosive actions, including such activities as sprinting.

● **Key Point** In fast-twitch fibers, the sarcoplasmic reticulum embraces every individual myofibril. In slow-twitch fibers, it may contain multiple myofibrils.[44]

TABLE 2-8 Comparison of Muscle Fiber Types

Characteristics	Type I	Type II A	Type II AB	Type II B
Diameter	Small	Intermediate	Large	Very large
Capillaries	Many	Many	Few	Few
Resistance to fatigue	High	Fairly high	Intermediate	Low
Glycogen content	Low	Intermediate	High	High
Respiration	Aerobic	Aerobic	Anaerobic	Anaerobic
Twitch rate	Slow	Fast	Fast	Fast
Major storage fuel	Triglycerides	Creatine phosphate Glycogen	Creatine phosphate Glycogen	Creatine phosphate Glycogen

Theory dictates that a muscle with a large percentage of the total cross-sectional area occupied by slow-twitch type I fibers should be more fatigue resistant than one in which the fast-twitch type II fibers predominate. The shape of a muscle determines its specific action. A number of muscle shapes are recognized:

- *Circular:* As their name suggests, these muscles appear circular in shape and are normally sphincter muscles that surround an opening such as the mouth or eyes.
- *Fusiform:* These muscles are more spindle-shaped, with the muscle belly being wider than the origin and insertion. Typically, these muscles are built to provide large ranges of motion. Examples include the biceps brachii and the psoas major.
- *Triangular (convergent):* These are muscles where the origin is wider than the point of insertion. This fiber arrangement allows for maximum force production. Examples include the gluteus medius and pectoralis major.

Key Point

- *Origin:* The proximal attachment of a muscle, tendon, or ligament
- *Insertion:* The distal attachment of a muscle, tendon, or ligament

- *Parallel (strap):* These are normally long muscles capable of producing large movements; although they are not very strong, they have very good endurance. Examples include the sartorius and sternocleidomastoid. Some textbooks include fusiform muscles in the parallel group.
- *Rhomboidal:* These muscles are characterized by expansive proximal and distal attachments, which make them well-suited to either stabilize a joint or provide large forces. Examples include the rhomboids and gluteus maximus.
- *Pennate:* These muscles resemble the shape of a feather, with muscle fibers approaching a central tendon at an oblique angle. This diagonal orientation of the fibers maximizes the muscle's force potential and many more muscle fibers can fit into the muscle compared with a similar sized fusiform muscle. They can be divided into the following subcategories:
  - *Unipennate:* These fibers are arranged to insert in a diagonal direction onto the tendon, which allows for greater strength. Examples include the lumbricals (deep hand muscles) and the extensor digitorum longus (wrist and finger extensor).
  - *Bipennate:* These have two rows of muscle fibers, facing in opposite diagonal directions, with a central tendon, like a feather. This arrangement allows for even greater power than the unipennate but less range of motion. An example is the rectus femoris.
  - *Multipennate:* These muscles have multiple rows of diagonal fibers, with a central tendon that branches into two or more

tendons. An example is the deltoid muscle, which has three sections, anterior, posterior, and middle.

Key Point A muscle's shape is one important indicator of its specific action. For example, short, thick muscles typically provide large forces, whereas long, straplike muscles typically provide large ranges of motion.[45]

Muscle Function

Muscle groups are classified based on the following functions (Figure 2-9):

- *Agonist muscle:* An agonist muscle contracts to produce the desired movement.
- *Antagonist muscle:* The antagonist muscle typically opposes the desired movement and is responsible for returning a limb to its initial position. Antagonists ensure that the desired motion occurs in a coordinated and controlled fashion by relaxing and lengthening in a gradual manner.
- *Synergist muscle (supporters):* Synergist muscles are muscle groups that perform, or assist in performing, joint motions. Although synergists can work with the agonists, they can also oppose the agonists, as occurs in force couples.

Key Point Agonists and antagonists are usually located on opposite sides of the affected joint (e.g., the hamstrings and quadriceps, the triceps and biceps); synergists are usually located on the same side of the joint near the agonists.

- *Neutralizers:* These muscles help cancel out, or neutralize, extra motion from the agonists to make sure the force generated works within the desired plane of motion. An example is when the flexor carpi ulnaris and extensor carpi ulnaris neutralize the flexion/extension forces at the wrist to produce ulnar deviation.
- *Stabilizers (fixators):* These muscles provide the necessary support to help stabilize an area so that another area can be moved. For example, the trunk core stabilizers become active when the upper extremities are being used.

Key Point A co-contraction occurs when the agonist and antagonist muscles are simultaneously activated in a pure or near isometric fashion. This type of contraction can help stabilize and protect a joint.

Stable posture results from a balance of competing forces, whereas movement occurs when competing forces are unbalanced.[46]

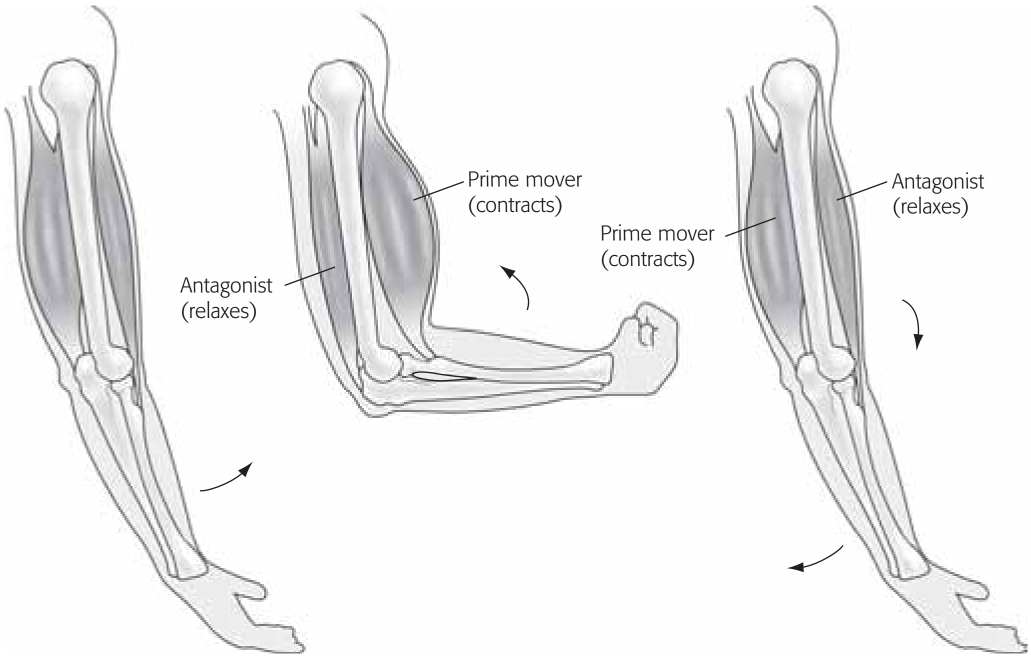

Figure 2-9 Agonist and antagonist muscle actions.

TABLE 2-9 Examples of Skeletal Muscles That Cross Two or More Joints

Erector spinae
Biceps brachii
Long head of the triceps brachii
Hamstrings
Iliopsoas
Sartorius
Rectus femoris
Gastrocnemius
A number of muscles crossing the wrist/finger and foot/ankle joints

Key Point

- Movements generated or stimulated by active muscle are referred to as *active movements*.
- Movements generated by sources other than muscular activation, such as gravity, are referred to as *active-assisted* or *passive movements*.

Most skeletal muscles span only one joint; however, some skeletal muscles cross two or more joints (**Table 2-9**). A two-joint muscle is more prone to adaptive shortening than a one-joint muscle.

Key Point The graded contractions of whole muscles occur because the number of fibers participating in the contraction varies. The increase in the force of movement is achieved by recruiting more cells into cooperative action. The different types of muscle contractions are described in Chapter 10.

The physiologic cross-sectional area of the muscle describes its thickness—an indirect and relative measure of the amount of contractile elements available to generate force.[45] The larger a muscle's cross-sectional area, the greater its force potential (see Chapter 4). Different activities place differing demands on a muscle. For example, movement activities involve a predominance of fast-twitch fiber recruitment, whereas postural activities and those activities requiring stabilization entail more involvement of the slow-twitch fibers. In humans, most limb muscles contain a relatively equal distribution of each muscle fiber type, whereas the back and trunk demonstrate a predominance of slow-twitch fibers.

If a contraction proceeds normally there is an orderly recruitment of muscle fibers, which proceeds according to the following: slow twitch→ fast twitch→ fast twitch A→ fast twitch AB→ fast twitch B.

Although it would seem possible that physical training may cause fibers to convert from slow twitch to fast twitch or the reverse, this has not been shown to be the case.[47] However, fiber conversion from fast twitch A to fast twitch B, and vice versa, has been found to occur with training.[48] Muscle tissue is capable of significant adaptions. The various types of muscle contraction and their relationship to therapeutic exercise and impaired muscle performance are described in Chapter 10.

Assessment of Musculoskeletal Tissues

Assessment of the musculoskeletal tissues involves an examination of range of motion, flexibility, joint mobility, and strength.

Key Point For the purpose of an orthopaedic examination, Cyriax subdivided musculoskeletal tissue into *contractile* and *inert* (noncontractile) tissues.[49]

Range of Motion

A normal joint has an available range of active, or physiologic, motion, which is limited by a physiologic barrier as tension develops within the surrounding tissues. At the physiologic barrier, there is an additional amount of passive range of motion. Beyond the available passive range of motion, the anatomic barrier is found. This barrier cannot be exceeded without disruption to the integrity of the joint. Both passive and active range of motion can be measured using a goniometer, which has been shown to have a satisfactory level of intraobserver reliability.[50–52]

Goniometry

It is not within the scope of this text to cover every aspect of goniometry, but merely to provide a description so that the PTA can fully appreciate its function in the overall assessment of a patient. The term *goniometry* is derived from two Greek words, *gonia* meaning angle and *metron* meaning measure. Thus, a goniometer is an instrument used to measure angles. Within the field of physical therapy, goniometry is used to measure the total amount of available motion at a specific joint. Goniometry can be used to measure both active and passive range of motion.

Goniometers are produced in a variety of sizes and shapes and are usually constructed of either plastic or metal. The two most common types of instruments used to measure joint angles are the bubble inclinometer and the traditional goniometer.

The bubble goniometer has a 360° rotating dial and scale with fluid indicator. The traditional goniometer consists of three parts:

1. *Body:* The body of the goniometer is designed like a protractor and may form a full or half circle. A measuring scale is located around the body. The scale can extend either from 0 to 180 degrees and 180 to 0 degrees for the half circle models, or from 0 to 360 degrees and from 360 to 0 degrees on the full circle models. The intervals on the scales can vary from 1 to 10 degrees.
2. *Stationary arm:* The stationary arm is structurally a part of the body and therefore cannot move independently of the body.
3. *Moving arm:* The moving arm is attached to the fulcrum in the center of the body by a rivet or screwlike device that allows the moving arm to move freely on the body of the device. In some instruments, the screwlike device can be tightened to fix the moving arm in a certain position or loosened to permit free movement.

The correct selection of which type of goniometer to use depends on the joint angle to be measured. The length of arms varies among instruments and can range from 3–18 inches. Extendable goniometers allow varying ranges from 9½ inches to 26 inches. The longer armed goniometers, or the bubble inclinometer, are recommended when the landmarks are further apart, such as when measuring hip, knee, elbow, and shoulder movements. Bubble inclinometers are recommended when measuring spinal motions. In the smaller joints such as the wrist and hand and foot and ankle, a traditional goniometer with a shorter arm is used.

To use the goniometer, the patient is positioned in the recommended testing position. While stabilizing the proximal joint component, the clinician gently moves the distal joint component through the available range of motion until the end feel is determined. An estimate is made of the available range of motion, and the distal joint component is returned to the starting position. The clinician palpates the relevant bony landmarks and aligns the goniometer. A record is made of the starting measurement. The goniometer is then removed and the patient moves the joint through the available range of motion. Once the joint has been moved through the available range of motion, the goniometer is replaced and realigned, and a measurement is read and recorded. A brief summary of the goniometric technique for each of the upper and lower extremity joints is provided in **Table 2-10** and **Table 2-11**.

Active Range of Motion

Active range of motion testing gives the clinician information about:

- The quantity of available physiologic motion
- The presence of muscle substitutions
- The willingness of the patient to move
- The integrity of the contractile and inert tissues
- The quality of motion
- Symptom reproduction
- The pattern of motion restriction

Active range of motion testing may be deferred if small and unguarded motions provoke intense pain because this may indicate a high degree of joint irritability.

Full and pain-free active range of motion suggests normalcy for that movement, although it is important to remember that normal *range* of motion is not synonymous with normal motion.[53] Normal motion implies that the control of motion must also be present. Single motions in the cardinal planes are usually tested first. Dynamic testing involves repeated movements in specific directions. Pain that increases after the repeated motions may indicate a retriggering of the inflammatory response, and repeated motions in the opposite direction should be explored.

Key Point Static testing involves sustaining a position. Sustained static positions may be used to help detect postural syndromes.[54]

Combined motions, as their name suggests, use single plane motions with other motions superimposed. For example at the elbow, the single plane motion of elbow flexion is tested together with forearm supination and then forearm pronation. The active range of motion will be found to be either abnormal or normal. Abnormal motion is typically described as being reduced. It must be remembered,

TABLE 2-10 Goniometric Techniques for the Upper Extremity

Joint	Motion	Axis	Stationary Arm	Movable Arm	Normal Ranges (Degrees)
Shoulder	Flexion	Acromion process	Mid-axillary line of the thorax	Lateral midline of the humerus using the lateral epicondyle of the humerus for reference	0–180
	Extension	Acromion process	Mid-axillary line of the thorax	Lateral midline of the humerus using the lateral epicondyle of the humerus for reference	0–40
	Abduction	Anterior aspect of the acromion process	Parallel to the midline of the anterior aspect of the sternum	Medial midline of the humerus	0–180
	Adduction	Anterior aspect of the acromion process	Parallel to the midline of the anterior aspect of the sternum	Medial midline of the humerus	90–0
	Internal rotation	Olecranon process	Parallel or perpendicular to the floor	Ulna using the olecranon process and ulnar styloid for reference	0–80
	External rotation	Olecranon process	Parallel or perpendicular to the floor	Ulna using the olecranon process and ulnar styloid for reference	0–90
Elbow	Flexion	Lateral epicondyle of the humerus	Lateral midline of the humerus using the center of the acromion process for reference	Lateral midline of the radius using the radial head and radial styloid process for reference	0–150
	Extension	Lateral epicondyle of the humerus	Lateral midline of the humerus using the center of the acromion process for reference	Lateral midline of the radius using the radial head and radial styloid process for reference	0–5
Forearm	Pronation	Lateral to the ulnar styloid process	Parallel to the anterior midline of the humerus	Dorsal aspect of the forearm, just proximal to the styloid process of the radius and ulna	0–75
	Supination	Medial to the ulnar styloid process	Parallel to the anterior midline of the humerus	Ventral aspect of the forearm, just proximal to the styloid process of the radius and ulna	0–85
Wrist	Flexion	Lateral aspect of the wrists over the triquetrum	Lateral midline of the ulna using the olecranon and ulnar styloid process for reference	Lateral midline of the fifth metacarpal	0–80
	Extension	Lateral aspect of the wrists over the triquetrum	Lateral midline of the ulna using the olecranon and ulnar styloid process for reference	Lateral midline of the fifth metacarpal	0–60

TABLE 2-10 Goniometric Techniques for the Upper Extremity (continued)

Joint	Motion	Axis	Stationary Arm	Movable Arm	Normal Ranges (Degrees)
	Radial deviation	Over the middle of the dorsal aspect of the wrist over the capitate	Dorsal midline of the forearm using the lateral epicondyle of the humerus for reference	Dorsal midline of the third metacarpal	0–20
	Ulnar deviation	Over the middle of the dorsal aspect of the wrist over the capitate	Dorsal midline of the forearm using the lateral epicondyle of the humerus for reference	Dorsal midline of the third metacarpal	0–30
Thumb	Carpometacarpal flexion	Over the palmar aspect of the first carpometacarpal joint	Ventral midline of the radius using the ventral surface of the radial head and radial styloid process for reference	Ventral midline of the first metacarpal	CMC: 45–50; MCP: 50–55; IP: 85–90
	Carpometacarpal extension	Over the palmar aspect of the first carpometacarpal joint	Ventral midline of the radius using the ventral surface of the radial head and radial styloid process for reference	Ventral midline of the first metacarpal	MCP: 0; IP: 0–5
	Carpometacarpal abduction	Over the lateral aspect of the radial styloid process	Lateral midline of the second metacarpal using the center of the second metacarpal or phalangeal joint for reference	Lateral midline of the first metacarpal using the center of the first metacarpal or phalangeal joint for reference	60–70
	Carpometacarpal adduction	Over the lateral aspect of the radial styloid process	Lateral midline of the second metacarpal using the center of the second metacarpal or phalangeal joint for reference	Lateral midline of the first metacarpal using the center of the first metacarpal or phalangeal joint for reference	30
Fingers	Metacarpophalangeal flexion	Over the dorsal aspect of the metacarpophalangeal joint	Over the dorsal midline of the metacarpal	Over the dorsal midline of the proximal phalanx	Flexion: MCP: 85–90; PIP: 100–115; DIP: 80–90 Extension: MCP: 30–45; PIP: 0; DIP: 20 Abduction: 20–30 Adduction: 0
	Metacarpophalangeal extension	Over the dorsal aspect of the metacarpophalangeal joint	Over the dorsal midline of the metacarpal	Over the dorsal midline of the proximal phalanx	
	Metacarpophalangeal abduction	Over the dorsal aspect of the metacarpophalangeal joint	Over the dorsal midline of the metacarpal	Over the dorsal midline of the proximal phalanx	
	Metacarpophalangeal adduction	Over the dorsal aspect of the metacarpophalangeal joint	Over the dorsal midline of the metacarpal	Over the dorsal midline of the proximal phalanx	

(*continued*)

TABLE 2-10 Goniometric Techniques for the Upper Extremity (continued)

Joint	Motion	Axis	Stationary Arm	Movable Arm	Normal Ranges (Degrees)
Fingers	Proximal interphalangeal flexion	Over the dorsal aspect of the proximal interphalangeal joint	Over the dorsal midline of the proximal phalanx	Over the dorsal midline of the middle phalanx	
	Proximal interphalangeal extension	Over the dorsal aspect of the proximal interphalangeal joint	Over the dorsal midline of the proximal phalanx	Over the dorsal midline of the middle phalanx	
	Distal interphalangeal flexion	Over the dorsal aspect of the proximal interphalangeal joint	Over the dorsal midline of the middle phalanx	Over the dorsal midline of the distal phalanx	
	Distal interphalangeal extension	Over the dorsal aspect of the proximal interphalangeal joint	Over the dorsal midline of the middle phalanx	Over the dorsal midline of the distal phalanx	

TABLE 2-11 Goniometric Techniques for the Lower Extremity

Joint	Motion	Axis	Stationary Arm	Movable Arm	Normal Ranges (Degrees)
Hip	Flexion	Over the lateral aspect of the hip joint using the greater trochanter of the femur for reference	Lateral midline of the pelvis	Lateral midline of the femur using the lateral epicondyle for reference	0–125
	Extension	Over the lateral aspect of the hip joint using the greater trochanter of the femur for reference	Lateral midline of the pelvis	Lateral midline of the femur using the lateral epicondyle for reference	0–30
	Abduction	Over the anterior superior iliac spine (ASIS) of the extremity being measured	Aligned with an imaginary horizontal line extending from one ASIS to the other ASIS	Anterior midline of the femur using the midline of the patella for reference	0–40
	Adduction	Over the anterior superior iliac spine (ASIS) of the extremity being measured	Aligned with an imaginary horizontal line extending from one ASIS to the other ASIS	Anterior midline of the femur using the midline of the patella for reference	0–20
	Internal rotation	Anterior aspect of the patella	Perpendicular to the floor or parallel to the supporting surface	Anterior midline of the lower leg using the crest of the tibia and a point midway between the two malleoli for reference	0–40
	External rotation	Anterior aspect of the patella	Perpendicular to the floor or parallel to the supporting surface	Anterior midline of the lower leg using the crest of the tibia and a point midway between the two malleoli for reference	0–50

TABLE 2-11 Goniometric Techniques for the Lower Extremity (continued)

Joint	Motion	Axis	Stationary Arm	Movable Arm	Normal Ranges (Degrees)
Knee	Flexion	Lateral epicondyle of the femur	Lateral midline of the femur using the greater trochanter for reference	Lateral midline of the fibula using the lateral malleolus and fibular head for reference	0–150
	Extension	Lateral epicondyle of the femur	Lateral midline of the femur using the greater trochanter for reference	Lateral midline of the fibula using the lateral malleolus and fibular head for reference	0–5
Ankle	Dorsiflexion	Lateral aspect of the lateral malleolus	Lateral midline of the fibula using the head of the fibula for reference	Parallel to the lateral aspect of the fifth metatarsal	0–20
	Plantarflexion	Lateral aspect of the lateral malleolus	Lateral midline of the fibula using the head of the fibula for reference	Parallel to the lateral aspect of the fifth metatarsal	0–40
	Inversion	Anterior aspect of the ankle midway between the malleoli	Anterior midline of the lower leg using the tibial tuberosity for reference	Anterior midline of the second metatarsal	0–30
	Eversion	Anterior aspect of the ankle midway between the malleoli	Anterior midline of the lower leg using the tibial tuberosity for reference	Anterior midline of the second metatarsal	0–20

though, that abnormal motion may also be excessive. Excessive motion is often missed and is erroneously classified as normal motion. To help determine whether the motion is normal or excessive, passive range of motion, in the form of passive overpressure, and the end feel is assessed by the PT.

Passive Range of Motion

If the active motions do not reproduce the patient's symptoms, or the active range of motion appears incomplete, it is important to perform gentle passive range of motion and overpressure at the end of the active range in order to fully test the motion. The passive overpressure should be applied carefully in the presence of pain. The barrier to active motion should occur earlier in the range than the barrier to passive motion. Pain that occurs at the end-range of active and passive movement is suggestive of hypermobility or instability, a capsular contraction, or scar tissue that has not been adequately remodeled.[55]

> **Key Point** If active and passive motions are limited/painful in the same direction, the injured tissue is likely inert in nature. If active and passive motions are limited/painful in the opposite direction, the injured tissue is likely contractile in nature. The exception to these generalizations occurs with tenosynovitis.

Passive range of motion testing gives the clinician information about the integrity of the contractile and inert tissues, and the *end feel*. Cyriax[49] introduced the concept of the end feel, which is the quality of resistance at end range. The end feel can indicate to the clinician the cause of the motion restriction (**Table 2-12**). If the PTA detects an abnormal end feel that was not present at the time of initial examination, the intervention must be terminated and the supervising PT must be notified immediately.

> **Key Point** An association has been demonstrated between an increase in pain and abnormal-pathological end feels compared to normal end feels.[56]

TABLE 2-12 End Feels

Type	Cause	Characteristics and Examples
Bony	Produced by bone-to-bone approximation	Abrupt and unyielding Examples: *Normal:* Elbow extension *Abnormal:* Cervical rotation (may indicate osteophyte)
Elastic/stretch	Produced by the muscle–tendon unit	Stretch with elastic recoil Examples: *Normal:* Wrist flexion with finger flexion, and ankle dorsiflexion with the knee extended *Abnormal:* Decreased dorsiflexion of the ankle with the knee flexed as compared to knee extended
Soft tissue approximation	Produced by the contact of two muscle bulks on either side of a flexing joint	A very forgiving end feel Examples: *Normal:* Knee flexion, elbow flexion *Abnormal:* Elbow flexion with an obese subject
Capsular/firm	Produced by capsule or ligaments	Various degrees of stretch without elasticity Stretch ability depends on the thickness of the tissue Examples: *Normal:* Wrist flexion (soft), elbow flexion in supination (medium), and knee extension (hard) *Abnormal:* Inappropriate stretch ability for a specific joint
Springy	Produced by the articular surface rebounding from an intra-articular meniscus or disc	A rebound sensation Examples: *Normal:* Axial compression of the cervical spine *Abnormal:* Knee flexion or extension with a displaced meniscus
Boggy	Produced by fluid (blood) within a joint	A "squishy" sensation as the joint is moved towards its end range Further forcing feels as if it will burst the joint Examples: *Normal:* None *Abnormal:* Hemarthrosis at the knee
Spasm	Produced by reflex and reactive muscle contraction	An abrupt end to movement that is unyielding With acute joint inflammation, it occurs early in the range Note: Muscle guarding is not a true end feel because it involves a co-contraction Examples: *Normal:* None *Abnormal:* Significant traumatic arthritis, recent traumatic hypermobility, grade II muscle tears
Empty	Produced solely by pain	The limitation of motion has no tissue resistance component The resistance is from the patient being unable to tolerate further motion due to severe pain Examples: *Normal:* None *Abnormal:* Acute subdeltoid bursitis, sign of the buttock

The PT bases the planned intervention and its intensity on the type of tissue resistance to movement demonstrated by the end feel and the acuteness of the condition.[49] This information may indicate whether the resistance is caused by pain, muscle, capsule ligament, disturbed mechanics of the joint, or a combination.

Recording Range of Motion

The methods of recording range of motion vary. The measurements depicted in **Tables 2-13**, **Table 2-14**, and **Table 2-15** highlight one method.

Flexibility

Flexibility is examined to determine if a particular structure, or group of structures, has sufficient extensibility to perform a desired activity. The extensibility and habitual length of connective tissue is a factor of the demands placed upon it. These demands produce changes in the viscoelastic properties and, thus, the length–tension relationship of a muscle or muscle group (see Chapter 4), resulting in an increase or decrease in the length of those structures. A loss of flexibility can be produced by:

- Restricted mobility
- Poor posture
- Tissue damage secondary to trauma
- Prolonged immobilization
- Disease
- Hypertonia (the muscle will feel hard and may stand out from those around it)

> **Key Point** The concepts of contracture and adaptive shortening are important to understand.
>
> - A contracture is a condition of fixed high resistance to passive stretch of the tissue resulting from fibrosis or shortening of the soft tissues around the joint, including the muscles. Contractures occur after injury, surgery, or immobilization and are the result of the remodeling of dense connective tissue.
> - Adaptive shortening occurs when the length of the tissue shortens relative to its normal resting length. Immobilization of the tissue in a shortened position or a prolonged posture results in adaptive shortening.

Capsular and Noncapsular Patterns of Restriction

A capsular pattern of restriction is a limitation of pain and movement in a joint-specific ratio, which is usually present with arthritis, or following prolonged

TABLE 2-13 Recording Range of Motion Measurements for the Spine

		Clinical Examples	
Region	Normal AROM (in degrees)	Patient Example	Documentation Recording (in degrees)
Cervical	Extension (60) Flexion (50)	Patient extends to 30 degrees and flexes to 45 degrees	30-0-45
	Sidebend (45)	Patient bends 30 degrees to left, 40 degrees to right	30-0-40
	Rotation (80)	Patient rotates 40 degrees to the left, 50 degrees to the right	40-0-50
Thoracic	Extension (5) Flexion (45)	Patient extends to 0 degrees, flexes to 45 degrees	0-0-45
	Sidebend (45)	Bends left 45 degrees, right 20 degrees	45-0-20
	Rotation (30)	Rotates left 15 degrees, right 20 degrees	15-0-20
Lumbar	Extension (25) Flexion (60)	Extends to 25 degrees, flexes to 40 degrees	25-0-40
	Left side bend-0-Right lateral bend (25-0-25)	Ankylosis of the spine in 20 degrees left side bend Restricted motion from 20–30 degrees of left lateral bending	20-0 F: 30-20-0

AROM, active range of motion.
Data from American Medical Association: Guides to the Evaluation of Permanent Impairment (ed 5). Chicago, American Medical Association, 2001

TABLE 2-14 Recording Range of Motion Measurements for the Upper Extremities

Joint	Normal AROM (in degrees)	Clinical Examples: Patient Example	Clinical Examples: Documentation Recording (in degrees)
Shoulder	Extension (40) Flexion (180)	Patient extends left shoulder to 40 degrees, flexes to 150 degrees	Left: 40-0-150
	Abduction (180) Adduction (30)	Patient extends left shoulder to 100 degrees, adducts to 10 degrees	Left: 100-0-10
	External rotation (90) Internal rotation (80)	Patient rotates left shoulder to 90 degrees, internal rotation to 80 degrees	Left: 90-0-80
Elbow	Extension-0-Flexion (0)-0-(150)	Patient extends left elbow to 0 degrees, flexes to 150 degrees	Left: 0-0-150
		Patient hyperextends left elbow to 5 degrees, flexes to 110 degrees	Left: 5-0-110
Forearm	Supination-0-Pronation (80)-0-(80)	Left supinates to 60 degrees, pronates to 80 degrees	Left: 60-0-80
Wrist	Extension-0-Flexion (60)-0-(60)	Patient extends left wrist to 20 degrees, flexes to 50 degrees	Left: 20-0-50
Wrist	Radial deviation-0-Ulnar deviation (20)-0-(30)	Patient radial deviates left wrist to 20 degrees, ulnar deviates to 30 degrees	Left: 20-0-30

AROM, active range of motion.
Data from American Medical Association: Guides to the Evaluation of Permanent Impairment (ed 5). Chicago, American Medical Association, 2001

TABLE 2-15 Recording Range of Motion Measurements for the Lower Extremities

Joint	Normal AROM (in degrees)	Clinical Examples: Patient Example	Clinical Examples: Documentation Recording (in degrees)
Hip	Extension (30) Flexion (100)	Patient extends the left hip to 30 degrees, flexes to 80 degrees	Left: 30-0-80
	Abduction (40) Adduction (20)	Patient abducts the left hip to 30 degrees, adducts to 10 degrees	Left: 30-0-10
	External rotation (50) Internal rotation (40)	Patient externally rotates the left hip to 30 degrees, internally rotates to 30 degrees	Left: 30-0-30
Knee	Extension (0) Flexion (150)	Patient extends the left knee to 0 degrees, flexes to 150 degrees	Left: 0-0-150
Ankle (Talocrural)	Dorsiflexion (20) Plantarflexion (40)	Patient dorsiflexes left ankle to 10 degrees, plantarflexes to 10 degrees	Left: 10-0-10
Ankle (Subtalar)	Eversion (20) Inversion (30)	Patient everts left ankle to 20 degrees, inverts to 30 degrees	Left: 20-0-30

AROM, active range of motion.
Data from American Medical Association: Guides to the Evaluation of Permanent Impairment (ed5). Chicago, American Medical Association, 2001

TABLE 2-16 Capsular Patterns of Restriction

Joint	Limitation of Motion (Passive Angular Motion)
Glenohumeral	External rotation > Abduction > Internal rotation (3:2:1)
Acromioclavicular	No true capsular pattern; possible loss of horizontal adduction, pain (and sometimes slight loss of end range) with each motion
Sternoclavicular	See above: acromioclavicular joint
Humeroulnar	Flexion > Extension (±4:1)
Humeroradial	No true capsular pattern; possible equal limitation of pronation and supination
Superior radioulnar	No true capsular pattern; possible equal limitation of pronation and supination with pain at end ranges
Inferior radioulnar	No true capsular pattern; possible equal limitation of pronation and supination with pain at end ranges
Wrist (carpus)	Flexion = Extension
Radiocarpal	See above: wrist (carpus)
Carpometacarpal	
Midcarpal	
First carpometacarpal	Retroposition
Carpometacarpal 2–5	Fan > Fold
Metacarpophalangeal 2-5	Flexion > Extension (±2:1)
Interphalangeal	
Proximal (PIP)	Flexion > Extension (±2:1)
Distal (DIP)	
Hip	Internal rotation > Flexion > Abdduction = Extension > other motions
Tibiofemoral	Flexion > Extension (±5:1)
Superior tibiofibular	No capsular pattern: pain at end range of translatory movements
Talocrural	Plantarflexion > Dorsiflexion
Talocalcaneal (subtalar)	Varus > Valgus
Midtarsal	
Talonavicular calcaneocuboid	Inversion (plantarflexion, adduction, supination) > Dorsiflexion
First metatarsophalangeal	Extension > Flexion (±2:1)
Metatarsophalangeal 2–5	Flexion ≥ Extension
Interphalangeal 2–5	
Proximal	Flexion ≥ Extension
Distal	Flexion ≥ Extension

Data from Cyriax J: Textbook of Orthopaedic Medicine, Diagnosis of Soft Tissue Lesions (ed 8). London, Bailliere Tindall, 1982

immobilization (Table 2-16).[49] A noncapsular pattern of restriction is a limitation in a joint in any pattern other than a capsular one, and may indicate the presence of either a derangement, a restriction of one part of the joint capsule, or an extra-articular lesion, that obstructs joint motion.[49]

Joint Integrity and Mobility

The small motion available at joint surfaces is referred to as *accessory* or *arthrokinematic motion*. A variety of measurement scales have been proposed for judging the amount of accessory joint motion present between two joint surfaces, most of which are based on a comparison with a comparable contralateral joint using manually applied forces in a logical and precise manner.[57] Using these techniques to assess the joint glide, the PT can describe joint motion as hypomobile (restricted), normal (unrestricted but not excessive), or hypermobile (excessive).

Passive accessory mobility tests assess the accessory motions of a joint. The joint glides are tested in the loose (open) pack position of a peripheral joint (see Chapter 6) and at the end of available range in the spinal joints to avoid soft tissue tension affecting the results. The information gathered from these tests will help the PT determine the integrity of the inert structures.

Muscle Strength

Strength measures the power with which musculotendinous units act across a bone–joint lever-arm system to actively generate motion or passively resist movement against gravity and variable resistance.[58]

> **Key Point** A measure of a person's strength is really a measurement of an individual's torque production (see Chapter 4). Specific joint positions are used when performing manual muscle testing because force production is highly dependent on muscular length and joint angle.

A number of methods can be used to measure strength including dynamometry, isokinetics, and cable tensiometry. The *Guide to Physical Therapist Practice* lists both manual muscle testing (MMT) and dynamometry as appropriate measures of muscle strength.

- Manual muscle testing evaluates the function and strength of individual muscles and muscle groups based on the effective performance of a movement in relation to the forces of gravity and manual resistance.
- Dynamometry is a method of strength testing using sophisticated strength measuring devices (e.g., hand-grip, hand-held, fixed, isokinetic dynamometry).

Manual Muscle Testing

Manual muscle testing (MMT) is traditionally used by the clinician to assess the strength of a muscle or muscle group. MMT is designed to assess a muscle or muscle group's ability to isometrically resist the force applied by the clinician. When performing strength testing, a particular muscle or muscle group is first isolated, and then an external force is applied. Resistance applied at the end of the tested range is termed a *break test*. This method is best used solely as a screening tool. Resistance applied throughout the range is termed a *make test*. The results of the strength testing differ depending on the method used. The isometric hold (break test) shows the muscle to have a higher test grade than the resistance given throughout the range (make test).

Whichever testing method is used, resistance should be applied and released gradually to give the patient sufficient time to offer resistance. Following the manual muscle test, the muscle tested is said to be "weak" or "strong" based upon the muscle's ability to resist the externally applied force over time. If a position other than the standard position is used, it must be documented.

Interpretation of Manual Muscle Testing Results

A number of grading scales have been devised to assess muscle strength (**Table 2-17**).[59,60] Each system specifies patient testing position, clinician positioning to maximize patient stabilization and minimize substitution of agonist muscles, the force vector for clinician resistance, and a corresponding grading scheme describing the clinician's results (**Table 2-18**).[61] In the Medical Research Council scale, the grades of 0, 1, and 2 are tested in the gravity-minimized position (contraction is perpendicular to the gravitational force). All other grades are tested in the antigravity position. The Daniels and Worthingham grading system is considered by some as the most functional of the three grading systems outlined in Table 2-17 because it tests a motion that utilizes all of the agonists and synergists involved in the motion.[62] The Kendall and McCreary approach is designed to test a specific muscle rather than the motion, and it requires both selective recruitment of a muscle by the patient and a sound knowledge of anatomy and kinesiology on the part of the clinician to determine the correct alignment of the muscle fibers.[62]

> **Key Point** Choosing a particular grading system is based on the skill level of the clinician while ensuring consistency for each patient, so that coworkers who may be re-examining the patient are using the same testing methods.
>
> To confirm a finding, another muscle that shares the same innervation (spinal nerve or peripheral nerve) is tested. Knowledge of both spinal nerve and peripheral nerve innervation will aid the clinician in determining which muscle to select.

All of the grading systems for manual muscle testing produce ordinal data with unequal rankings between grades, and all are innately subjective

TABLE 2-17 Comparison of MMT Grades

Medical Research Council	Daniels and Worthingham	Kendall and McCreary	Explanation
5	Normal (N)	100%	Holds test position against maximal resistance
4+	Good + (G+)		Holds test position against moderate to strong pressure
4	Good (G)	80%	Holds test position against moderate resistance
4–	Good – (G–)		Holds test position against slight to moderate pressure
3+	Fair + (F+)		Holds test position against slight resistance
3	Fair (F)	50%	Holds test position against gravity
3–	Fair– (F–)		Gradual release from test position
2+	Poor + (P+)		Moves through partial ROM against gravity *or* Moves through complete ROM gravity eliminated and holds against pressure
2	Poor (P)	20%	Able to move through full ROM gravity eliminated
2–	Poor – (P–)		Moves through partial ROM gravity eliminated
1	Trace (T)	5%	No visible movement; palpable or observable tendon prominence/flicker contraction
0	0	0%	No palpable or observable muscle contraction

Data from Frese E, Brown M, Norton B: Clinical reliability of manual muscle testing: Middle trapezius and gluteus medius muscles. Phys Ther 67:1072–1076, 1987; Daniels K, Worthingham C: Muscle Testing Techniques of Manual Examination (ed 5). Philadelphia, WB Saunders, 1986; and Kendall FP, McCreary EK, Provance PG: Muscles: Testing and Function. Baltimore, Williams & Wilkins, 1993

TABLE 2-18 Manual Muscle Testing Procedure

Explanation	It is important that the clinician provides instructions to the patient. For example, the following statements may be used: "I'm going to test the strength of one of the muscles that bends your elbow." "This is the movement pattern I want you to do. Do it first on your uninvolved side."
Patient positioning	The patient and the part to be tested should be positioned comfortably on a firm surface in the correct testing position. The correct testing position ensures that the muscle fibers to be tested are correctly aligned. The patient is properly draped so that the involved body part is exposed as necessary.
Stabilization	Stabilization, which helps to prevent substitute movements can be provided manually or through the use of an external support such as a belt. The stabilization is applied to the proximal segment using counterpressure to the resistance.
Active range of motion	The patient moves through the test movement actively against gravity. (If using the Daniels and Worthingham grading system, the clinician passively moves the patient's joint through the test movement.) The clinician palpates the muscle for activity and also notes any adaptive shortening (slight to moderate loss of motion), substitutions or trick movements (weakness or instability), or contractures (marked loss of motion). The joint is then returned to the start position. If the patient is unable to perform the muscle action against gravity, the patient is positioned in the gravity-minimized position.

(*continued*)

TABLE 2-18 Manual Muscle Testing Procedure (continued)

Test	The test should be completed on the uninvolved side first to ascertain normal strength before being repeated on the involved side. The patient is instructed to complete the test movement again and then hold the segment in the desired position. The clinician alerts the patient that resistance will be applied and then applies resistance in the appropriate direction and in a smooth and gradual fashion. The proper location for the application of resistance is as far distal as possible from the axis of movement on the moving segment without crossing another joint. Resistance should never cross an intervening joint unless the integrity of the joint has been assessed as normal. The resistance is applied in a direction opposite the muscle's rotary component and at right angles to the long axis of the segment (opposite the line of the pull of the muscle fibers). The test is repeated three times and the muscle strength grade is determined. Fatigue with three repetitions may be suggestive of nerve root compression.

because they rely on the subject's ability to exert the maximal contraction.

Key Point The primary tenet of manual muscle testing is that each muscle should be tested just proximal to the next distal joint of the muscle's insertion and that the clinician must place the subject in positions that will isolate, as much as possible, the specific muscle or muscles being examined and eliminate substitution of agonist muscles.[61]

To be a valid test, strength testing must elicit a maximum contraction of the muscle being tested. Four strategies ensure this:

1. *Placing the muscle to be tested in a shortened position.* This puts the muscle in an ineffective physiologic position, and has the effect of increasing motor neuron activity.
2. *Having the patient perform an eccentric muscle contraction by using the command "Don't let me move you."* The tension at each cross-bridge and the number of active cross-bridges is greater during an eccentric contraction, so the maximum eccentric muscle tension developed is greater with an eccentric contraction than with a concentric one.
3. *Breaking the contraction.* It is important to break the patient's muscle contraction in order to ensure that the patient is making a maximal effort and that the full power of the muscle is being tested.
4. *Holding the contraction for at least 5 seconds.* Weakness due to nerve palsy has a distinct fatigability. The muscle demonstrates poor endurance because it is usually able to sustain a maximum muscle contraction for only about 2–3 seconds before complete failure occurs. This is based on the theories behind muscle recruitment wherein a normal muscle performing a maximum contraction uses only a portion of its motor units, keeping the remainder in reserve to help maintain the contraction. A palsied muscle with its fewer functioning motor units has very few, if any, in reserve. If a muscle appears to be weaker than normal, further investigation is required. The test is repeated three times. Muscle weakness resulting from disuse will be consistently weak and should not get weaker with several repeated contractions.

Key Point Multiple studies have shown good intertester and intratester reliability with manual muscle testing and a high degree of exact consistency to within one grade using some form of the Medicine Research Council's grading sequence (0–5).[61]

Substitutions by other muscle groups during testing indicate the presence of weakness. They do not, however, tell the clinician the cause of the weakness.

Key Point From a functional perspective, wherever possible, strength testing by the clinician should assess the function of a muscle. If a power muscle is assessed, its ability to produce power should be assessed. In contrast, an endurance muscle should be tested for its ability to sustain a contraction for a prolonged period, such as that which occurs with sustained postures.

Whenever possible, the same muscle is tested on the opposite side, using the same testing procedure, as a comparison is made.

Key Point Remember that the grades obtained with MMT are largely subjective and depend on a number of factors including the effect of gravity, the manual force used by the clinician, the patient's age, the extent of the injury, and cognitive and emotional factors of both patient and clinician.[63–66]

Dynamometry

A handheld dynamometer (HHD) is a precision measurement instrument designed to obtain more discrete, objective measures of strength during MMT than can be achieved via traditional MMT. A prerequisite for quality MMT measures, and likewise HHD measures, is adequate force-generating capacity by the testers performing the measurements. When subject strength is clearly beyond a tester's capability to control, use of an HHD does not appear to be indicated. This issue is often encountered when attempting to measure plantar flexion. Aside from limitations regarding mechanical advantage and strength when using an HHD, there is also the issue of patient comfort as a potential limitation. Even though the HHD is padded, it does not and cannot conform to a given body part like a tester's hand, and a common subject complaint is tenderness over the dynamometer placement site.

Key Point The handheld devices used in dynamometry can help quantify the "breaking force" necessary to depress a limb held in a specific position by the patient.

Clinical Relevance of Strength Testing

According to Cyriax, pain with a contraction generally indicates an injury to the muscle or a capsular structure.[49] The PT confirms this by combining the findings from the isometric test with the findings of the passive motion and the joint distraction and compression. In addition to examining the integrity of the contractile and inert structures, strength testing may also be used to examine the integrity of the myotomes. A myotome is a muscle or group of muscles served by a single nerve root. *Key muscle* is a better, more accurate term, because the muscles tested are the most representative of the supply from a particular segment. Cyriax reasoned that if you isolate and then apply tension to a structure, you could make a conclusion as to the integrity of that structure.[49] His work also introduced the concept of tissue reactivity, which is the manner in which different stresses and movements can alter the clinical signs and symptoms. This knowledge can be used to gauge any subtle changes to the patient's condition.[67]

Pain that occurs consistently with resistance, at whatever the length of the muscle, may indicate a tear of the muscle belly. Pain with muscle testing may indicate a muscle injury, a joint injury, or a combination of both.

Pain that does not occur during the contraction, but occurs upon the release of the contraction, is thought to have an articular source, produced by the joint glide that occurs following the release of tension.

Key Point The degree of significance with the findings in resisted testing depends on the position of the muscle and the force applied. For example, pain reproduced with a minimal contraction in the rest position for the muscle is more strongly suggestive of a contractile lesion than pain reproduced with a maximal contraction in the lengthened position for the muscle.

Summary

Numerous types of tissue exist throughout the body, each having specific functional capabilities; for example, upon studying the structure and function of joints, one can see that some joints are designed for mobility (e.g., glenohumeral), whereas other joints are designed for stability (e.g., elbow). Although these characteristics are helped by joint design, other factors such as ligamentous and muscular support play a role. The various types of connective tissue that are contained in fascia, tendons, ligaments, bone, and muscle give each of these structures unique characteristics based on the function they must perform. In physical therapy, injury to any of the musculoskeletal structures must be diagnosed and treated. The physical therapy diagnosis is based on an assessment that includes range of motion measurements, measurement of joint and ligament integrity, and the measurement of muscle performance.

REVIEW Questions

1. True or false: Connective tissue (CT) is found throughout the body and serves to provide structural and metabolic support for other tissues and organs of the body.
2. What are the three types of cartilage and bone tissue?
3. True or false: Fascia is an example of dense regular connective tissue.

4. True or false: A bursa is a synovial membrane–lined sac.
5. All of the following functions are true of the living skeleton except:
   a. It supports the surrounding tissues.
   b. It assists in body movement.
   c. It provides a storage area for mineral salts.
   d. It determines the individual's developing somatotype.
6. What is the type of cartilage found in synovial joints called?
7. Approximately how many bones are in the human body?
8. True or false: Hyaline and elastic cartilage has no nerve supply whereas fibrocartilage is well innervated.
9. What is the shaft of a long bone called?
10. Which area of the bone is responsible for increasing the bone length during growth?
11. What are the three types of muscle tissue?
12. Which structure separates each muscle fiber from its neighbor?
13. Which type of muscle fiber is activated during moderate-intensity, long-duration exercise?
14. What is the function of a tendon?
15. True or false: Bone is a highly vascular form of connective tissue.
16. Give four functions of bone.
17. The smallest organized unit of the contractile mechanism of skeletal muscle is the:
   a. Myofilaments
   b. Actin
   c. Myosin
   d. Sarcomere
18. All of the following are true about the epiphyseal plate except:
   a. It is formed from cartilage.
   b. It serves as the site of progressive lengthening in long bones.
   c. It is located between the epiphysis and the diaphysis.
   d. It is found in all bones.
19. Hyaline cartilage is nourished through the:
   a. Vessels from the periosteum
   b. Haversian canals
   c. Joint fluid
   d. Nutrient arteries
20. The epiphysis of a bone is located:
   a. Directly adjacent to the periosteum
   b. Directly above the diaphysis
   c. Directly below the metaphysis
   d. Directly adjacent to the joint
21. The biceps is an elbow flexor. Which of the following are considered antagonists to the biceps?
   a. Brachioradialis
   b. Supinator
   c. Triceps
   d. Supraspinatus
22. A patient who is substituting with the sartorius muscle during testing of the iliopsoas muscle for a grade 3 (fair) muscle test would demonstrate:
   a. External rotation and abduction of the hip
   b. Internal rotation and abduction of the hip
   c. Flexion of the hip and extension of the knee
   d. Extension of the hip and knee
23. Manual muscle testing of a grade 4/5 (good) strength lower trapezius muscle (for scapular depression and adduction) should be conducted with the patient prone and shoulder positioned in:
   a. 145 degrees of abduction, the forearm in neutral with the thumb pointing at the ceiling
   b. 180 degrees of abduction and fully externally rotated
   c. 90 degrees of abduction, elbow flexed to 90 degrees, and the forearm in neutral with the thumb pointing inward
   d. Neutral at the side and the shoulder and forearm internally rotated with the thumb pointing inward
24. The stationary arm of a goniometer is placed in line with the lateral midline of the trunk, the fulcrum is placed at the greater trochanter, and the movable arm is aligned with the lateral femoral condyle. What motion is being measured?
   a. Hip flexion
   b. Hip abduction
   c. Trunk lateral flexion
   d. Trunk extension
25. When assessing joint range of motion for ankle dorsiflexion and plantarflexion, the preferred goniometric technique is to align the stationary arm parallel to the midline:
   a. Of the fibula and the moving arm parallel to the fifth metatarsal, keeping the patient's knee somewhat flexed
   b. Of the fibula and the moving arm parallel to the fifth metatarsal, keeping the knee stabilized and fully extended

c. Of the tibia and the moving arm parallel to the first metatarsal, keeping the knee somewhat flexed

d. Of the tibia and the moving arm parallel to the first metatarsal, keeping the knee stabilized and fully extended

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