Selected Key Terms

The following terms and other boldface terms in the chapter are defined in the Glossary

acetylcholine
actin
antagonist
bursitis
fascicle
glycogen
insertion
lactic acid
motor unit
myalgia
myoglobin
myosin
neuromuscular junction
neurotransmitter
origin
oxygen debt
prime mover
spasm
synapse
synergist
tendon
tonus

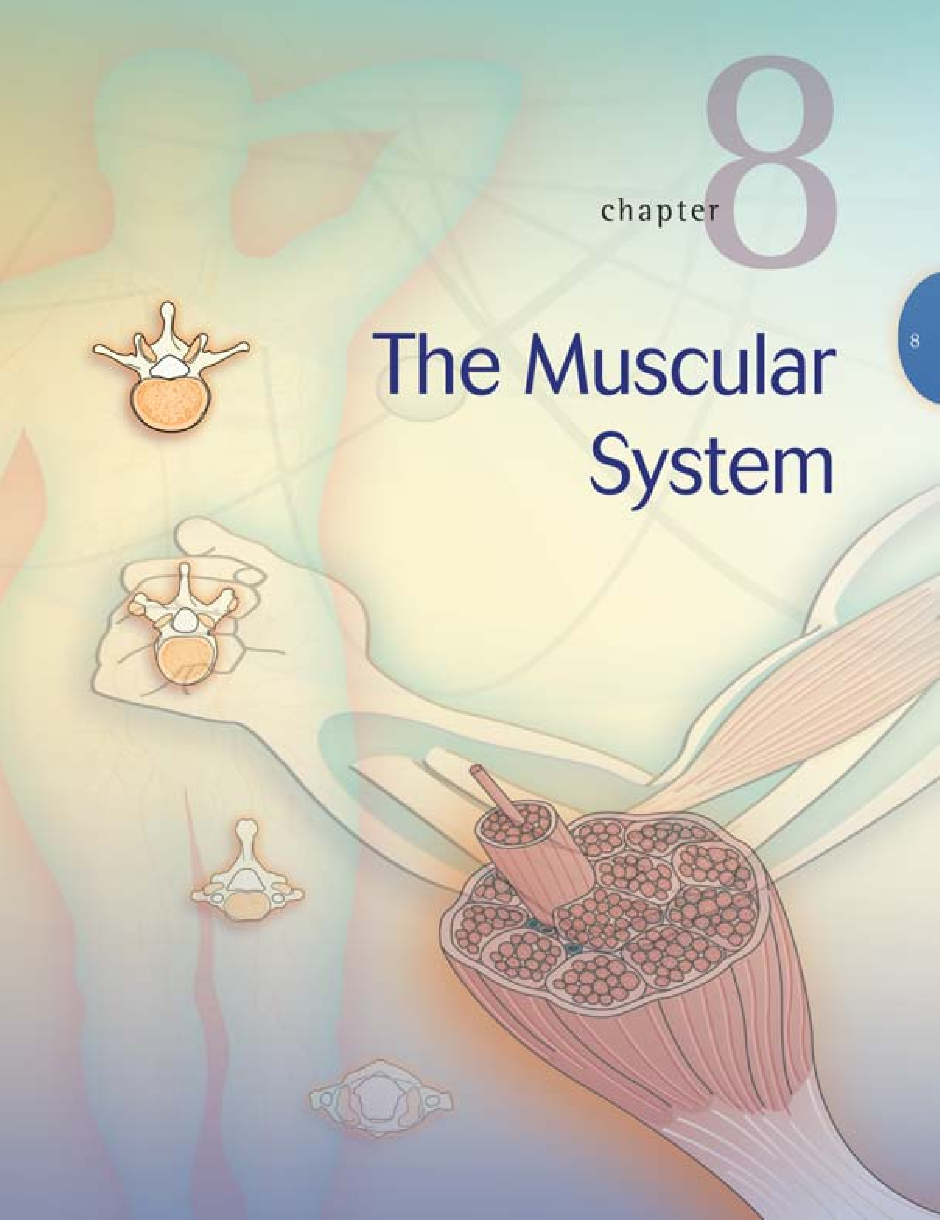
Learning Outcomes

After careful study of this chapter, you should be able to:

1. Compare the three types of muscle tissue
2. Describe three functions of skeletal muscle
3. Briefly describe how skeletal muscles contract
4. List the substances needed in muscle contraction and describe the function of each
5. Define the term oxygen debt
6. Describe three compounds stored in muscle that are used to generate energy in highly active muscle cells
7. Cite the effects of exercise on muscles
8. Compare isotonic and isometric contractions
9. Explain how muscles work in pairs to produce movement
10. Compare the workings of muscles and bones to lever systems
11. Explain how muscles are named
12. Name some of the major muscles in each muscle group and describe the main function of each
13. Describe how muscles change with age
14. List the major muscular disorders
15. Show how word parts are used to build words related to the muscular system (see Word Anatomy at the end of the chapter)

chapter 8

The Muscular System



Types of Muscle

There are three kinds of muscle tissue: smooth, cardiac, and skeletal muscle, as introduced in Chapter 4. After a brief description of all three types (Table 8-1), this chapter concentrates on skeletal muscle, which has been studied the most.

Smooth Muscle

Smooth muscle makes up the walls of the hollow body organs as well as those of the blood vessels and respiratory passageways. It moves involuntarily and produces the wavelike motions of peristalsis that move substances through a system. Smooth muscle can also regulate the diameter of an opening, such as the central opening of blood vessels, or produce contractions of hollow organs, such as the uterus. Smooth muscle fibers (cells) are tapered at each end and have a single, central nucleus. The cells appear smooth under the microscope because they do not contain the visible bands, or **striations**, that are seen in the other types of muscle cells. Smooth muscle may contract in response to a nerve impulse, hormonal stimulation, stretching, and other stimuli. The muscle contracts and relaxes slowly and can remain contracted for a long time.

Cardiac Muscle

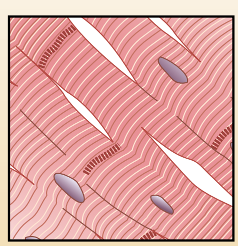
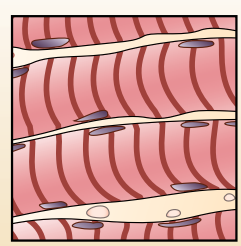
Cardiac muscle, also involuntary, makes up the wall of the heart and creates the pulsing action of that organ. The cells of cardiac muscle are striated, like those of skeletal muscle. They differ in having one nucleus per cell and branching interconnections. The membranes between the cells are specialized to allow electrical impulses to travel rapidly through them, so that contractions can be better coordinated. These membranes appear as dark lines between the cells (see Table 8-1) and are called intercalated (in-TER-kah-la-ted) disks, because they are "inserted between" the cells. The electrical impulses that produce contractions of cardiac muscle are generated within the muscle itself but can be modified by nervous stimuli and hormones.

Skeletal Muscle

When viewed under the microscope, skeletal muscle cells appear heavily striated. The arrangement of protein threads within the cell that produces these striations is described later. The cells are very long and cylindrical and have multiple nuclei per cell. During development, the nuclei of these cells divide repeatedly by mitosis without division of the cell contents, resulting in a large, multinucleated cell. Such cells can contract as a large unit when stimulated. The nervous system stimulates skeletal muscle to contract, and the tissue usually contracts and relaxes rapidly. Because it is under conscious control, skeletal muscle is described as voluntary.

Skeletal muscle is so named because most of these muscles are attached to bones and produce movement at the joints. There are a few exceptions. The muscles of the abdominal wall, for example, are partly attached to other muscles, and the muscles of facial expression are attached to the

Table 8•1 Comparison of the Different Types of Muscle

	SMOOTH	CARDIAC	SKELETAL
Location	Wall of hollow organs, vessels, respiratory passageways	Wall of heart	Attached to bones
Cell characteristics	Tapered at each end, branching networks, nonstriated	Branching networks; special membranes (intercalated disks) between cells; single nucleus; lightly striated	Long and cylindrical; multinucleated; heavily striated
			
Control	Involuntary	Involuntary	Voluntary
Action	Produces peristalsis; contracts and relaxes slowly; may sustain contraction	Pumps blood out of heart; self-excitatory but influenced by nervous system and hormones	Produces movement at joints; stimulated by nervous system; contracts and relaxes rapidly

skin. Skeletal muscles constitute the largest amount of the body's muscle tissue, making up about 40% of the total body weight. This muscular system is composed of more than 600 individual skeletal muscles. Although each one is a distinct structure, muscles usually act in groups to execute body movements.

Checkpoint 8-1 What are the three types of muscle?

Table 8•2 Connective Tissue Layers in Skeletal Muscle

NAME OF LAYER	LOCATION
Endomysium	Around each individual muscle fiber
Perimysium	Around fascicles (bundles) of muscle fibers
Epimysium	Around entire muscle; forms the innermost layer of the deep fascia.

The Muscular System

The three primary functions of skeletal muscles are:

- Movement of the skeleton. Muscles are attached to bones and contract to change the position of the bones at a joint.
- Maintenance of posture. A steady partial contraction of muscle, known as **muscle tone**, keeps the body in position. Some of the muscles involved in maintaining posture are the large muscles of the thighs, back, neck, and shoulders as well as the abdominal muscles.
- Generation of heat. Muscles generate most of the heat needed to keep the body at 37°C (98.6°F). Heat is a natural byproduct of muscle cell metabolism. When we are cold, muscles can boost their heat output by the rapid small contractions we know of as shivering.

Checkpoint 8-2 What are the three main functions of skeletal muscle?

Structure of a Muscle

In forming whole muscles, individual muscle fibers are arranged in bundles, or **fascicles** (FAS-ih-kls), held together by fibrous connective tissue (Fig. 8-1, Table 8-2). The deepest layer of this connective tissue, the **endomysium** (en-do-MIS-e-um) surrounds the individual fibers in the fascicles. Around each fascicle is a connective tissue layer known as the **perimysium** (per-ih-MIS-e-um). The entire muscle is then encased in a tough connective tissue sheath, the **epimysium** (ep-ih-MIS-e-um), which forms the innermost layer of the **deep fascia**, the tough, fibrous sheath that encloses a muscle. (Note that all these layers are named with prefixes that describe their position added to the root *my/o,* meaning "muscle.") All of these supporting tissues merge to form the **tendon**, the band of connective tissue that attaches a muscle to a bone (see Fig. 8-1).

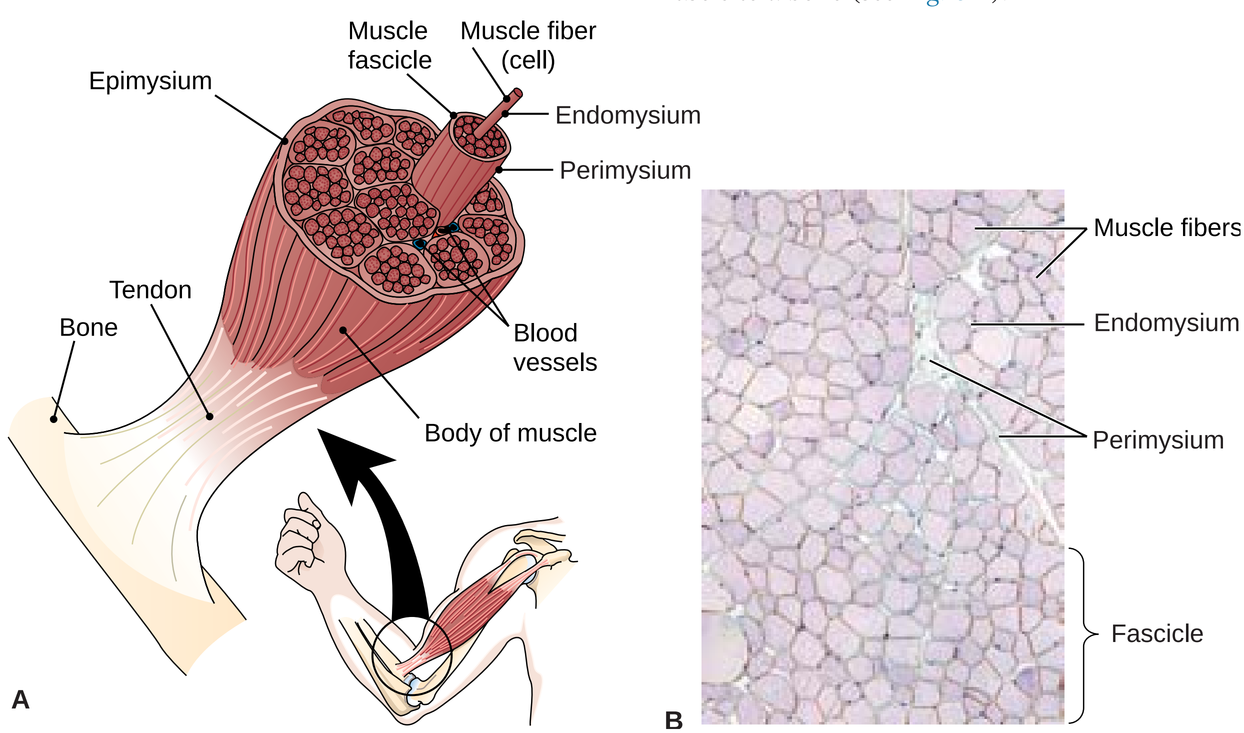


Figure 8-1 Structure of a skeletal muscle. (A) Structure of a muscle showing the tendon that attaches it to a bone. **(B)** Muscle tissue seen under a microscope. Portions of several fascicles are shown with connective tissue coverings. (B, Reprinted with permission from Gartner LP, Hiatt JL. Color Atlas of Histology. 3rd ed. Philadelphia: Lippincott Williams & Wilkins, 2000.) ***ZOOMING IN ✦ What is the innermost layer of connective tissue in a muscle? What layer of connective tissue surrounds a fascicle of muscle fibers?***

Muscle Cells in Action

Nerve impulses coming from the brain and the spinal cord stimulate skeletal muscle fibers (see Chapter 9). Because these impulses are traveling away from the central nervous system (CNS), they are described as **motor** impulses (as contrasted to sensory impulses traveling toward the CNS), and the neurons (nerve cells) that carry these impulses are described as motor neurons. As the neuron contacts the muscle, its axon (fiber) branches to supply from a few to hundreds of individual muscle cells, or in some cases more than 1000 (Fig. 8-2).

A single neuron and all the muscle fibers it stimulates comprise a **motor unit**. Small motor units are used in fine coordination, as in movements of the eye. Larger motor units are used for maintaining posture or for broad movements, such as walking or swinging a tennis racquet.

The Neuromuscular Junction The point at which a nerve fiber contacts a muscle cell is called the **neuromuscular junction** (NMJ) (Fig. 8-3). It is here that a chemical classified as a **neurotransmitter** is released from the neuron to stimulate the muscle fiber. The specific neurotransmitter released here is **acetylcholine** (as-e-til-KO-lene), abbreviated ACh, which is found elsewhere in the body as well. A great deal is known about the events that occur at this junction, and this information is important in understanding muscle action.

The neuromuscular junction is an example of a **synapse** (SIN-aps), a point of communication between cells. Between the cells there is a tiny space, the **synaptic cleft**, across which the neurotransmitter must travel. Until its release, the neurotransmitter is stored in tiny membranous sacs, called vesicles, in the endings of the nerve fiber. Once released, the neurotransmitter crosses the synaptic cleft and attaches to receptors, which are proteins embedded in the muscle cell membrane. The membrane forms multiple folds at this point that increase surface area and hold a maximum number of receptors. The receiving membrane of the muscle cell is known as the **motor end plate**.

Muscle fibers, like nerve cells, show the property of **excitability;** that is, they are able to transmit electrical current along the plasma membrane. When the muscle is stimulated at the neuromuscular junction, an electrical impulse is generated that spreads rapidly along the muscle cell membrane. This spreading wave of electrical current is called the **action potential** because it calls the muscle cell into action. Chapter 9 provides more information on synapses and the action potential.

Figure 8-2 **Nervous stimulation of skeletal muscle.** A motor axon branches to stimulate multiple muscle fibers (cells). The point of contact between the neuron and the muscle cell is the neuromuscular junction. (Reprinted with permission from Cormack DH. Essential Histology. 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2001.)

> **Checkpoint 8-3** Muscles are activated by the nervous system. What is the name of the special synapse where a nerve cell makes contact with a muscle cell?

> **Checkpoint 8-4** What neurotransmitter is involved in the stimulation of skeletal muscle cells?

Contraction Another important property of muscle tissue is **contractility**. This is the capacity of a muscle fiber to undergo shortening and to change its shape, becoming thicker. Studies of muscle chemistry and observation of cells under the powerful electron microscope have given a concept of how muscle cells work.

These studies reveal that each skeletal muscle fiber contains many threads, or filaments, made of two kinds of proteins, called **actin** (AK-tin) and **myosin** (MI-o-sin). Filaments made of actin are thin and light; those made of myosin are thick and dark. The filaments are present in alternating bundles within the muscle cell (Fig. 8-4). It is the alternating bands of light actin and heavy myosin filaments that give skeletal muscle its striated appearance. They also give a view of what occurs when muscles contract.

Note that the actin and myosin filaments overlap where they meet, just as your fingers overlap when you fold your hands together. A contracting subunit of skeletal muscle is called a **sarcomere** (SAR-ko-mere). It consists of a band of myosin filaments and the actin filaments on each side of them (see Fig. 8-4). In movement, the myosin filaments "latch on" to the actin filaments in their overlapping region by means of many paddlelike extensions called myosin heads. In this way, the myosin heads form attachments between the actin and myosin filaments that are described as cross-bridges. Using the energy of ATP for repeated movements, the myosin heads, like the oars of a boat moving water, pull all the actin strands closer together within each sarcomere. As the overlapping filaments slide together, the

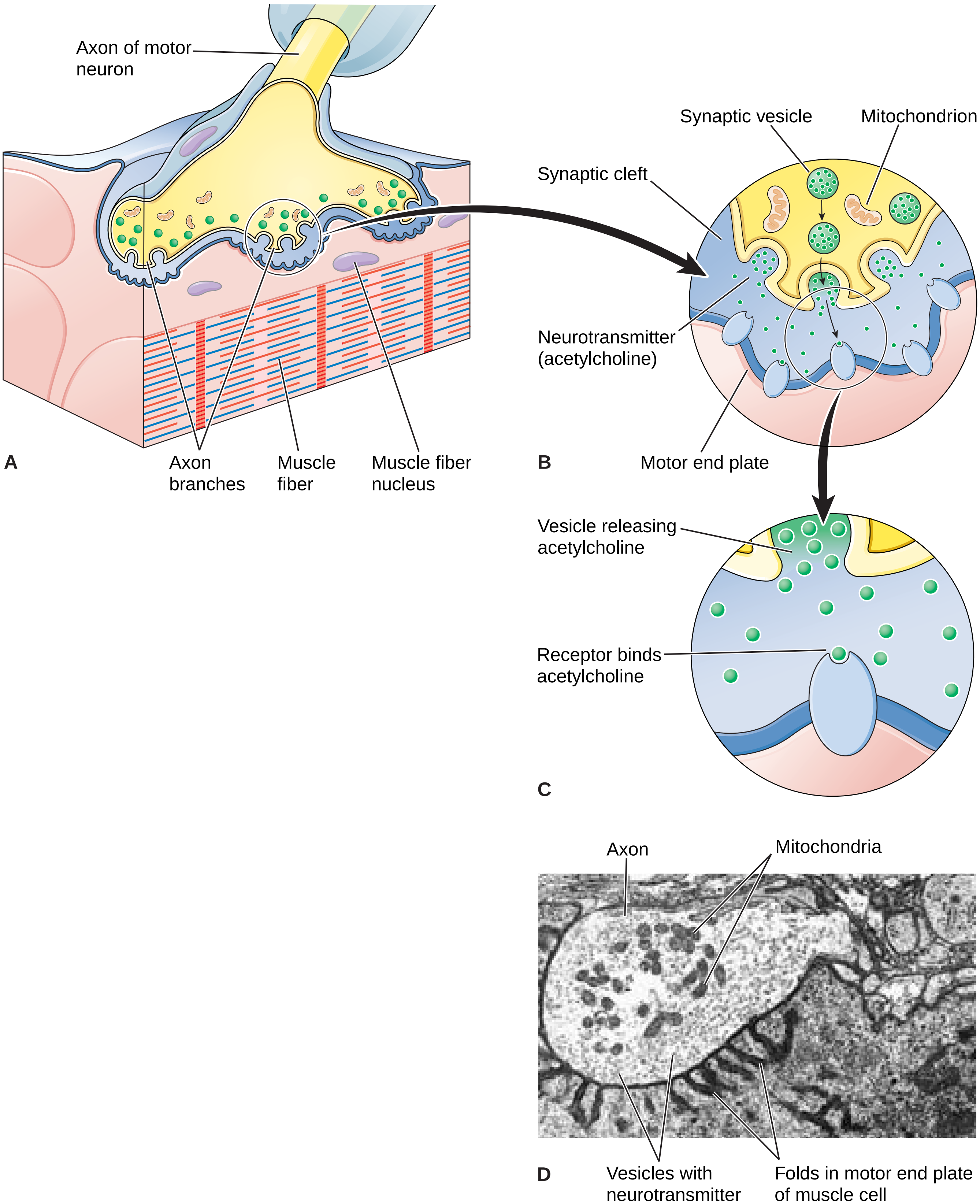


Figure 8-3 **Neuromuscular junction (NMJ). (A)** The branched end of a motor neuron makes contact with the membrane of a muscle fiber (cell). **(B)** Enlarged view of the NMJ showing release of neurotransmitter (acetylcholine) into the synaptic cleft. **(C)** Acetylcholine attaches to receptors in the motor end plate, whose folds increase surface area. **(D)** Electron microscope photograph of the neuromuscular junction. (D, Courtesy of A. Sima.)

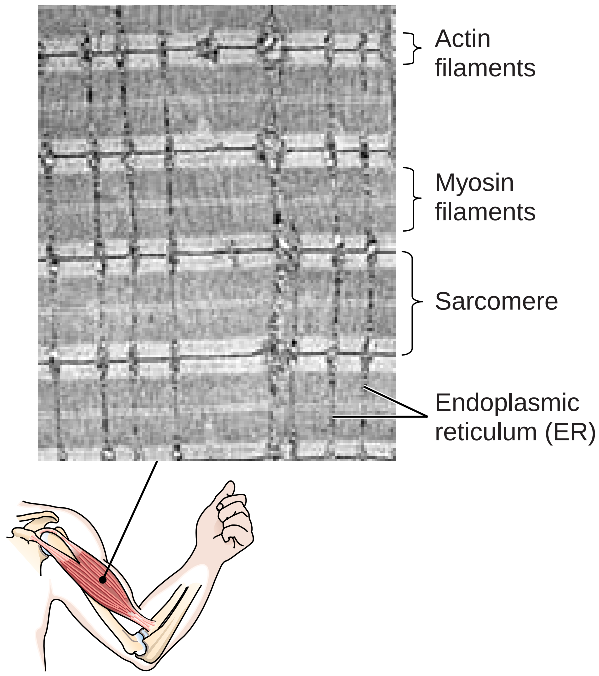


Figure 8-4 Electron microscope photograph of skeletal muscle cell (×6500). Actin makes up the light band and myosin makes up the dark band. The dark line in the actin band marks points where actin filaments are held together. A sarcomere is a contracting subunit of skeletal muscle. (Photomicrograph reprinted with permission from Ross MH, Kaye GI, Pawlina W. Histology. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2003.)

muscle fiber contracts, becoming shorter and thicker. Figure 8-5 shows a section of muscle as it contracts. Once the cross-bridges form, the myosin heads move the actin filaments forward, then they detach and move back to position for another "power stroke." Note that the filaments overlap increasingly as the cell contracts. (In reality, not all the myosin heads are moving at the same time. About one half are forward at any time, and the rest are preparing for another swing.) During contraction, each sarcomere becomes shorter, but the individual filaments do not change in length. As in shuffling a deck of cards, as you push the cards together, the deck becomes smaller, but the cards do not change in length.

Checkpoint 8-5 What are two properties of muscle cells that are needed for response to a stimulus?

Checkpoint 8-6 What are the filaments that interact to produce muscle contraction?

The Role of Calcium In additional to actin, myosin, and ATP, calcium is needed for muscle contraction. It enables cross-bridges to form between actin and myosin so the sliding filament action can begin. When muscles are at rest, two additional proteins called **troponin** (tro-PO-nin) and **tropomyosin** (tro-po-MI-o-sin) block the sites on actin filaments where cross-bridges can form

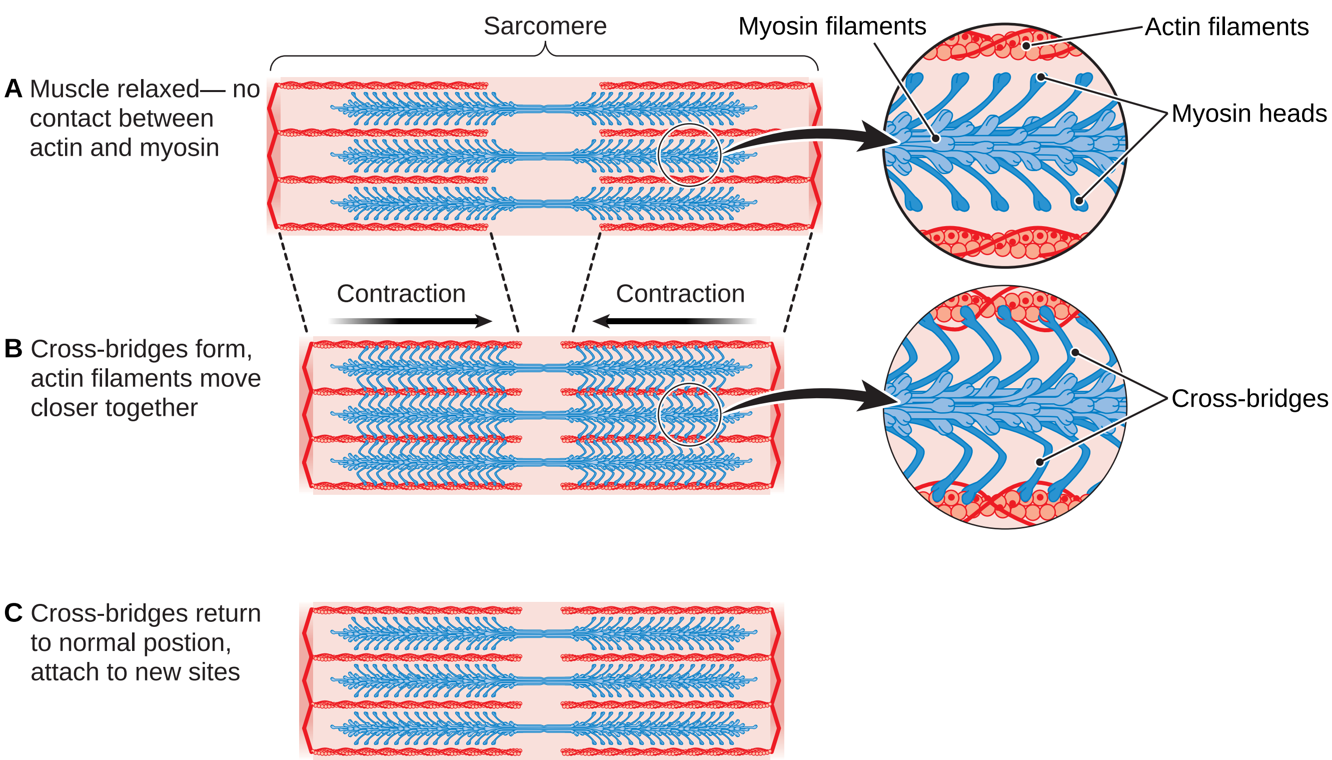


Figure 8-5 Sliding filament mechanism of skeletal muscle contraction. (A) Muscle is relaxed and there is no contact between the actin and myosin filaments. **(B)** Cross-bridges form and the actin filaments are moved closer together as the muscle fiber contracts. **(C)** The cross-bridges return to their original position and attach to new sites to prepare for another pull on the actin filaments and further contraction. *ZOOMING IN ✦ Do the actin or myosin filaments change in length as contraction proceeds?*

(Fig. 8-6). When calcium attaches to these proteins, they move aside, uncovering the binding sites. In resting muscles, the calcium is not available because it is stored within the endoplasmic reticulum (ER) of the muscle cell. It is released into the cytoplasm only when the cell is stimulated by a nerve fiber. Muscles relax when nervous stimulation stops and the calcium is then pumped back into the ER, ready for the next contraction.

A summary of the events in a muscle contraction is as follows:

1. Acetylcholine (ACh) is released from a neuron ending into the synaptic cleft at the neuromuscular junction
2. ACh binds to the motor end plate of the muscle and produces an action potential
3. The action potential travels to the endoplasmic reticulum (ER)
4. The endoplasmic reticulum releases calcium into the cytoplasm
5. Calcium shifts troponin and tropomyosin so that binding sites on actin are exposed
6. Myosin heads bind to actin, forming cross-bridges
7. Myosin heads pull actin filaments together within the sarcomeres and cell shortens
8. ATP is used to detach myosin heads and move them back to position for another "power stroke"
9. Muscle relaxes when stimulation ends and the calcium is pumped back into the ER

Box 8-1, Muscle Contraction and Energy, has additional details on skeletal muscle contraction.

Energy Sources

As noted earlier, all muscle contraction requires energy in the form of ATP. The source of this energy is the oxidation (commonly called "burning") of nutrients within the cells.

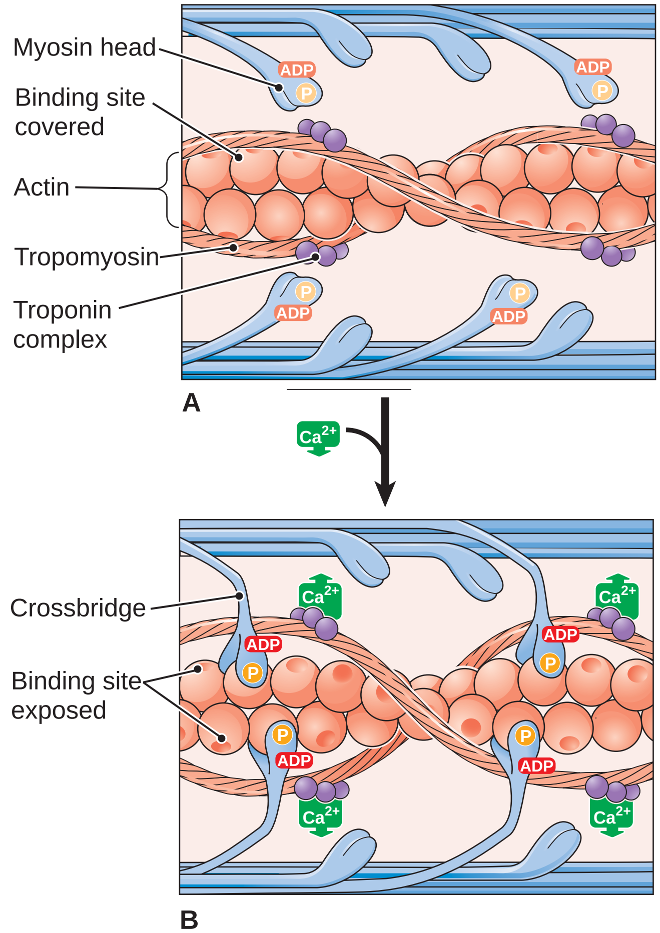


Figure 8-6 Role of calcium in muscle contraction. (A) Troponin and tropomyosin cover the binding sites where cross-bridges can form between actin and myosin. **(B)** Calcium shifts troponin and tropomyosin away from binding sites so cross-bridges can form.

Box 8-1 A Closer Look

Muscle Contraction and Energy

When we think of muscle contraction, we might imagine a runner's rippling muscles. But muscle contraction actually occurs at a microscopic level within the sarcomere's working parts: the thick and thin filaments.

Thick filaments are composed of many myosin molecules, each shaped like two golf clubs twisted together with the myosin heads projecting away from the sarcomere's center (see Fig. 8-6). Each myosin head can bind ATP and convert it into ADP and a phosphate molecule, which remain bound. The chemical energy released during this reaction charges the myosin head, enabling it to do work.

Thin filaments' actin molecules are twisted together like two strands of beads. Each "bead" has a myosin-binding site, but the two regulatory proteins, troponin and tropomyosin, cover the binding sites when the muscle is at rest. When calcium shifts these proteins away from the binding sites, the following cycle of events occurs:

1. The charged myosin heads attach to the actin molecules and form cross-bridges between the thick and thin filaments.
2. Using their stored energy, the myosin heads pull the thin filaments to the center of the sarcomere, releasing the ADP and phosphate molecules.
3. New ATP molecules bind to the myosin heads, causing them to detach from actin and breaking the cross-bridges.
4. The myosin heads convert ATP into ADP and phosphate, which recharges them.

After death, muscles enter a stage of rigidity known as rigor mortis. This phenomenon illustrates ATP's crucial role in muscle contraction. Shortly after death, muscle cells begin to degrade. Calcium escapes into the cytoplasm, and the muscle filaments slide together. Metabolism has ceased, however, and there is no ATP to disengage the filaments, so they remain locked in a contracted state. Rigor mortis lasts about 24 hours, gradually fading as enzymes break down the muscle filaments.

To produce ATP, muscle cells must have an adequate supply of oxygen and glucose or other usable nutrient. The circulating blood constantly brings these substances to the cells, but muscle cells also store a small reserve supply of each to be used when needed, during vigorous exercise, for example. The following are compounds that store oxygen, energy, or nutrients in muscle cells:

- **Myoglobin** (mi-o-GLO-bin) stores additional oxygen. This compound is similar to the blood's hemoglobin but is located specifically in muscle cells, as indicated by the prefix *myo-* in its name.
- **Glycogen** (GLI-ko-jen) stores additional glucose. It is a polysaccharide made of multiple glucose molecules and it can be broken down into glucose when needed by the muscle cells.
- **Creatine** (KRE-ah-tin) **phosphate** stores energy. It is a compound similar to ATP, in that it has a high energy bond that releases energy when it is broken. This energy is used to make ATP for muscle contraction when the muscle cell has used up its ATP.

Checkpoint 8-7 What mineral is needed to allow actin and myosin to interact?

Checkpoint 8-8 Muscle cells obtain energy for contraction from the oxidation of nutrients. What compound is formed in oxidation that supplies the energy for contraction?

Oxygen Consumption During most activities of daily life, the tissues receive adequate oxygen, and muscles can function aerobically. During strenuous activity, however, a person may not be able to breathe in oxygen rapidly enough to meet the needs of the hard-working muscles. At first, the myoglobin, glycogen, and creatine phosphate stored in the tissues meet the increased demands, but continual exercise depletes these stores.

For a short time, glucose may be used anaerobically, that is, without the benefit of oxygen. This anaerobic process generates ATP rapidly and permits greater magnitude of activity than would otherwise be possible, as, for example, allowing sprinting instead of jogging. However, anaerobic metabolism is inefficient; it does not produce as much ATP as does metabolism in the presence of oxygen. Also, an organic acid called **lactic acid** accumulates in the cells when this alternate pathway of metabolism is used. Anaerobic metabolism can continue only until the buildup of lactic acid causes the muscles to fatigue.

Muscles operating anaerobically are in a state of **oxygen debt**. After stopping exercise, a person must continue to take in extra oxygen by continued rapid breathing (panting) until the debt is paid in full. That is, enough oxygen must be taken in to convert the lactic acid to other substances that can be metabolized further. In addition, the glycogen, myoglobin, and creatine phosphate that are stored in the cells must be replenished. The time after strenuous exercise during which extra oxygen is needed is known as the period of recovery oxygen consumption.

Checkpoint 8-9 When muscles work without oxygen, a compound is produced that causes muscle fatigue. What is the name of this compound?

Effects of Exercise

Regular exercise results in a number of changes in muscle tissue. These changes correspond to the three components of exercise: stretching, aerobics, and resistance training. When muscles are stretched, they contract more forcefully, as the internal filaments can interact over a greater length. Stretching also helps with balance and promotes flexibility at the joints. Aerobic exercise, that is, exercise that increases oxygen consumption, such as running, biking, or swimming, leads to improved endurance. Resistance training, such as weight lifting, causes muscle cells to increase in size, a condition known as hypertrophy (hi-PER-tro-fe). This change can be seen in the enlarged muscles of body-builders. Some of the changes in muscle tissue that lead to improved endurance and strength include:

- Increase in the number of capillaries in the muscle tissue, which brings more blood to the cells
- Increase in the number of mitochondria to increase production of ATP
- Increase in reserves of myoglobin, glycogen, and creatine phosphate to promote endurance

An exercise program should include all three methods—stretching, aerobic exercise, and resistance training—with periods of warm-up and cool-down before and after working out. This type of varied program is described as cross-training or interval training.

In addition to affecting muscle tissue itself, exercise causes some systemic changes. The **vasodilation** (vas-o-di-LA-shun), or widening of blood vessel diameter, that occurs during exercise allows blood to flow more easily to muscle tissue. With continued work, more blood is pumped back to the heart. The temporarily increased load on the heart strengthens the heart muscle and improves its circulation. With exercise training, the chambers of the heart gradually enlarge to accommodate more blood. The resting heart rate of a trained athlete is lower than the average rate because the heart can function more efficiently.

Regular exercise also improves breathing and respiratory efficiency. Circulation in the capillaries surrounding the alveoli (air sacs) is increased, and this brings about enhanced gas exchange. The more efficient distribution and use of oxygen delays the onset of oxygen debt. Even moderate regular exercise has the additional benefits of weight control, strengthening of the bones, decreased blood pressure, and decreased risk of heart attacks. The effects of exercise on the body are studied in the fields of

Box 8-2 **Hot Topics**

Anabolic Steroids: Winning at All Costs?

Anabolic steroids mimic the effects of the male sex hormone testosterone by promoting metabolism and stimulating growth. These drugs are legally prescribed to promote muscle regeneration and prevent atrophy from disuse after surgery. However, athletes also purchase them illegally, using them to increase muscle size and strength and improve endurance.

When steroids are used illegally to enhance athletic performance, the doses needed are large enough to cause serious side effects. They increase blood cholesterol levels, which may lead to atherosclerosis, heart disease, kidney failure, and stroke. Steroids damage the liver, making it more susceptible to disease and cancer, and suppress the immune system, increasing the risk of infection and cancer. In men, steroids cause impotence, testicular atrophy, low sperm count, infertility, and the development of female sex characteristics such as breasts (gynecomastia). In women, steroids disrupt ovulation and menstruation and produce male sex characteristics such as breast atrophy, enlargement of the clitoris, increased body hair, and deepening of the voice. In both sexes steroids increase the risk for baldness and, especially in men, cause mood swings, depression, and violence.

sports medicine and exercise physiology. Box 8-2, Anabolic Steroids: Winning at all Costs?, has information on how steroids affect muscles.

Types of Muscle Contractions

Muscle **tone** refers to a partially contracted state of the muscles that is normal even when the muscles are not in use. The maintenance of this tone, or **tonus** (TO-nus), is due to the action of the nervous system in keeping the muscles in a constant state of readiness for action. Muscles that are little used soon become flabby, weak, and lacking in tone.

In addition to the partial contractions that are responsible for muscle tone, there are two other types of contractions on which the body depends:

- **Isotonic** (i-so-TON-ik) **contractions** are those in which the tone or tension within the muscle remains the same but the muscle as a whole shortens, producing movement; that is, work is accomplished. Lifting weights, walking, running, or any other activity in which the muscles become shorter and thicker (forming bulges) are isotonic contractions.
- **Isometric** (i-so-MET-rik) **contractions** are those in which there is no change in muscle length but there is a great increase in muscle tension. Pushing against an immovable force produces an isometric contraction. For example, if you push the palms of your hands hard against each other, there is no movement, but you can feel the increased tension in your arm muscles.

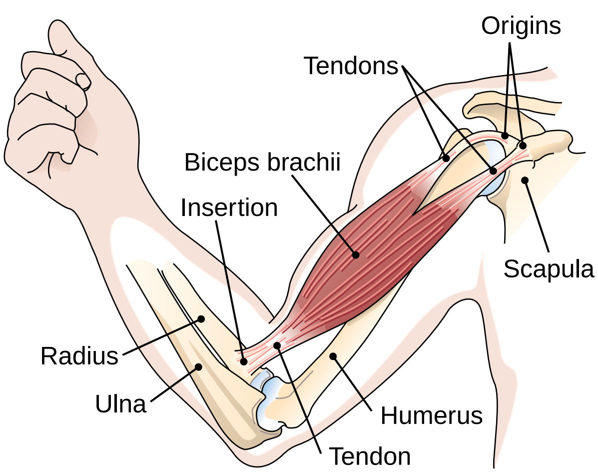


Figure 8-7 Muscle attachments to bones. Three attachments are shown—two origins and one insertion. *ZOOMING IN ✦ Does contraction of the biceps brachii produce flexion or extension at the elbow?*

Most movements of the body involve a combination of both isotonic and isometric contractions. When walking, for example, some muscles contract isotonically to propel the body forward, but at the same time, other muscles are contracting isometrically to keep your body in position.

The Mechanics of Muscle Movement

Most muscles have two or more points of attachment to the skeleton. The muscle is attached to a bone at each end by means of a cordlike extension called a **tendon** (Fig. 8-7). All of the connective tissue within and around the muscle merges to form the tendon, which then attaches directly to the periosteum of the bone (see Fig. 8-1). In some instances, a broad sheet called an **aponeurosis** (ap-o-nu-RO-sis) may attach muscles to bones or to other muscles.

In moving the bones, one end of a muscle is attached to a more freely movable part of the skeleton, and the other end is attached to a relatively stable part. The less movable (more fixed) attachment is called the **origin**; the attachment to the part of the body that the muscle puts into action is called the **insertion.** When a muscle contracts, it pulls on both points of attachment, bringing the more movable insertion closer to the origin and thereby causing movement of the body part. Figure 8-7 shows the action of the biceps brachii (in the upper arm) in flexing the arm at the elbow. The insertion on the radius of the forearm is brought toward the origin at the scapula of the shoulder girdle.

Checkpoint 8-10 Muscles are attached to bones by means of tendons: one attached to a less movable part of the skeleton, and one attached to a movable part. What are the names of these two attachment points?

Muscles Work Together

Many of the skeletal muscles function in pairs. A movement is performed by a muscle called the **prime mover;** the muscle that produces an opposite movement to that of the prime mover is known as the **antagonist.** Clearly, for any given movement, the antagonist must relax when the prime mover contracts. For example, when the biceps brachii at the front of the arm contracts to flex the arm, the triceps brachii at the back must relax; when the triceps brachii contracts to extend the arm, the biceps brachii must relax. In addition to prime movers and antagonists, there are also muscles that serve to steady body parts or to assist prime movers. These "helping" muscles are called **synergists** (SIN-er-jists), because they work with the prime movers to accomplish a movement.

As the muscles work together, body movements are coordinated, and a large number of complicated movements can be carried out. At first, however, the nervous system must learn to coordinate any new, complicated movement. Think of a child learning to walk or to write, and consider the number of muscles she or he uses unnecessarily or forgets to use when the situation calls for them.

Checkpoint 8-11 Muscles work together to produce movement. What is the name of the muscle that produces a movement as compared with the muscle that produces an opposite movement?

Levers and Body Mechanics

Proper body mechanics help conserve energy and ensure freedom from strain and fatigue; conversely, such ailments as lower back pain—a common complaint—can be traced to poor body mechanics. Body mechanics have special significance to healthcare workers, who are frequently called on to move patients and handle cumbersome equipment. Maintaining the body segments in correct relation to one another has a direct effect on the working capacity of the vital organs that are supported by the skeleton.

If you have had a course in physics, recall your study of levers. A lever is simply a rigid bar that moves about a fixed pivot point, the fulcrum. There are three classes of levers, which differ only in the location of the fulcrum (F), the effort (E), or force, and the resistance (R), the weight or load. In a first-class lever, the fulcrum is located between the resistance and the effort; a see-saw or a scissors is an example of this class (Fig. 8-8). The second-class lever has the resistance located between the fulcrum and the effort; a wheelbarrow or a mattress lifted at one end is an illustration of this class (Fig. 8-8 B). In the third-class lever, the effort is between the resistance and the fulcrum. A forceps or a tweezers is an example of this type of lever. The effort is applied in the center of the tool, between the fulcrum, where the pieces join, and the resistance at the tip.

The musculoskeletal system can be considered a system of levers, in which the bone is the lever, the joint is the fulcrum, and the force is applied by a muscle. An example of a first-class lever in the body is using the muscles at the back of the neck to lift the head at the joint between the occipital bone of the skull and the first cervical vertebra (atlas) (see Fig. 8-8). A second-class lever is exemplified by raising your weight to the ball of your foot (the fulcrum) using muscles of the calf.

However, there are very few examples of first- and second-class levers in the body. Most lever systems in the body are of the third-class type. A muscle usually inserts over a joint and exerts force between the fulcrum and the resistance. That is, the fulcrum is behind both the point of effort and the weight. As shown in Figure 8-8 C, when the biceps brachii flexes the forearm at the elbow, the muscle exerts its force at its insertion on the radius. The weight of the hand and forearm creates the resistance, and the fulcrum is the elbow joint, which is behind the point of effort.

By understanding and applying knowledge of levers to body mechanics, the healthcare worker can improve his or her skill in carrying out numerous clinical maneuvers and procedures.

Checkpoint 8-12 Muscles and bones work together as lever systems. Of the three classes of levers, which one represents the action of most muscles?

Skeletal Muscle Groups

The study of muscles is made simpler by grouping them according to body regions. Knowing how muscles are named can also help in remembering them. A number of different characteristics are used in naming muscles, including the following:

- Location, named for a nearby bone, for example, or for position, such as lateral, medial, internal, or external
- Size, using terms such as maximus, major, minor, longus, brevis
- Shape, such as circular (orbicularis), triangular (deltoid), trapezoid (trapezius)
- Direction of fibers, including straight (rectus) or angled (oblique)
- Number of heads (attachment points) as indicated by the suffix *-ceps*, as in biceps, triceps, quadriceps
- Action, as in flexor, extensor, adductor, abductor, levator

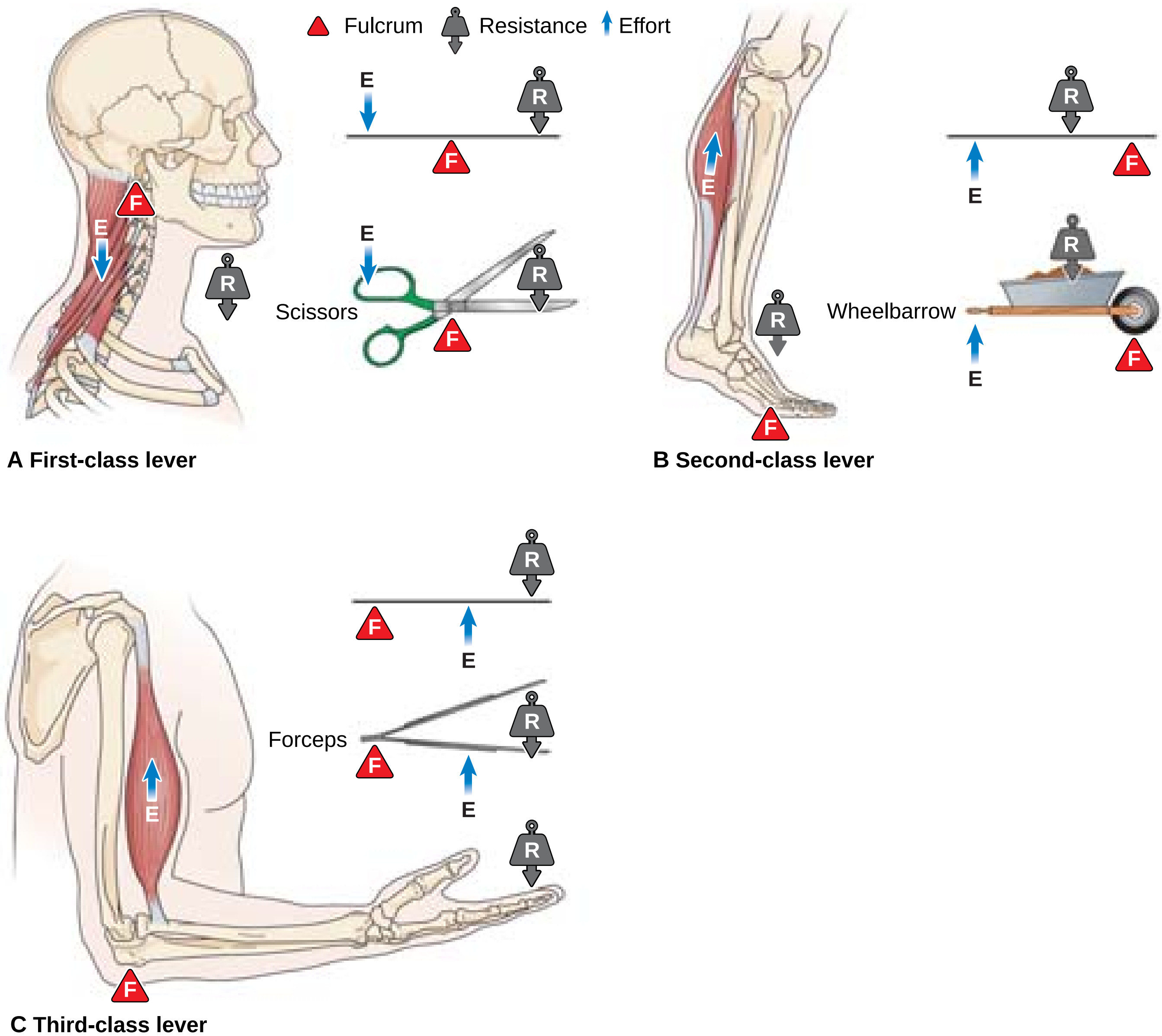


Figure 8-8 **Levers.** Three classes of levers are shown along with tools and anatomic examples that illustrate each type. R = resistance (weight); E = effort (force); F = fulcrum (pivot point).

Often, more than one feature is used in naming. Refer to Figures 8-9 and 8-10 as you study the locations and functions of some of the skeletal muscles and try to figure out why each has the name that it does. Although they are described in the singular, most of the muscles are present on both sides of the body.

Muscles of the Head

The principal muscles of the head are those of facial expression and of mastication (chewing) (Fig. 8-11, Table 8-3).

The muscles of facial expression include ring-shaped ones around the eyes and the lips, called the **orbicularis** (or-bik-u-LAH-ris) **muscles** because of their shape (think of "orbit"). The muscle surrounding each eye is called the **orbicularis oculi** (OK-u-li), whereas the muscle of the lips is the **orbicularis oris.** These muscles, of course, all have antagonists. For example, the **levator palpebrae** (PAL-pe-bre) **superioris**, or lifter of the upper eyelid, is the antagonist for the orbicularis oculi.

One of the largest muscles of expression forms the fleshy part of the cheek and is called the **buccinator** (BUK-se-na-tor). Used in whistling or blowing, it is sometimes referred to as the trumpeter's muscle. You can readily think of other muscles of facial expression: for instance, the antagonists of the orbicularis oris can produce a smile, a sneer, or a grimace. There are a number of scalp muscles by means of which the eyebrows are lifted or drawn together into a frown.

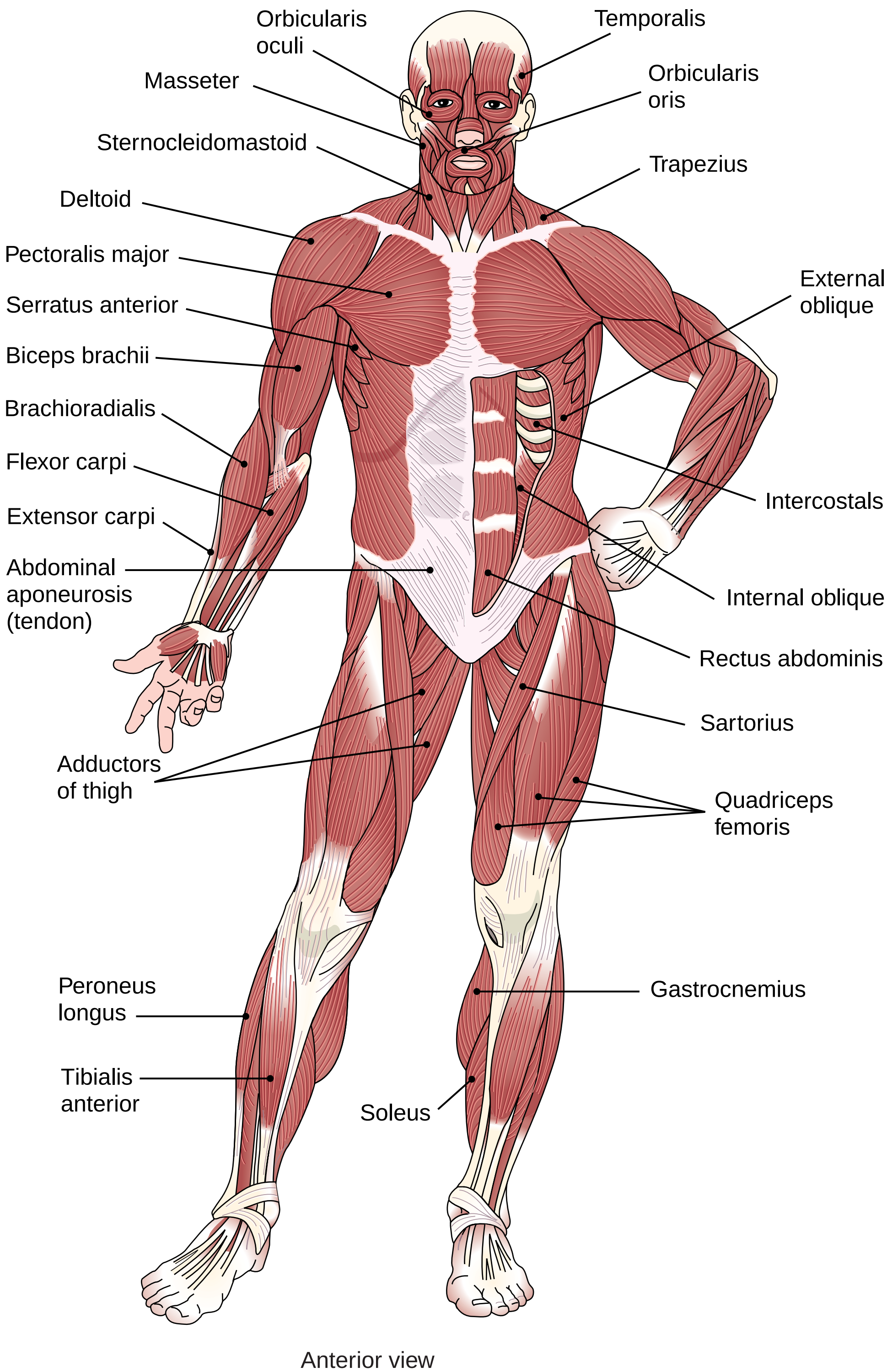


Figure 8-9 **Superficial muscles, anterior view.** Associated structure is labeled in parentheses.

There are four pairs of muscles of mastication, all of which insert on and move the mandible. The largest are the **temporalis** (TEM-po-ral-is), which is superior to the ear, and the **masseter** (mas-SE-ter) at the angle of the jaw.

The tongue has two groups of muscles. The first group, called the **intrinsic muscles**, is located entirely within the tongue. The second group, the **extrinsic muscles**, originates outside the tongue. It is because of these many muscles that the tongue has such remarkable flexibility and can perform so many different functions. Consider the intricate tongue motions involved in speaking, chewing, and swallowing.

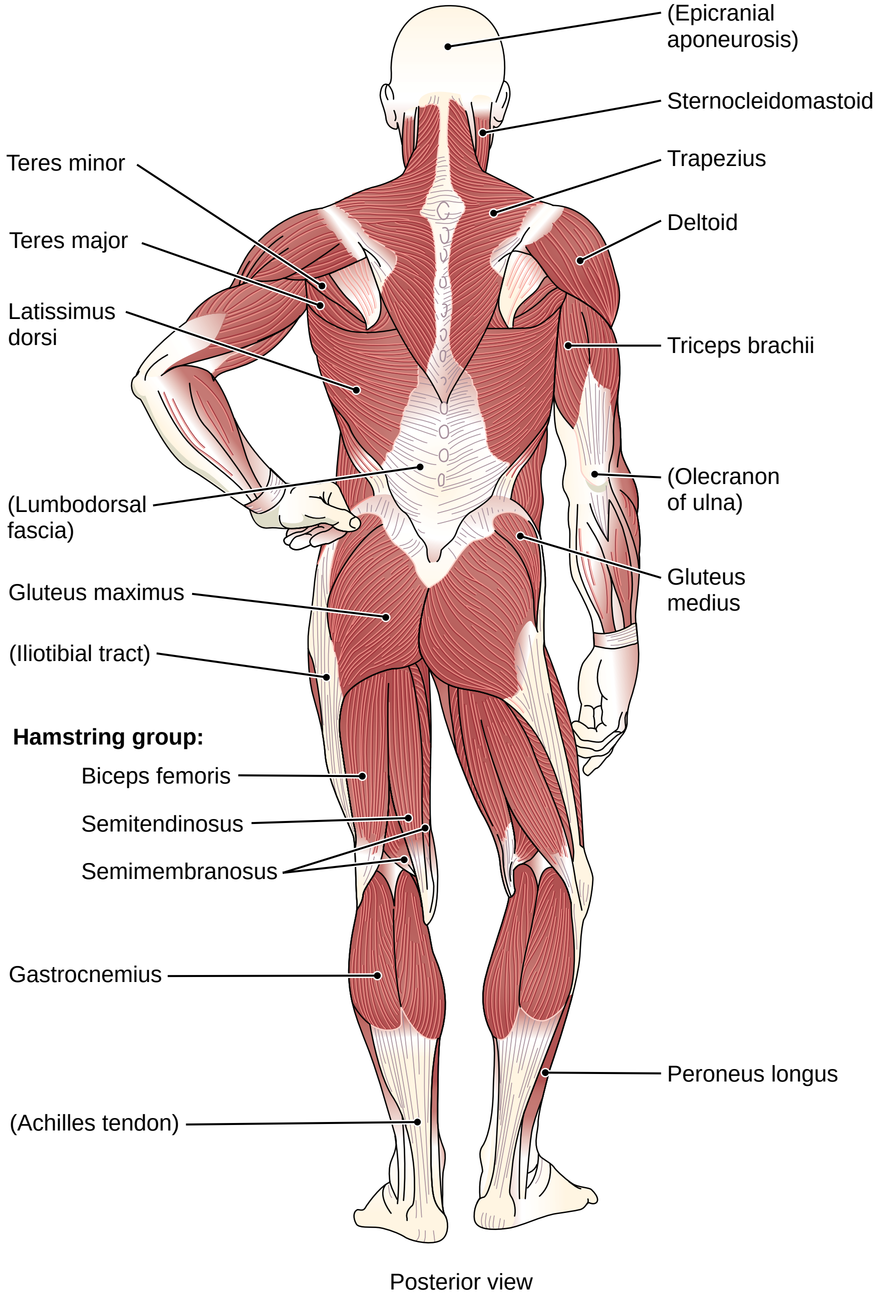


Figure 8-10 **Superficial muscles, posterior view.** Associated structures are labeled in parentheses.

Figure 8-11 shows some additional muscles of the face.

Muscles of the Neck

The neck muscles tend to be ribbonlike and extend up and down or obliquely in several layers and in a complex manner (Fig. 8-11, Table 8-3). The one you will hear of most frequently is the **sternocleidomastoid** (ster-no-kli-do-MAS-toyd), sometimes referred to simply as the sternomastoid. This strong muscle extends superiorly from the sternum across the side of the neck to the mastoid process. When the left and right muscles work together, they bring the head forward on the chest (flexion). Working alone, each muscle tilts and rotates the head so as to orient the face toward the side opposite that muscle. If the head is abnormally fixed in this position, the person is said to have **torticollis** (tor-tih-KOL-is), or wryneck; this condition may be due to injury or spasm of the muscle.

A portion of the trapezius muscle (described later) is located at the posterior of the neck, where it helps hold the head up (extension). Other larger deep muscles are the chief extensors of the head and neck.

Muscles of the Upper Extremities

Muscles of the upper extremities include the muscles that determine the position of the shoulder, the anterior and posterior muscles that move the arm, and the muscles that move the forearm and hand.

Muscles That Move the Shoulder and Arm The position of the shoulder depends to a large extent on the degree of contraction of the **trapezius** (trah-PE-ze-us), a triangular muscle that covers the posterior neck and extends across the posterior shoulder to insert on the clavicle and scapula (Fig. 8-10, Table 8-4). The trapezius muscles enable one to raise the shoulders and pull them back. The upper portion of each trapezius can also extend the head and turn it from side to side.

The **latissimus** (lah-TIS-ih-mus) **dorsi** is the wide muscle of the back and lateral trunk. It originates from the vertebral spine in the middle and lower back and covers the lower half of the thoracic region, forming the posterior portion of the axilla (armpit). The fibers of each muscle converge to a tendon that inserts on the humerus. The latissimus dorsi powerfully extends the arm, bringing it down forcibly as, for example, in swimming.

A large **pectoralis** (pek-to-RAL-is) **major** is located on either side of the superior part of the chest (see Fig. 8-9). This muscle arises from the sternum, the upper ribs, and the clavicle and forms the anterior "wall" of the armpit, or axilla; it inserts on the superior part of the humerus. The pectoralis major flexes and adducts the arm, pulling it across the chest.

The **serratus** (ser-RA-tus) **anterior** is below the axilla, on the lateral part of the chest. It originates on the upper eight or nine ribs on the lateral and anterior thorax and inserts in the scapula on the side toward the vertebrae. The serratus anterior moves the scapula forward when, for example, one is pushing something. It also aids in raising the arm above the horizontal level.

The **deltoid** covers the shoulder joint and is responsible for the roundness of the upper part of the arm just inferior to the shoulder (see Figs. 8-9 and 8-10). This muscle is named for its triangular shape, which resembles the Greek letter delta. The deltoid is often used as an injection site. Arising from the shoulder girdle (clavicle and scapula), the deltoid fibers converge to insert on the lateral surface of the humerus. Contraction of this muscle abducts the arm, raising it laterally to the horizontal position.

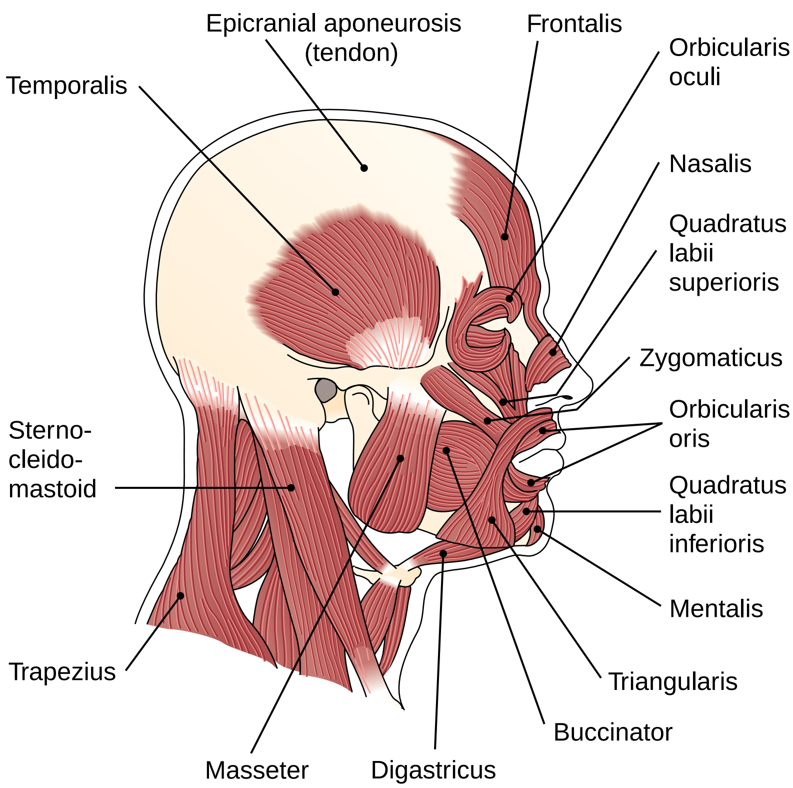


Figure 8-11 **Muscles of the head**. Associated structure is labeled in parentheses. *ZOOMING IN ✦ Which of the muscles in this illustration is named for a bone it is near?*

Table 8•3 Muscles of the Head and Neck*

NAME	LOCATION	FUNCTION
Orbicularis oculi	Encircles eyelid	Closes eye
Levator palpebrae superioris (deep muscle; not shown)	Back of orbit to upper eyelid	Opens eye
Orbicularis oris	Encircles mouth	Closes lips
Buccinator	Fleshy part of cheek	Flattens cheek; helps in eating, whistling, and blowing wind instruments
Temporalis	Above and near ear	Closes jaw
Masseter	At angle of jaw	Closes jaw
Sternocleidomastoid	Along side of neck, to mastoid process	Flexes head; rotates head toward opposite side from muscle

These and other muscles of the face are shown in Fig. 8–11.

Table 8•4 Muscles of the Upper Extremities*

NAME	LOCATION	FUNCTION
Trapezius	Posterior of neck and upper back, to clavicle and scapula	Raises shoulder and pulls it back; extends head
Latissimus dorsi	Middle and lower back, to humerus	Extends and adducts arm behind back
Pectoralis major	Superior, anterior chest, to humerus	Flexes and adducts arm across chest; pulls shoulder forward and downward
Serratus anterior	Below axilla on lateral chest to scapula	Moves scapula forward; aids in raising arm, punching, or reaching forward
Deltoid	Covers shoulder joint, to lateral humerus	Abducts arm
Biceps brachii	Anterior arm along humerus, to radius	Flexes forearm at the elbow and supinates hand
Brachioradialis	Lateral forearm from distal end of humerus to distal end of radius	Flexes forearm at the elbow
Triceps brachii	Posterior arm, to ulna	Extends forearm to straighten upper extremity
Flexor carpi groups	Anterior forearm, to hand	Flex hand
Extensor carpi groups	Posterior forearm, to hand	Extend hand
Flexor digitorum groups	Anterior forearm, to fingers	Flex fingers
Extensor digitorum groups	Posterior forearm, to fingers	Extend fingers

**These and other muscles of the upper extremities are shown in Figs. 8–9, 8–10, and 8–12.*

The shoulder joint allows for a very wide range of movement. This freedom of movement is possible because the humerus fits into a shallow socket, the glenoid cavity of the scapula. This joint requires the support of four deep muscles and their tendons, which compose the **rotator cuff**. The four muscles are the **s**upraspinatus, **i**nfraspinatus, **t**eres minor, and **s**ubscapularis, known together as SITS, based on the first letters of their names. In certain activities, such as swinging a golf club, playing tennis, or pitching a baseball, the muscles of the rotator cuff may be injured, even torn, and may require surgery for repair.

Muscles That Move the Forearm and Hand The **biceps brachii** (BRA-ke-i), located at the anterior arm along the humerus, is the muscle you usually display when you want to "flex your muscles" to show your strength (Fig. 8-12 A). It inserts on the radius and flexes the forearm. It is a supinator of the hand.

Another flexor of the forearm at the elbow is the **brachioradialis** (bra-ke-o-ra-de-A-lis), a prominent muscle of the forearm that originates at the distal end of the humerus and inserts on the distal radius.

The **triceps brachii**, located on the posterior of the arm, inserts on the olecranon of the ulna (Fig. 8-12 B). It is used to straighten the arm, as in lowering a weight from an arm curl. It is also important in pushing because it converts the arm and forearm into a sturdy rod.

Most of the muscles that move the hand and fingers originate from the radius and the ulna (see Fig. 8-12). Some of them insert on the carpal bones of the wrist, whereas others have long tendons that cross the wrist and insert on bones of the hand and the fingers.

The **flexor carpi** and the **extensor carpi muscles** are responsible for many movements of the hand. Muscles that produce finger movements are the several **flexor digitorum** (dij-e-TO-rum) and the **extensor digitorum muscles.** The names of these muscles may include bones they are near, their action, or their length, for example, longus for long and brevis for short.

Special groups of muscles in the fleshy parts of the hand are responsible for the intricate movements that can be performed with the thumb and the fingers. The thumb's freedom of movement has been one of the most useful capacities of humans.

Muscles of the Trunk

The muscles of the trunk include the muscles involved in breathing, the thin muscle layers of the abdomen, and the muscles of the pelvic floor. The following discussion also includes the deep muscles of the back that support and move the vertebral column.

Muscles of Respiration The most important muscle involved in the act of breathing is the **diaphragm.** This dome-shaped muscle forms the partition between the thoracic cavity superiorly and the abdominal cavity inferiorly (Fig. 8-13). When the diaphragm contracts, the central dome-shaped portion is pulled downward, thus enlarging the thoracic cavity from top to bottom.

The **intercostal muscles** are attached to and fill the spaces between the ribs. The external and internal intercostals run at angles in opposite directions. Contraction of the intercostal muscles serves to elevate the ribs, thus enlarging the thoracic cavity from side to side and from anterior to posterior. The mechanics of breathing are described in Chapter 18.

> **Checkpoint 8-13** What muscle is most important in breathing?

Muscles of the Abdomen and Pelvis The wall of the abdomen has three layers of muscle that extend from the back (dorsally) and around the sides (laterally) to the front (ventrally) (Fig. 8-14, Table 8-5). They are the **ex-**

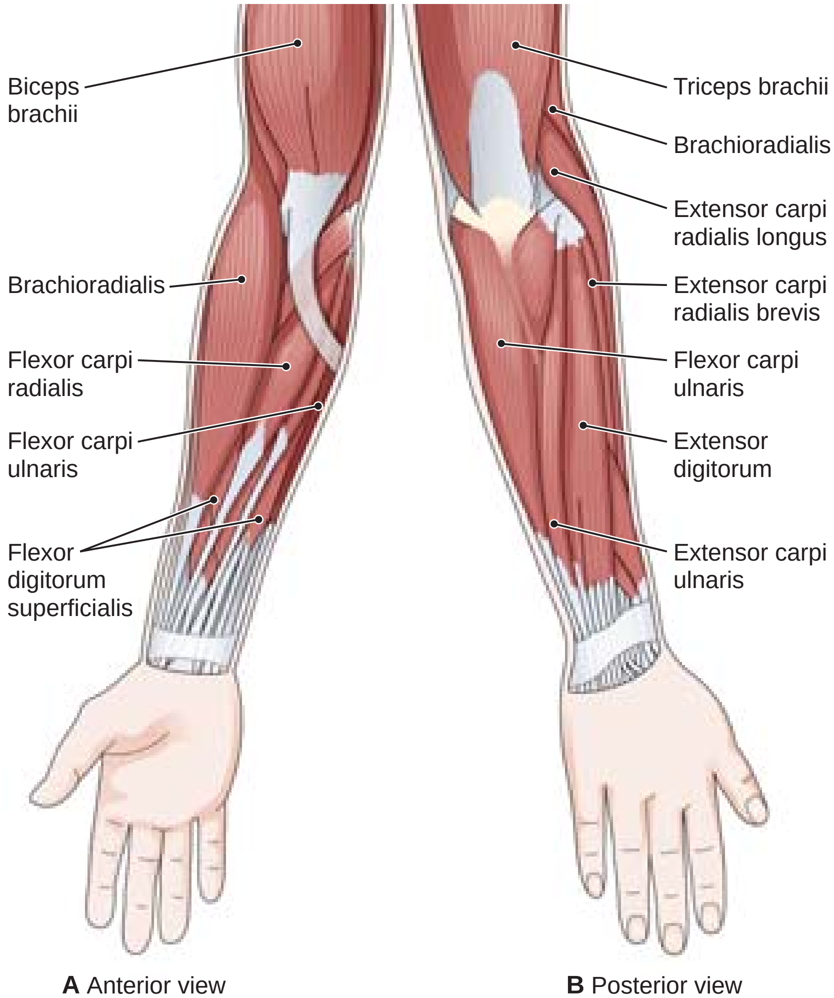


Figure 8-12 **Muscles that move the forearm and hand.**

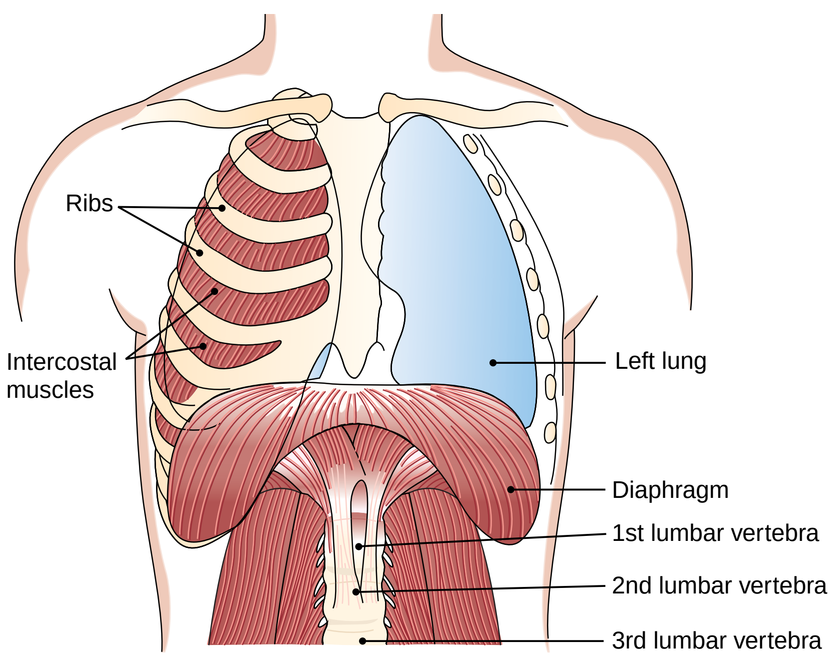


Figure 8-13 **Muscles of respiration.** Associated structures are also shown.

ternal oblique on the outside, the **internal oblique** in the middle, and the **transversus abdominis**, the innermost. The connective tissue from these muscles extends forward and encloses the vertical **rectus abdominis** of the anterior abdominal wall. The fibers of these muscles, as well as their connective tissue extensions (aponeuroses), run in different directions, resembling the layers in plywood and resulting in a strong abdominal wall. The midline meeting of the aponeuroses forms a whitish area called the **linea alba** (LIN-e-ah Al-ba), which is an important landmark on the abdomen. It extends from the tip of the sternum to the pubic joint.

These four pairs of abdominal muscles act together to protect the internal organs and compress the abdominal cavity, as in coughing, emptying the bladder (urination) and bowel (defecation), sneezing, vomiting, and childbirth (labor). The two oblique muscles and the rectus abdominis help bend the trunk forward and sideways.

The pelvic floor, or **perineum** (per-ih-NE-um), has its own form of diaphragm, shaped somewhat like a shallow dish. One of the principal muscles of this pelvic diaphragm is the **levator ani** (le-VA-tor A-ni), which acts on the rectum and thus aids in defecation. The superficial and deep muscles of the female perineum are shown in Figure 8-15 along with some associated structures.

> **Checkpoint 8-14** What structural feature gives strength to the muscles of the abdominal wall?

Deep Muscles of the Back The deep muscles of the back, which act on the vertebral column itself, are thick vertical masses that lie under the trapezius and latissimus dorsi. The **erector spinae** muscles make up a large group located between the sacrum and the skull. These muscles extend the spine and maintain the vertebral column in an erect posture. The muscles can be strained in lifting heavy objects if the spine is flexed while lifting. One should bend at the hip and knee in-

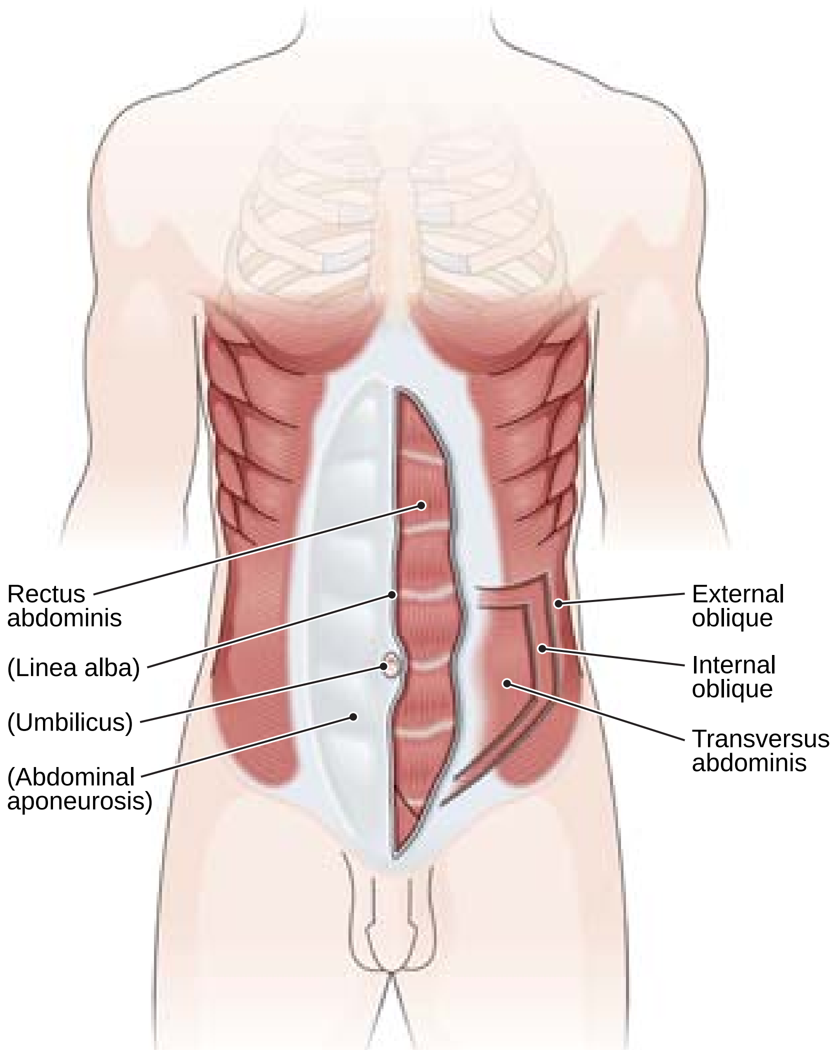


Figure 8-14 **Muscles of the abdominal wall.** Surface tissue is removed on the right side to show deeper muscles. Associated structures are labeled in parentheses.

Table 8•5 Muscles of the Trunk*

NAME	LOCATION	FUNCTION
Diaphragm	Dome-shaped partition between thoracic and abdominal cavities	Dome descends to enlarge thoracic cavity from top to bottom
Intercostals	Between ribs	Elevate ribs and enlarge thoracic cavity
Muscles of abdominal wall: External oblique, Internal oblique, Transversus abdominis, Rectus abdominis	Anterolateral abdominal wall	Compress abdominal cavity and expel substances from body; flex spinal column
Levator ani	Pelvic floor	Aids defecation
Erector spinae (deep; not shown)	Group of deep vertical muscles betweeen the sacrum and skull	Extends vertebral column to produce erect posture

**These and other muscles of the trunk are shown in Figs. 8–13, 8–14 and 8–15.*

stead and use the thigh and buttock muscles to help in lifting.

Deeper muscles in the lumbar area extend the vertebral column in that region. These deep muscles of the back are not shown in the illustrations.

Muscles of the Lower Extremities

The muscles in the lower extremities, among the longest and strongest muscles in the body, are specialized for locomotion and balance. They include the muscles that move the thigh and leg and those that control movement of the foot.

Muscles that Move the Thigh and Leg The **gluteus maximus** (GLU-te-us MAK-sim-us), which forms much of the fleshy part of the buttock, is relatively large in humans because of its support function when a person is standing in the erect position (Fig. 8-10, Table 8-6). This muscle extends the thigh and is important in walking and running. The **gluteus medius**, which is partially covered by the gluteus maximus, abducts the thigh. It is one of the sites used for intramuscular injections.

The **iliopsoas** (il-e-o-SO-as) arises from the ilium and the bodies of the lumbar vertebrae; it crosses the anterior of the hip joint to insert on the femur (Fig. 8-16 A). It is a powerful flexor of the thigh and helps keep the trunk from falling backward when one is standing erect.

The **adductor muscles** are located on the medial part of the thigh. They arise from the pubis and ischium and insert on the femur. These strong muscles press the thighs together, as in grasping a saddle between the knees when riding a horse. They include the **adductor longus** and **adductor magnus**.

The **sartorius** (sar-TO-re-us) is a long, narrow muscle that begins at the iliac spine, winds downward and inward across the entire thigh, and ends on the upper medial surface of the tibia. It is called the tailor's muscle because it is used in crossing the legs in

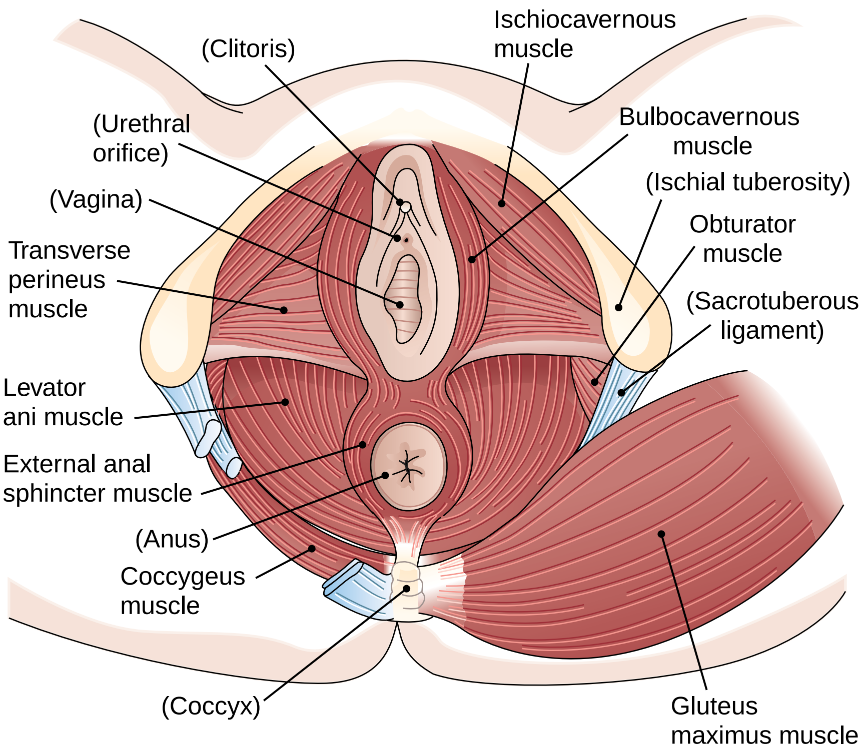


Figure 8-15 **Muscles of the female perineum (pelvic floor).** Associated structures are labeled in parentheses.

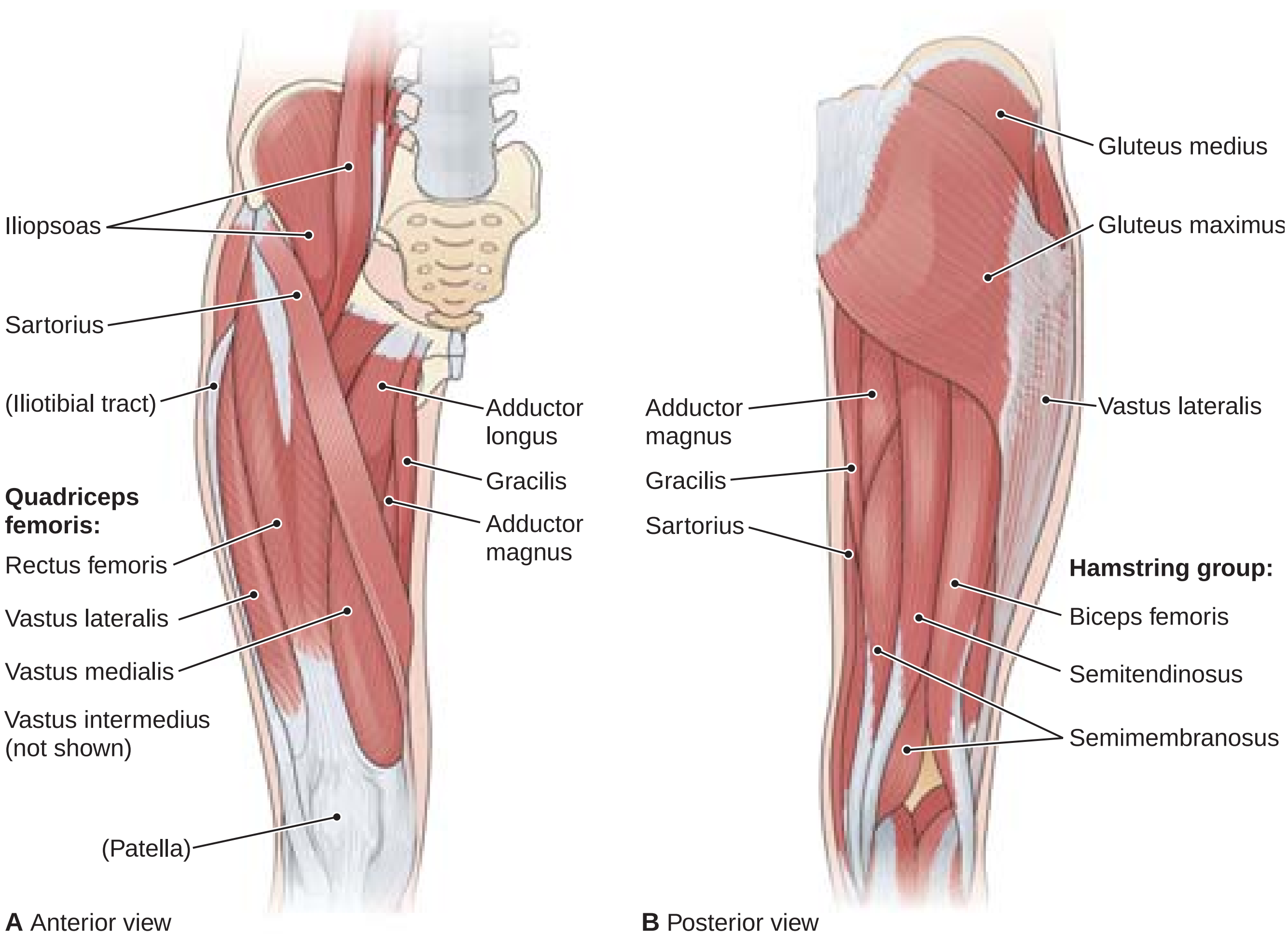


Figure 8-16 **Muscles of the thigh.** Associated structures are labeled in parentheses.

Table 8•6 Muscles of the Lower Extremities*

NAME	LOCATION	FUNCTION
Gluteus maximus	Superficial buttock, to femur	Extends thigh
Gluteus medius	Deep buttock, to femur	Abducts thigh
Iliopsoas	Crosses front of hip joint, to femur	Flexes thigh
Adductor group (*e.g.*, adductor longus, adductor magnus)	Medial thigh, to femur	Adducts thigh
Sartorius	Winds down thigh, ilium to tibia	Flexes thigh and leg (to sit cross-legged)
Gracilis	Pubic bone to medial surface of tibia	Adducts thigh at hip; flexes leg at knee
Quadriceps femoris: Rectus femoris, Vastus medialis, Vastus lateralis, Vastus intermedius (deep; not shown)	Anterior thigh, to tibia	Extends leg
Hamstring group: Biceps femoris, Semimembranosus, Semitendinosus	Posterior thigh, to tibia and fibula	Flexes leg
Gastrocnemius	Calf of leg, to calcaneus, inserting by the Achilles tendon	Plantar flexes foot at ankle (as in tiptoeing)
Soleus	Posterior leg deep to gastrocnemius	Plantar flexes foot at ankle
Tibialis anterior	Anterior and lateral shin, to foot	Dorsiflexes foot (as in walking on heels); inverts foot (sole inward)
Peroneus longus	Lateral leg, to foot	Everts foot (sole outward)
Flexor digitorum groups	Posterior leg and foot to inferior surface of toe bones	Flex toes
Extensor digitorum groups	Anterior surface of leg bones to superior surface of toe bones	Extend toes

**These and other muscles of the lower extremities are shown in Figs. 8–16 and 8–17.*

the manner of tailors, who in days gone by sat cross-legged on the floor. The **gracilis** (grah-SIL-is) extends from the pubic bone to the medial surface of the tibia. It adducts the thigh at the hip and flexes the leg at the knee.

The anterior and lateral femur are covered by the **quadriceps femoris** (KWOD-re-seps FEM-or-is), a large muscle that has four heads of origin. The individual parts are as follows: in the center, covering the anterior thigh, the **rectus femoris**; on either side, the **vastus medialis** and **vastus lateralis**; deeper in the center, the **vastus intermedius.** One of these muscles (rectus femoris) originates from the ilium, and the other three are from the femur, but all four have a common tendon of insertion on the tibia. You may remember that this is the tendon that encloses the knee cap, or patella. This muscle extends the leg, as in kicking a ball. The vastus lateralis is also a site for intramuscular injections.

The **hamstring muscles** are located in the posterior part of the thigh (see Fig. 8-16 B). Their tendons can be felt behind the knee as they descend to insert on the tibia and fibula. The hamstrings flex the leg on the thigh, as in kneeling. Individually, moving from lateral to medial position, they are the **biceps femoris**, the **semimembranosus**, and the **semitendinosus.** The name of this muscle group refers to the tendons at the back of the knee by which these muscles insert on the leg.

Muscles That Move the Foot

The **gastrocnemius** (gas-trok-NE-me-us) is the chief muscle of the calf of the leg (its name means "belly of the leg") (Fig. 8-17). It has been called the toe dancer's muscle because it is used in standing on tiptoe. It ends near the heel in a prominent cord called the **Achilles tendon** (see Fig. 8-17 B), which attaches to the calcaneus (heel bone). The Achilles tendon is the largest tendon in the body. According to Greek mythology, the region above the heel was the only place that Achilles was vulnerable, and if the Achilles tendon is cut, it is impossible to walk. The **soleus** (SO-le-us) is a flat muscle deep to the gastrocnemius. It also inserts by means of the Achilles tendon and, like the gastrocnemius, flexes the foot at the ankle.

Another leg muscle that acts on the foot is the **tibialis** (tib-e-A-lis) **anterior**, located on the anterior region of the leg (see Fig. 8-17 A). This muscle performs the opposite function of the gastrocnemius. Walking on the heels uses the tibialis anterior to raise the rest of the foot off the ground (dorsiflexion). This muscle is also responsible for inversion of the foot. The muscle for eversion of the foot is the **peroneus** (per-o-NE-us) **longus**, located on the lateral part of the leg. The long tendon of this muscle crosses under the foot, forming a sling that supports the transverse (metatarsal) arch.

The toes, like the fingers, are provided with flexor and extensor muscles. The tendons of the extensor muscles are located in superior part of the foot and insert on the superior surface of the phalanges (toe bones). The flexor digitorum tendons cross the sole of the foot and insert on the undersurface of the phalanges.

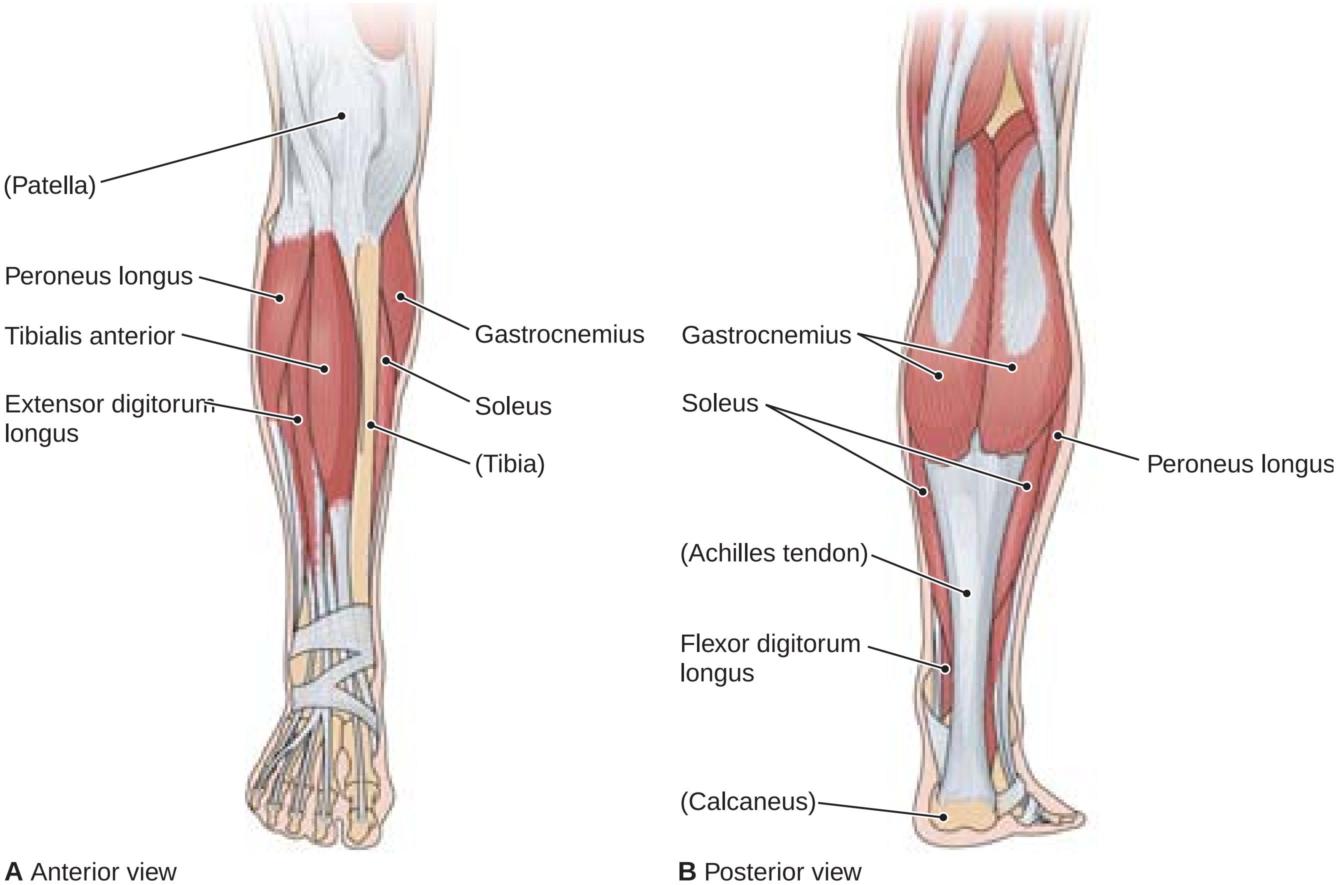


Figure 8-17 **Muscles that move the foot.** Associated structures are labeled in parentheses.

Effects of Aging on Muscles

Beginning at about 40 years of age, there is a gradual loss of muscle cells with a resulting decrease in the size of each individual muscle. There is also a loss of power, notably in the extensor muscles, such as the large sacrospinalis near the vertebral column. This causes the "bent over" appearance of a hunchback (kyphosis), which in women is often referred to as the *dowager's hump*. Sometimes, there is a tendency to bend (flex) the hips and knees. In addition to causing the previously noted changes in the vertebral column (see Chapter 7), these effects on the extensor muscles result in a further decrease in the elderly person's height. Activity and exercise throughout life delay and decrease these undesirable effects of aging. Even among the elderly, resistance exercise, such as weight lifting, increases muscle strength and function.

Muscular Disorders

A **spasm** is a sudden and involuntary muscular contraction, which is always painful. A spasm of the visceral muscles is called **colic**, a good example of which is the spasm of the intestinal muscles often referred to as a *bellyache*. Spasms also occur also in the skeletal muscles. If the spasms occur in a series, the condition may be called a **seizure** or **convulsion**.

Cramps are strong, painful contractions of muscles, especially of the leg and foot. They are most likely to follow unusually strenuous activity. Cramps that occur during sleep or rest are called *recumbency cramps*.

Strains are common muscle injuries caused by overuse or overstretching. With strains, there is pain, stiffness, and swelling, most commonly in the lower back or neck. The elbow or shoulder may also be affected. Charley horse is soreness and stiffness in a muscle caused by strain, usually refering to strain of the quadriceps muscle of the thigh. The term *Charley horse* comes from the practice of using Charley as a name for old lame horses that were kept around for family use when they were no longer able to do hard work.

Sprains are more severe than strains and involve tearing of the ligaments around a joint, usually as a result of abnormal or excessive movement at the joint. In severe cases, the ligament can actually tear away from its bone. The ankle is a common site of sprains, as when the ankle is "turned," that is, the foot is turned inward and body weight forces excessive inversion at the joint. The knee is another common site of this type of injury. The pain and swelling accompanying a sprain can be reduced by the immediate application of ice packs, which constrict some of the smaller blood vessels and reduce internal bleeding.

Atrophy (AT-ro-fe) is a wasting or decrease in the size of a muscle when it cannot be used, such as when an extremity must be placed in a cast after a fracture.

Diseases of Muscles

Muscular dystrophy (DIS-tro-fe) is a group of disorders in which there is deterioration of muscles that still have intact nerve function. These disorders all progress at different rates. The most common type, which is found most frequently in male children, causes weakness and paralysis. Death is due to weakness of the cardiac muscle or paralysis of the respiratory muscles. Life expectancy is about 20 years for the most common type of muscular dystrophy, and about 40 years for the other types. Progress toward definitive treatment for some forms of the disease may be possible now that the genetic defects that cause them have been identified.

Myasthenia gravis (mi-as-THE-ne-ah GRA-vis) is characterized by chronic muscular fatigue brought on by the slightest exertion. It affects adults and begins with the muscles of the head. Drooping of the eyelids (ptosis) is a common early symptom. This disease is caused by a defect in transmission at the neuromuscular junction.

Myalgia (mi-AL-je-ah) means "muscular pain"; **myositis** (mi-o-SI-tis) is a term that indicates actual inflammation of muscle tissue. **Fibrositis** (fi-bro-SI-tis) means "inflammation of connective tissues" and refers particularly to those tissues associated with muscles and joints. Usually, these disorders appear in combination as **fibromyositis**, which may be acute, with severe pain on motion, or may be chronic. Sometimes, the application of heat, together with massage and rest, relieves the symptoms.

Fibromyalgia syndrome (FMS) is associated with widespread muscle aches, tenderness, and stiffness along with fatigue and sleep disorders. FMS is difficult to diagnose, and there is no known cause, but it may be an autoimmune disease, in which the immune system reacts to one's own tissues. Treatment may include a controlled exercise program and treatment with pain relievers, muscle relaxants, or antidepressants.

Disorders of Associated Structures

Bursitis is inflammation of a bursa, a fluid-filled sac that minimizes friction between tissues and bone. Some bursae communicate with joints; others are closely related to muscles. Sometimes, bursae develop spontaneously in response to prolonged friction. Bursitis can be very painful, with swelling and limitation of motion. Some examples of bursitis are listed below:

- **Olecranon bursitis**, in which the bursa over the point of the elbow (olecranon) is inflamed. Another name for the disorder is student's elbow, as it can be caused by long hours of leaning on the elbows while studying.
- **Ischial bursitis**, which is said to be common among people who must sit a great deal, such as taxicab drivers and truckers
- **Prepatellar bursitis**, in which the bursa anterior to the patella is inflamed. This form of bursitis is found in people who must often kneel, hence the name from an earlier time, *housemaid's knee*.
- **Subdeltoid bursitis** and **subacromial bursitis** in the shoulder region, fairly common forms of the condition.

See Box 8-3, Careers in Physical Therapy, for information on how physical therapists participate in treatment of muscular disorders.

Box 8-3 • Health Professions

Careers in Physical Therapy

Physical therapy restores mobility and relieves back pain, arthritis, and joint and muscle injuries. Individuals with heart disease and brain injury, or those who are recovering from burns or major surgery, may benefit as well.

Physical therapists work closely with physicians, nurses, occupational therapists, speech pathologists, and audiologists. Some treat a wide range of ailments, whereas others specialize in pediatrics, geriatrics, orthopedics, sports medicine, neurology, or cardiology. Regardless of specialty, physical therapists are responsible for examining their patients and developing individualized treatment programs. The examination includes a medical history and tests measuring strength, mobility, balance, coordination, and endurance. The treatment plan may include stretching and exercise to improve mobility; hot packs, cold compresses, and massage to reduce pain; as well as the use of crutches, prostheses, and wheelchairs. Physical therapist assistants are responsible for implementing the treatment plan, teaching patients exercises and equipment use, and reporting results back to the physical therapist. To perform these duties, both physical therapists and assistants need a thorough understanding of anatomy and physiology. Most physical therapists in the United States have bachelor's or master's degrees and must pass a national licensing exam. Assistants typically train in a two-year program.

Physical therapists and physical therapist assistants practice in hospitals and clinics and may also visit homes and schools. As the American population continues to age and the need for rehabilitative therapy increases, job prospects are good. For more information about careers in physical therapy, contact the American Physical Therapy Association.

In some cases a local anesthetic, corticosteroids, or both may be injected to relieve the pain of bursitis. **Bunions** are enlargements commonly found at the base and medial side of the great toe. Usually, prolonged pressure has caused the development of a bursa, which has then become inflamed. Special shoes may be necessary if surgery is not performed.

Tendinitis (ten-din-I-tis), an inflammation of muscle tendons and their attachments, occurs most often in athletes who overexert themselves. It frequently involves the shoulder, the hamstring muscle tendons at the knee, and the Achilles tendon near the heel. **Tenosynovitis** (ten-o-sin-o-VI-tis), which involves the synovial sheath that encloses tendons, is found most often in women in their 40s after an injury or surgery. It may involve swelling and severe pain with activity.

Shinsplints is experienced as pain and soreness along the tibia ("shin bone") from stress injury of structures in the leg. Some causes of shinsplints are tendinitis at the insertion of the tibialis anterior muscle, sometimes with inflammation of the tibial periosteum, and even stress fracture of the tibia itself. Shinsplints commonly occurs in runners, especially when they run on hard surfaces without adequate shoe support.

Carpal tunnel syndrome involves the tendons of the flexor muscles of the fingers as well as the nerves supplying the hand and fingers. Numbness and weakness of the hand is caused by pressure on the median nerve as it passes through a tunnel formed by the carpal bones of the wrist. Carpal tunnel syndrome is one of the most common of the repetitive-use disorders. It affects many workers who use their hands and fingers strenuously, such as factory workers, keyboard operators, and musicians.

Word Anatomy

Medical terms are built from standardized word parts (prefixes, roots, and suffixes). Learning the meanings of these parts can help you remember words and interpret unfamiliar terms.

WORD PART	MEANING	EXAMPLE
The Muscular System		
my/o	muscle	The *endomysium* is the deepest layer of connective tissue around muscle cells.
sarc/o	flesh	A *sarcomere* is a contracting subunit of skeletal muscle.
troph/o	nutrition, nurture	Muscles undergo *hypertrophy*, an increase in size, under the effects of resistance training.
vas/o	vessel	*Vasodilation* (widening) of the blood vessels in muscle tissue during exercise brings more blood into the tissue.
iso-	same, equal	In an *isotonic* contraction muscle tone remains the same, but the muscle shortens.
ton/o	tone, tension	See preceding example.
metr/o	measure	In an *isometric* contraction, muscle length remains the same, but muscle tension increases.
The Mechanics of Muscle Movement		
brachi/o	arm	The biceps *brachii* and triceps *brachii* are in the arm.
erg/o	work	*Synergists* are muscles that work together.
Skeletal Muscle Groups		
quadr/i	four	The *quadriceps* muscle group consists of four muscles.
Muscular Disorders		
a-	absent, lack of	*Atrophy* is a wasting of muscle as a result of disuse (lack of nourishment).
dys-	disordered, difficult	In muscular *dystrophy,* there is deterioration of muscles.
sthen/o	strength	*Myasthenia* gravis is characterized by muscular fatigue (lack of strength).
-algia	pain	*Myalgia* is muscular pain.

Summary

I. Types of muscle

A. Smooth muscle
   1. In walls of hollow organs, vessels, and respiratory passageways
   2. Cells tapered, single nucleus, nonstriated
   3. Involuntary; produces peristalsis; contracts and relaxes slowly

B. Cardiac muscle
   1. Muscle of heart wall
   2. Cells branch; single nucleus; lightly striated
   3. Involuntary; self-excitatory

C. Skeletal muscle
   1. Most attached to bones and move skeleton
   2. Cells long, cylindrical; multiple nuclei; heavily striated
   3. Voluntary; contracts and relaxes rapidly

II. Muscular system

A. Functions
   1. Movement of skeleton
   2. Maintenance of posture
   3. Generation of heat

B. Structure of a muscle
   1. Held by connective tissue
      a. Endomysium around individual fibers
      b. Perimysium around fascicles (bundles)
      c. Epimysium around whole muscle

C. Muscle cells in action
   1. Neuromuscular junction
      a. Point where nerve fiber stimulates muscle cell
      b. Neurotransmitter is acetylcholine (ACh)
         (1) Generates an action potential
      c. Motor end plate—membrane of muscle cell
   2. Contraction—sliding together of filaments to shorten muscle
      a. Actin—thin and light
      b. Myosin—thick and dark with projecting heads
   3. Role of calcium—uncovers binding sites so cross-bridges can form between actin and myosin

D. Energy sources
   1. ATP—supplies energy
      a. Myoglobin—stores oxygen
      b. Glycogen—stores glucose
      c. Creatine phosphate—stores energy
   2. Oxygen consumption
      a. Oxygen debt—develops during strenuous exercise
         (1) Anaerobic metabolism
         (2) Yields lactic acid—causes muscle fatigue
      b. Recovery oxygen consumption
         (1) Removes lactic acid
         (2) Replenishes energy-storing compounds

E. Effects of exercise
   1. Changes in structure and function of muscle cells
   2. Vasodilation brings blood to tissues
   3. Heart strengthened
   4. Breathing improved

F. Types of muscle contractions
   1. Tonus—partially contracted state
   2. Isotonic contractions—muscle shortens to produce movement
   3. Isometric contractions—tension increases, but muscle does not shorten

III. Mechanics of muscle movement

A. Attachments of skeletal muscles
   1. Tendon—cord of connective tissue that attaches muscle to bone
      a. Origin—attached to more fixed part
      b. Insertion—attached to moving part
   2. Aponeurosis—broad band of connective tissue that attaches muscle to bone or other muscle

B. Muscles work together
   1. Prime mover—performs movement
   2. Antagonist—produces opposite movement
   3. Synergists—steady body parts and assist prime mover

C. Levers and body mechanics—muscles function with skeleton as lever systems
   1. Components
      a. Lever—bone
      b. Fulcrum—joint
      c. Force—muscle contraction
   2. Most muscles work as third class levers (fulcrum-effort-weight)

IV. Skeletal muscle groups

A. Naming of muscles—location, size, shape, direction of fibers, number of heads, action

B. Muscles of the head

C. Muscles of the neck

D. Muscles of the upper extremities
   1. Muscles that move the shoulder and arm
   2. Muscles that move the forearm and hand

E. Muscles of the trunk
   1. Muscles of respiration
   2. Muscles of the abdomen and pelvis
   3. Deep muscles of the back

F. Muscles of the lower extremities
   1. Muscles that move the thigh and leg
   2. Muscles that move the foot

V. Effects of aging on muscles

A. Decrease in size of muscles

B. Weakening of muscles, especially extensors

VI. Muscular disorders

A. Spasms and injuries
   1. Spasm—sudden painful contraction
   2. Strains—overuse injuries
   3. Sprains—tearing of ligament
   4. Atrophy—wasting

B. Diseases of muscles
   1. Muscular dystrophy—group of disorders
   2. Myasthenia gravis
   3. Myalgia, myositis, fibromyositis
   4. Fibromyalgia syndrome (FMS)—generalized disturbance of unknown cause

C. Disorders of associated structures—bursitis, bunions, tendinitis, shinsplints, carpal tunnel syndrome

Questions for Study and Review

Building Understanding

Fill in the blanks

1. Individual muscle fibers are arranged in bundles called ______.
2. The point at which a nerve fiber contacts a muscle cell is called the ______.
3. A contraction in which there is no change in muscle length but there is a great increase in muscle tension is ______.
4. A term that means "muscular pain" is ______.
5. A disease characterized by chronic muscular fatigue due to defects in neuromuscular transmission is called ______.

Matching

Match each numbered item with the most closely related lettered item.

___ 6. Extends vertebral column to produce erect posture
___ 7. Elevates ribs and enlarges thoracic cavity
___ 8. Flattens cheeks
___ 9. Aids in defecation
___ 10. Closes eye

a. levator ani
b. buccinator
c. orbicularis oris
d. erector spinae
e. intercostal muscles

Multiple choice

___ 11. From superficial to deep, the correct order of muscle structure is
a. deep fascia, epimysium, perimysium, and endomysium
b. epimysium, perimysium, endomysium, and deep fascia
c. deep fascia, endomysium, perimysium, and epimysium
d. endomysium, perimysium, epimysium, and deep fascia

___ 12. The function of calcium ions in skeletal muscle contraction is to:
a. bind to receptors on the motor end plate to stimulate muscle contraction.
b. cause a pH change in the cytoplasm to trigger muscle contraction.
c. bind to the myosin binding sites on actin so that myosin will have something to attach to.
d. bind to regulatory proteins so that the myosin binding sites on the actin can be exposed.

___ 13. A broad flat extension that attaches muscle to bone is called a(n)
a. tendon
b. fascicle
c. aponeurosis
d. motor end plate

___ 14. Seizures or convulsions are examples of
a. strains
b. fibrositis
c. myositis
d. spasms

___ 15. A disease associated with widespread muscle aches, tenderness, and stiffness and with no known cause is
a. muscular dystrophy
b. fibromyalgia
c. myositis
d. bursitis

Understanding Concepts

16. Compare smooth, cardiac, and skeletal muscle with respect to location, structure, and function. Briefly explain how each type of muscle is specialized for its function.
17. Describe three substances stored in skeletal muscle cells that are used to manufacture a constant supply of ATP.
18. Name and describe muscle(s) that
    a. open and close the eye
    b. close the jaw
    c. flex and extend the head
    d. flex and extend the forearm
    e. flex and extend the hand and fingers
    f. flex and extend the leg
    g. flex and extend the foot and toes
19. During a cesarean section, a transverse incision is made through the abdominal wall. Name the muscles incised and state their functions.
20. What effect does aging have on muscles? What can be done to resist these effects?
21. Define *atrophy* and give one cause.
22. What are muscular dystrophies, and what are some of their effects?
23. Describe bursitis and its several forms.

Conceptual Thinking

24. Recall that the neurotransmitter acetylcholine initiates skeletal muscle contraction. Normally, acetylcholine is broken down shortly after its release into the synaptic cleft by the enzyme acetylcholinesterase. Many

insecticides contain chemicals called organophosphates, which interfere with acetylcholinesterase activity. Based on this information, what could happen to an individual exposed to high concentrations of organophosphates?

25. Margo recently began "working out" and jogs three times a week. After her jog she is breathless and her muscles ache. From your understanding of muscle physiology, describe what has happened inside of Margo's skeletal muscle cells. How do Margo's muscles recover from this? If Margo continues to exercise, what changes would you expect to occur in her muscles?

26. Alfred suffered a mild stroke, leaving him partially paralyzed on his left side. Physical therapy was ordered to prevent left-sided atrophy. Prescribe some exercises for Alfred's shoulder and thigh.