7

CHAPTER

Muscular System

Melanie and a few of her friends head out early one morning for a short hike up a nearby mountain to a scenic overlook. As the wind gusts, forcing the temperature below freezing, they study a map and debate what trail to take. Melanie wonders if they made a good decision to hike today as her hands and feet begin to go numb despite her gloves and lined winter boots. Shivering violently, Melanie follows her friends up the mountain. The hike is strenuous because the trail they chose is both steep and rocky. The heat being created through the vigorous contractions of her skeletal muscles begins to gradually warm her body. In a short while, Melanie notices that she is no longer shivering or feeling the cold around her. By the time Melanie reaches the overlook, she is actually so warm that she begins to sweat. The friends sit on the edge of the overlook enjoying the view and each other's company. As the effects of the cold settle in once more, Melanie happily leads the way down the mountain to where a mug of hot chocolate and a roaring fire are waiting.

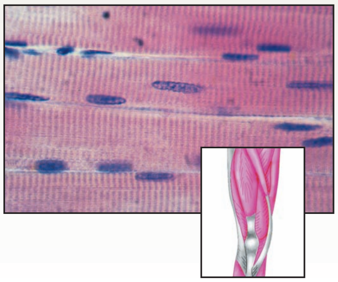
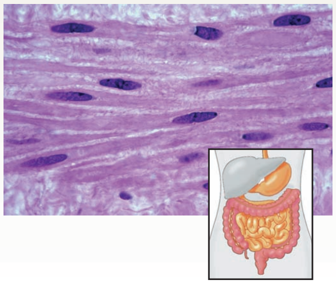
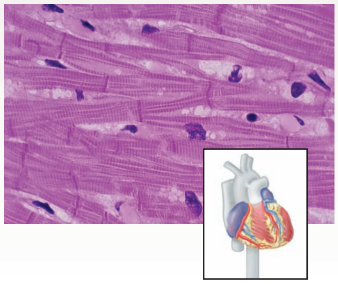
CHAPTER OUTLINE

SELECTED KEY TERMS

Agonist (agogos = leader) A muscle whose contraction leads an action.
Antagonist (anti = against) A muscle whose contraction opposes the action of the agonist.
Aponeurosis (apo = from; neur = cord) A broad sheet of dense regular connective tissue that attaches a muscle to another muscle or connective tissue.
Creatine phosphate An energy storage molecule found in muscle cells.
Insertion The attachment of a muscle that moves when the muscle contracts.
Motor unit A somatic motor neuron and the muscle fibers that it controls.
Muscle fiber A single skeletal muscle cell.
Muscle tone The state of slight contraction in a skeletal muscle.
Myoglobin (myo = muscle) An oxygen-storage molecule in muscle cells.
Neurotransmitter (neuro = nerve; transmit = to send across) A chemical released by terminal boutons of neurons that activates a muscle cell, gland, or another neuron.
Origin The attachment of a muscle that remains fixed when the muscle contracts.
Tendon A narrow band of dense regular connective tissue that attaches a muscle to a bone.
Tetany (tetan = rigid, stiff) A sustained muscle contraction.

MUSCLE TISSUE is the only tissue in the body that is specialized for contraction (shortening). The body contains three types of muscle tissue: skeletal, smooth, and cardiac. Each type of muscle tissue exhibits unique structural and functional characteristics. Contraction of skeletal muscle tissue produces locomotion, movement of body parts, and movement of the skin, as in making facial expressions. Cardiac muscle tissue produces the driving force responsible for pumping blood through the cardiovascular system, as you will see in chapter 12. Smooth muscle tissue is responsible for various internal functions, such as controlling the movement of blood through blood vessels and air through respiratory passageways. It is also directly involved in vision and moving contents through hollow internal organs as described in future chapters. Refresh your understanding of these tissues by referring to the discussion of muscle tissue in chapter 4. Table 7.1 summarizes the characteristics of muscle tissues.

Table 7.1 Types of Muscle Tissue

Characteristic	Skeletal	Smooth	Cardiac
Striations	Present	Absent	Present
Nucleus	Many peripherally located nuclei	Single centrally located nucleus	Usually a single centrally located nucleus
Cells	Long and parallel, called fibers	Short; tapered ends; parallel	Short and branching; intercalated discs join cells end to end to form network
Neural control	Voluntary	Involuntary	Involuntary
Contractions	Fast, variable fatigability; slow, resistant to fatigue	Slow; resistant to fatigue	Rhythmic; resistant to fatigue
Location	Attached to bones, dermis, ligaments, and other muscles	Walls of hollow visceral organs and blood and lymphatic vessels, skin, and inside eyes	Wall of the heart
Micrograph			

7.1 Structure of Skeletal Muscle

Learning Objectives

1. Describe the structure of a skeletal muscle.
2. Explain how a skeletal muscle is attached to a bone or other tissues.
3. Describe the structure of a muscle fiber.
4. Describe a motor unit.
5. Describe the structure and function of a neuromuscular junction.

Skeletal muscles are the organs of the muscular system. They are called skeletal muscles because most of them are attached to bones. A skeletal muscle is composed mainly of skeletal muscle tissue bound together and electrically insulated by connective tissue layers. Individual skeletal muscle cells, called **muscle fibers** due to their long skinny shape, are wrapped in areolar connective tissue. Muscle fibers extend most of the length of a whole muscle and are arranged in small bundles called *muscle fascicles* (fah′-si-kuls) that are each surrounded by a layer of dense irregular connective tissue. A muscle is formed when many muscle fascicles are packaged and held together by an external layer of dense irregular connective tissue. Groups of whole muscles with similar functions are connected by a superficial layer of dense irregular connective tissue called *fascia* (fash′-e-ah). The fascia is deep and connected to the subcutaneous tissue, which is how the muscles can produce skin movement. These muscle connective tissues extend beyond the end of the muscle tissue to form a tough, cordlike **tendon,** which attaches the muscle to a bone (figure 7.1). Fibers of the tendon and periosteum intermesh to form a secure attachment. A few muscles attach to other muscles, dermis, and ligaments, in addition to bones. In these muscles there is a broad, sheetlike attachment called an **aponeurosis.** (ap″-ō-nū-rō′-sis).

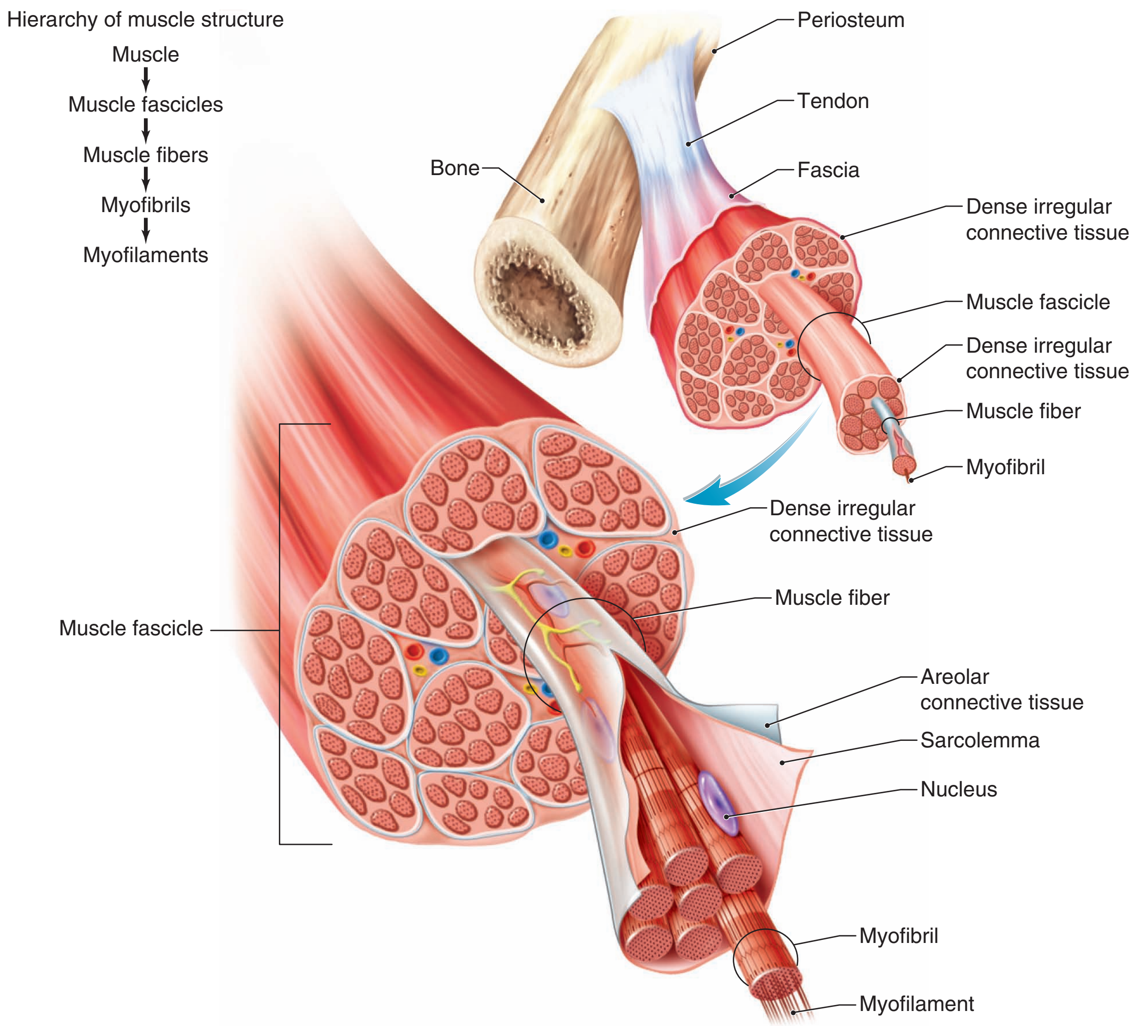


Figure 7.1 A skeletal muscle is primarily composed of skeletal muscle fibers supported and bound together in muscle fascicles by dense irregular connective tissue. Myofibrils are the contractile elements of a muscle fiber.

Skeletal Muscle Fibers

The internal structure of skeletal muscle tissue is so highly specialized that specific terminology is used to describe some muscle fiber structures. The prefixes *sarco-* (flesh) and *myo-* (muscle) are often used in renaming muscular structures. Therefore, the plasma membrane of a muscle fiber is called the **sarcolemma** (sar-kō-lem′-ah), and its cytoplasm is the **sarcoplasm.**

The sarcoplasm contains many threadlike **myofibrils,** which extend the length of the muscle fiber, as shown in figure 7.1. Myofibrils are the contractile elements of a muscle fiber. They consist of two kinds of myofilaments that interact to produce muscle contractions: (1) *thin myofilaments* composed mostly of the protein **actin** and (2) *thick myofilaments* composed of the protein **myosin** (table 7.2).

A thin myofilament consists of two twisted strands of actin molecules joined together like tiny strands of pearls. Two additional proteins, *troponin* and *tropomyosin,* are present in thin myofilaments and play a role in muscle contraction. Double strands of tropomyosin coil over each actin strand and cover the *myosin binding sites.* Troponin occurs at regular intervals on the tropomyosin strands. A thick myofilament is composed of hundreds of myosin molecules, each shaped like a double-headed golf club. The myosin heads are able to attach to the myosin bind sites on the actin molecules to form cross-bridges (figure 7.2). The organization of thin and thick myofilaments within a muscle fiber produces *striations*–the light and dark cross bands that are characteristic of skeletal muscle fibers when viewed microscopically.

Table 7.2 Microscopic Anatomy of a Skeletal Muscle Fiber

Structure	Description/Function
Sarcolemma	Plasma membrane of a muscle fiber maintaining the integrity of the cell
Sarcoplasm	Cytoplasm of a muscle fiber that contains organelles
Nuclei	Contain DNA, which determines cell structure and function
Sarcoplasmic reticulum	Smooth ER in a muscle fiber that stores Ca^{2+}
Transverse tubules	Extensions of the sarcolemma that penetrate into the sarcoplasm carrying muscle impulses, which trigger the release of Ca^{2+} from the sarcoplasmic reticulum
Myofibril	A bundle of myofilaments
Myofilaments	Threadlike contractile proteins that interact to produce contractions

As shown in figure 7.2, the arrangement of thin and thick myofilaments repeats itself throughout the length of a myofibril. These repeating units are called sarcomeres. A **sarcomere** is a functional unit of skeletal muscle–that is, it is the smallest portion of a myofibril capable of contraction. A sarcomere extends from a Z line to the next Z line. **Z lines** are composed of proteins arranged perpendicular to the longitudinal axis of the myofilament. Thin myofilaments are attached to each side of the Z lines and extend toward the middle of the sarcomeres. The *I band*, which is the light band in a micrograph, possesses thin myofilaments only and spans across the Z lines. The *A band*, which is the dark band in a micrograph, spans the length of the thick myofilaments. Note that the ends of the thin myofilaments do not meet, leaving a space at the center of the A band, which contains only thick myofilaments, called the *H band* (pale zone). Proteins that maintain the structure of the center the sarcomere make up the *M line.*

Figure 7.3 illustrates the relationship of the sacroplasmic reticulum and transverse (T) tubules to myofibrils in a muscle fiber. The **sarcoplasmic reticulum** is the name given to the smooth endoplasmic reticulum in a muscle fiber. It plays an important role in contraction by storing and releasing calcium (Ca^{2+}) ions. The **transverse (T) tubules** consist of invaginations of the sarcolemma that penetrate into the sarcoplasm so that they lie alongside and contact the sarcoplasmic reticulum.

Neuromuscular Interaction

A muscle fiber must be stimulated by nerve impulses in order to contract. Nerve impulses are carried from the brain or spinal cord to a muscle fiber by a long, thin process (an axon) of a motor neuron. A *motor neuron* is an action-causing neuron–its nerve impulses produce an action in the target cells. In muscle fibers, this action is contraction and the specific type of motor neuron is called a *somatic motor neuron.*

Motor Units

A somatic motor neuron and all of the muscle fibers to which it attaches, or innervates, form a **motor unit** (figure 7.4). Whereas a muscle fiber is attached to only one motor neuron, a single somatic motor neuron may innervate from 3 to 2,000 muscle fibers. Where precise muscle control rather than strength is needed, such as in the fingers, a motor unit contains very few muscle fibers. Large numbers of motor units are involved in the manipulative movements of the fingers. In contrast, where strength rather than precise control is needed, such as in the postural muscles, a motor unit controls hundreds of muscle fibers. Whenever a motor neuron is activated, it stimulates contraction of all the muscle fibers that it innervates. Neighboring muscle fibers do not contract due to the insulation provided by the connective tissue coverings.

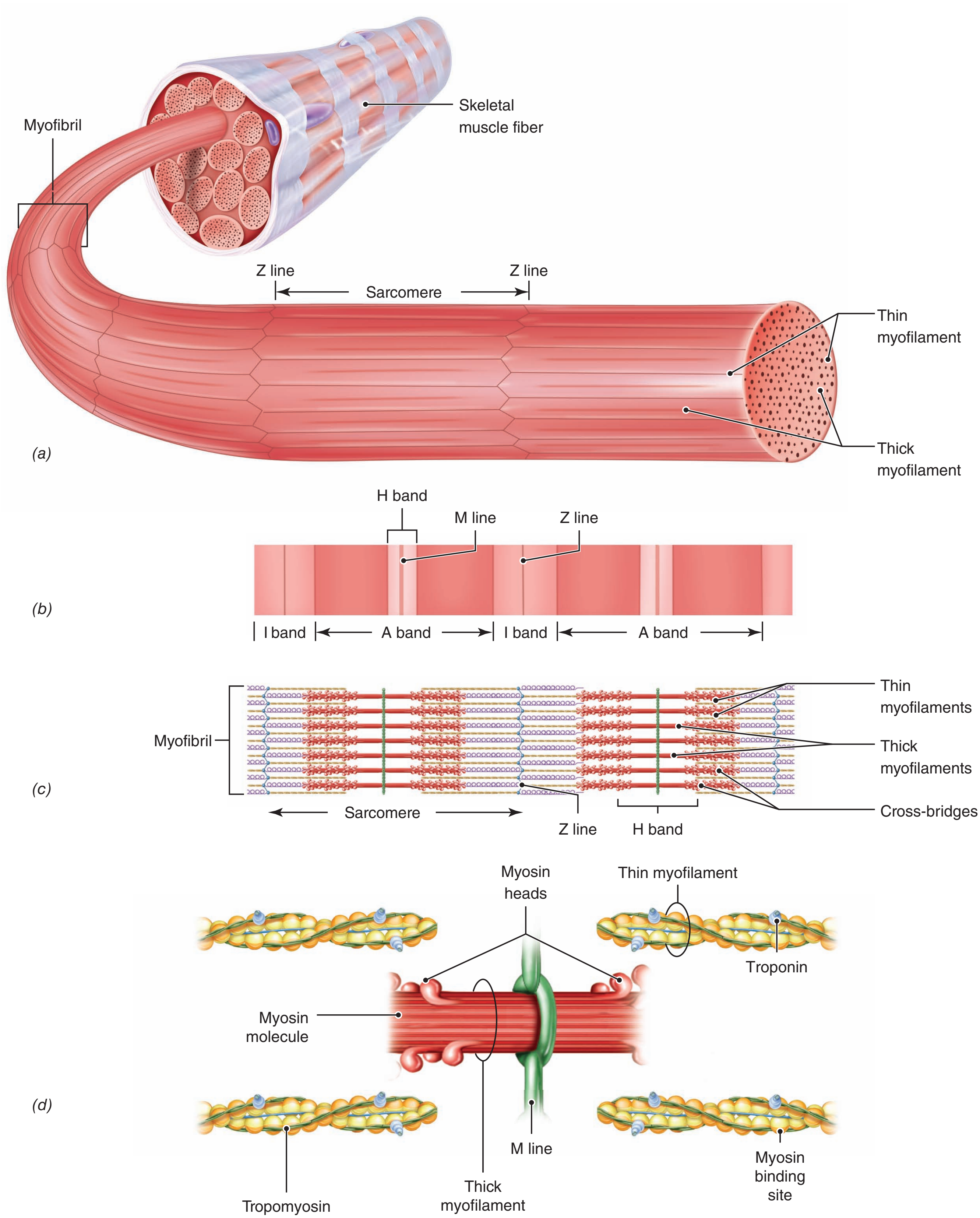


Figure 7.2 Structure of a myofibril. *(a)* A muscle fiber contains many myofibrils. Each myofibril consists of repeating functional units called sarcomeres. *(b)* The characteristic bands of sarcomeres. *(c)* The arrangement of thin and thick myofilaments within the sarcomeres. *(d)* Details of thin myofilaments and thick myofilaments.

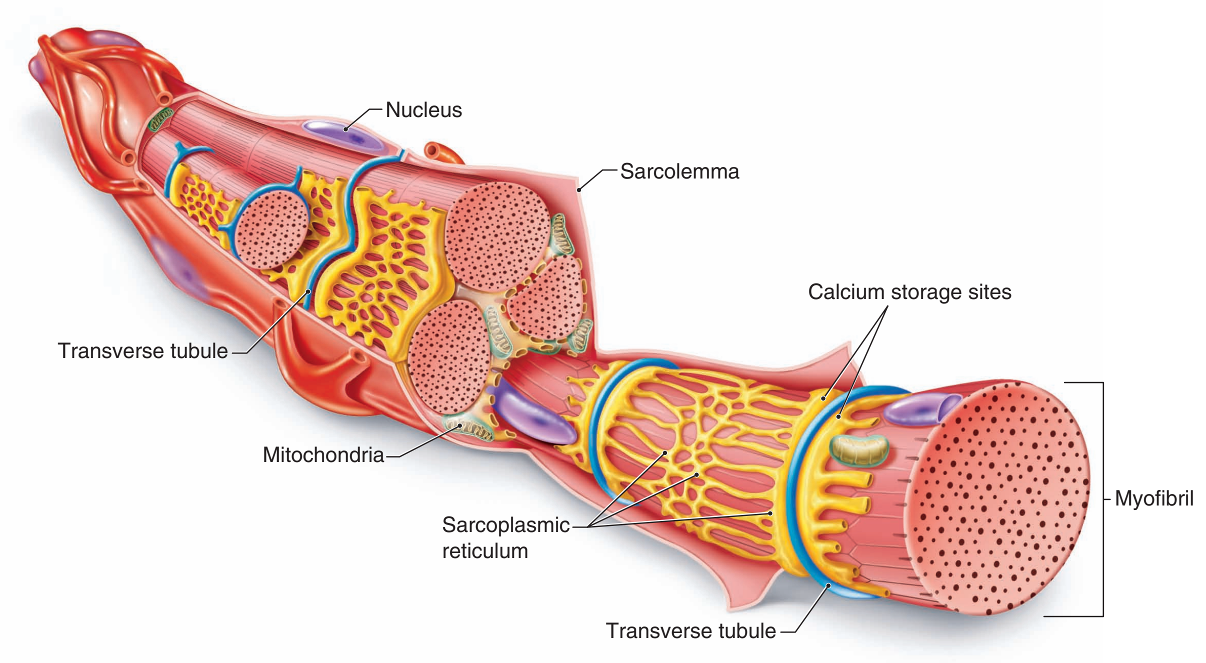


Figure 7.3 A portion of a muscle fiber showing the sarcoplasmic reticulum and the transverse (T) tubules associated with the myofibrils.

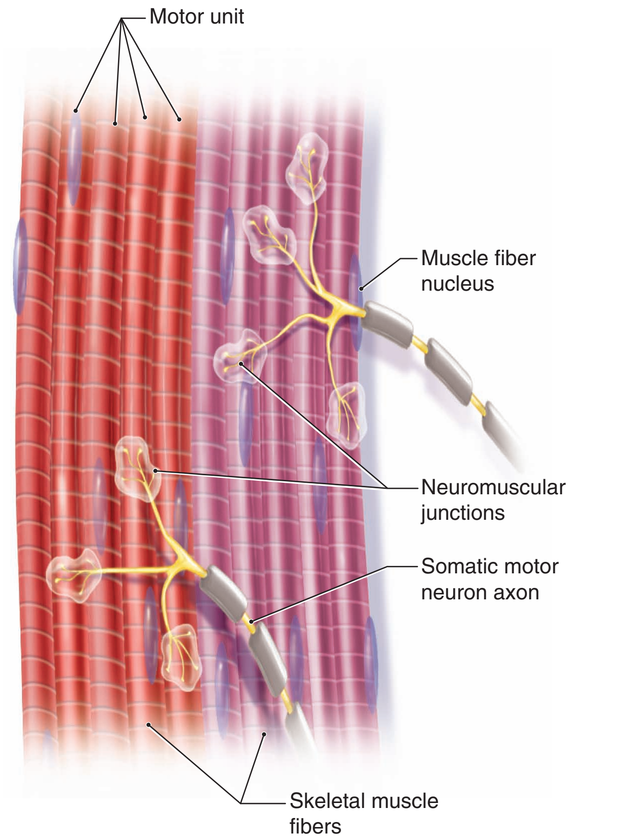


Figure 7.4 A motor unit consists of one somatic motor neuron and all the muscle fibers that it innervates. Note the attachment of the terminal boutons to the muscle fibers.

Neuromuscular Junction

The part of a somatic motor neuron that leads to a muscle fiber is called an *axon*. The connection between the terminal branches of an axon and the sarcolemma of a muscle fiber is known as a **neuromuscular junction** (figure 7.4). As shown in figure 7.5, the *terminal boutons* (axon tips) fit into depressions, the *motor end plates*, in the sarcolemma. The tiny space between the terminal bouton and the motor end plate is the *synaptic cleft*. Numerous secretory vesicles in the terminal bouton contain the **neurotransmitter** (nū-rō-trans′-mit-er) *acetylcholine* (as″-ē-til-kō′-lē n) or ACh. When a somatic motor neuron is activated and a nerve impulse reaches the terminal bouton, ACh is released from secretory vesicles into the synaptic cleft. The attachment of ACh to ACh receptors on the motor end plate triggers a series of reactions causing the muscle fiber to contract.

Clinical Insight

Anabolic steroids, substances similar to the male sex hormone testosterone, have been used by some athletes to promote muscle development and strength. However, physicians have warned that such use can produce a number of harmful side effects, including damage to kidneys, increased risk of heart disease and liver cancer, and increased irritability. Other side effects include decreased testosterone and sperm production in males and increased facial hair and deepening of the voice in females.

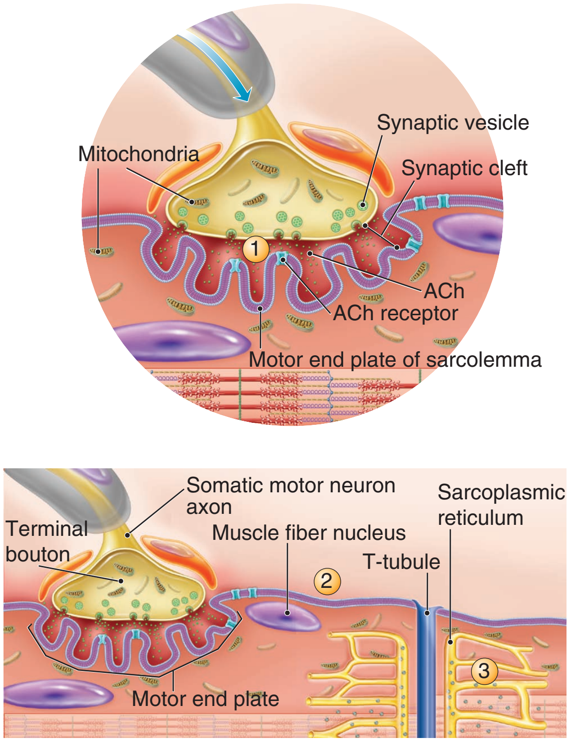


Figure 7.5 A neuromuscular junction is formed by the terminal bouton of a somatic motor neuron and the motor end plate of a muscle fiber. The detailed insert shows the synaptic vesicles, the synaptic cleft, and the folded surface of the motor end plate.

Check My Understanding

1. How are muscle tissue and connective tissue arranged in a skeletal muscle?
2. What composes a muscle fiber?

7.2 Physiology of Skeletal Muscle Contraction

Learning Objectives

6. Describe the physiology of contraction.
7. Explain the cause of excess post-exercise oxygen consumption (EPOC).
8. Explain the all-or-none contraction of muscle fibers.
9. Discuss how graded contractions of whole muscles produce a variety of contraction strengths.

Contraction of a muscle fiber is a complex process that involves a number of rapid structural and chemical changes within the muscle fiber. The molecular mechanism of contraction is explained by the *sliding-filament model* described in the next section.

Mechanism of Contraction

As mentioned in the previous section, in order for a muscle fiber to contract it needs to first be stimulated or "excited" by a somatic motor neuron. The pairing of a nerve impulse (an electrochemical signal) and physical contraction of the muscle fiber is referred to as **excitation-contraction coupling.** Figure 7.5 shows the steps of excitation.

1. Contraction of a muscle fiber is initiated when the terminal bouton of an activated somatic motor neuron releases ACh into the synaptic cleft.
2. Acetylcholine binds to ACh-receptors on the motor end plate causing the formation of a muscle impulse (similar to the nerve impulse that will be described in chapter 8), that spreads over the sarcolemma and is carried into the sarcoplasm by the T tubules.
3. Stimulation of the sarcoplasmic reticulum from the nearby T tubules triggers the release of Ca^{2+} from the sarcoplasmic reticulum into the sarcoplasm.

Figure 7.6 shows the steps of the contraction cycle.

Step 1a–Ca^{2+} within the sarcoplasm binds to troponin, which then causes the tropomyosin strands to change position, exposing the myosin binding sites on actin molecules.

Step 1b–With the myosin binding sites exposed, each myosin head binds to a myosin binding site to form a cross-bridge with the actin molecule.

Step 2–While the cross-bridge is formed the inorganic phosphate detaches, causing the myosin head to pivot and exert a power stroke that pulls the thin myofilaments toward the M line of the sarcomere. ADP detaches during the pivoting of the myosin head.

Step 3–The power stroke causes sliding of the myofilaments past one another, and the sarcomere shortens.

Step 4–A new molecule of ATP binds to the myosin head, causing myosin to release the actin molecule.

Step 5–The detached myosin head returns to its relaxed position and then becomes energized after hydrolyzing the ATP to ADP and Pi.

Step 6–This returns us to **Step 1b,** wherein the energized myosin head reattaches to a new binding site on actin, releases Pi, and uses its energy to repeat the power stroke in **Step 2.** This cycle rapidly repeats itself to maintain a contraction as long as ATP and Ca^{2+} are available.

When the somatic motor neuron stops stimulating the muscle fiber, an enzyme in the synaptic cleft called *acetylcholinesterase* begins decomposing ACh. The breakdown of ACh prevents continued stimulation of the muscle fiber. Consequently, Ca^{2+} is no longer released from the sarcoplasmic reticulum and is instead actively transported

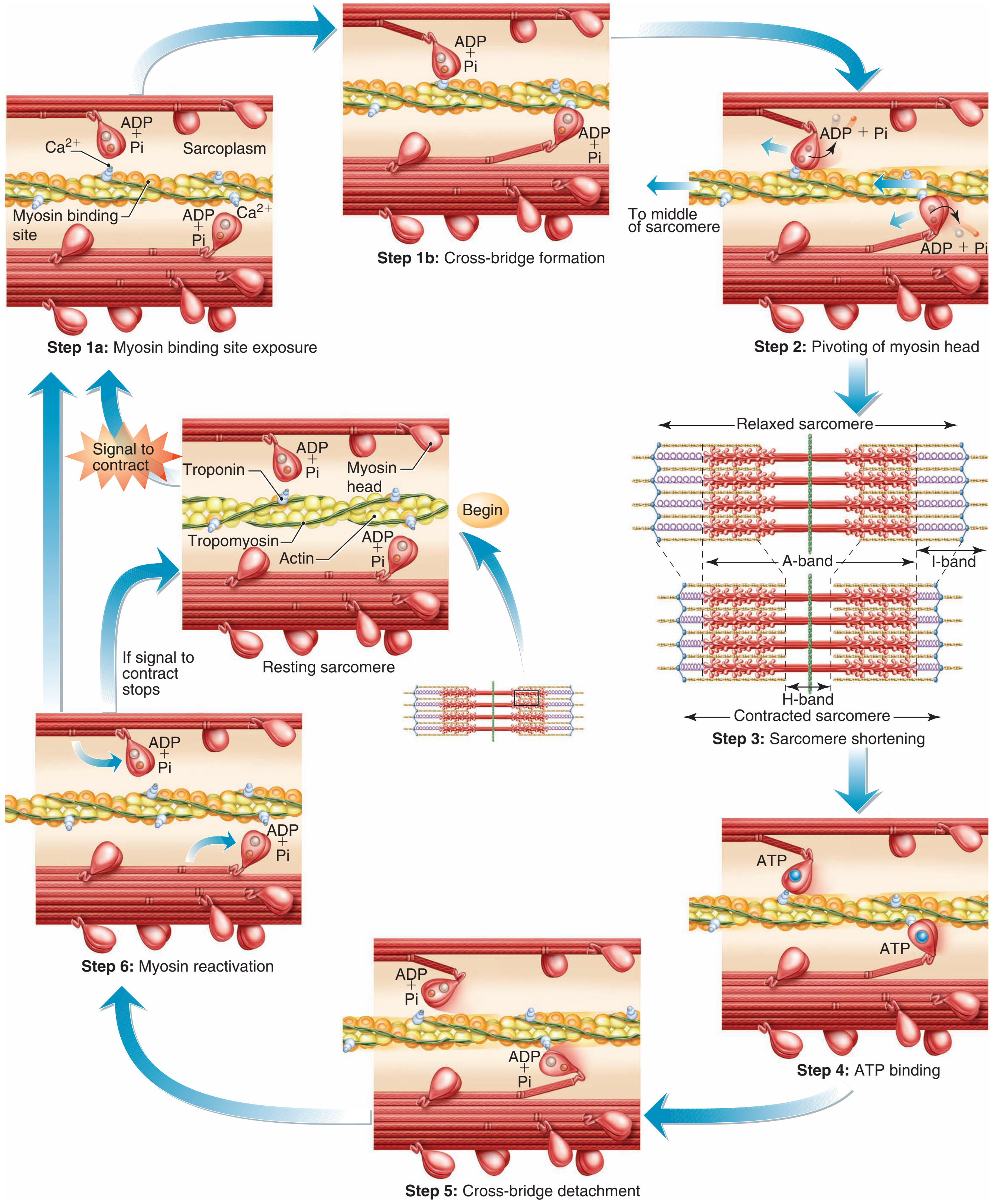


Figure 7.6 Sliding-filament model of muscle contraction. The release of Ca^{2+} into sarcoplasm causes the exposure of myosin binding sites on actin molecules, enabling the contraction cycle to begin. ATP powers the contraction cycle.

from the sarcoplasm into the sarcoplasmic reticulum. This causes Ca^{2+} to unbind troponin, which allows tropomyosin to move back over the myosin binding sites and stop the contraction cycle. The thin and thick myofilaments then slide back to their original positions, moving the Z lines apart, lengthening the sarcomeres (muscle relaxation).

Carefully study figure 7.6, which illustrates the sliding-filament model of muscle contraction. Note the configuration of thin myofilaments and thick myofilaments in a relaxed muscle fiber, how they interact in the steps of the contraction cycle, and how contraction is powered by ATP. Although the sliding myofilaments produce contraction (i.e., the shortening of the sarcomeres), the lengths of the thin myofilaments and thick myofilaments remain unchanged (step 3, figure 7.6).

Energy for Contraction

The energy for muscle contraction comes from ATP molecules in the muscle fiber. Recall that ATP is a product of cellular respiration. However, there is only a small amount of ATP in each muscle fiber. Once it is used up, more ATP must be formed in order for additional contractions to occur. Figure 7.7 summarizes the processes involved in the replenishment of ATP.

While a muscle fiber is relaxed it uses cellular respiration to release energy from nutrients and transfers that energy to the high-energy phosphate bonds of ATP. Once there are sufficient amounts of ATP available in the muscle fiber, the high-energy phosphate is transferred to creatine to form **creatine phosphate (CP),** which serves as a storage form of readily available energy. The resulting ADP is then reconverted to ATP using cellular respiration.

Muscle contraction quickly reduces ATP levels, resulting in the high-energy phosphate group being transferred back from the creatine phosphate to the ADP, forming ATP, which can then be used to power additional contractions (Figure 7.7a).

There is four to six times more creatine phosphate than ATP in a muscle fiber so it is an important source for immediate ATP formation without waiting for the slower process of cellular respiration. However, it can also be depleted in under 10 seconds in a muscle that is contracting repeatedly.

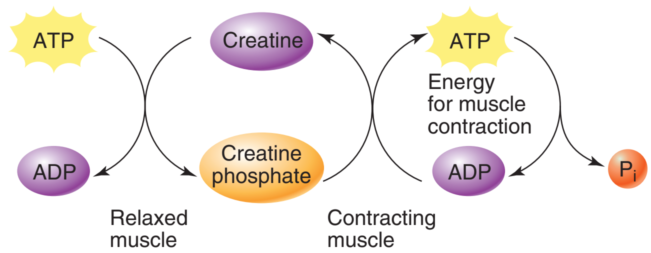
Clinical Insight

The reaction that transfers the phosphate between creatine phosphate and ADP is controlled by an enzyme unique to muscle tissue. When muscle tissue is damaged this enzyme is released into the blood. Elevated levels of the cardiac version of this enzyme in blood tests suggest that a heart attack may have occurred. Blood levels of cardiac troponin can be used as an indicator of heart damage as well.

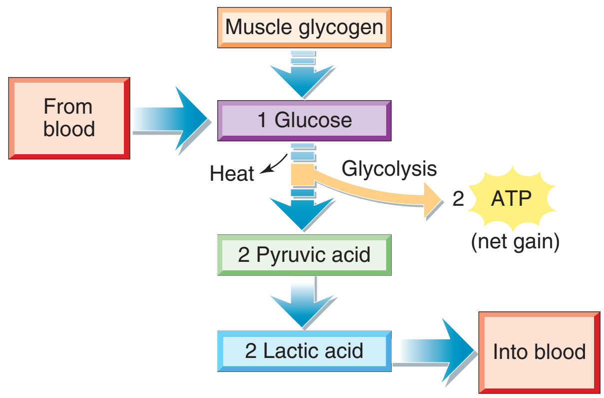
Oxygen and Cellular Respiration

Recall from chapter 3 that cellular respiration is the process of breaking down glucose in two steps: (1) anaerobic respiration in the cytosol and (2) aerobic respiration in the mitochondria. Due to the need of a constant supply for glucose to generate ATP, muscle fibers store large amounts of glucose as **muscle glycogen.** Recall from chapter 2 that glycogen is a polysaccharide of glucose.

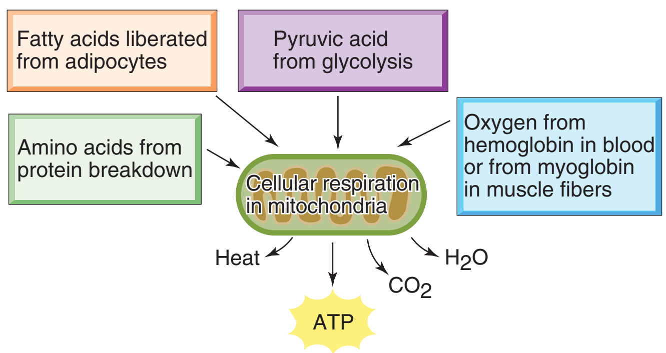
Whether or not a muscle fiber uses just anaerobic respiration or also includes aerobic respiration depends on the availability of oxygen. During periods of strenuous exercise such as weight lifting, muscle fibers will employ mostly anaerobic respiration because the respiratory and



(a) ATP from creatine phosphate



(b) ATP from anaerobic respiration



(c) ATP from aerobic respiration

Figure 7.7 A summary of the sources of ATP in muscle fibers.

cardiovascular systems cannot provide oxygen to muscle fibers quickly enough to maintain aerobic respiration. The muscle fibers will break down glycogen to glucose and glucose to pyruvic acid, in a process called *glycolysis*, forming only a small amount of ATP per molecule of glucose (see Chapter 3 and figure 7.7*b*).

Since anaerobic respiration is not favorable in muscle fibers, muscle tissue is adapted to facilitate aerobic respiration. Muscle tissue possesses a large number of blood vessels and obtains large amounts of oxygen from the blood via **hemoglobin,** the red pigment in red blood cells. Muscle fibers also have a similar pigment, **myoglobin,** which stores oxygen within the sarcoplasm and helps transfer oxygen to the mitochondria. In the same manner that creatine phosphate stores extra energy in times of muscle inactivity, some of the oxygen carried to muscle fibers is transferred from hemoglobin to myoglobin and stored for later use during periods of muscle activity. This function of myoglobin reduces the muscle fiber's dependence on oxygen carried to it by the blood at the onset of exercise. During inactivity or light to moderate physical activity (e.g. endurance training), muscle fibers receive sufficient oxygen to carry on the aerobic respiration. As shown in figure 7.7*c*, this process involves the breakdown of *pyruvic acid* produced in glycolysis, or other organic nutrients, into carbon dioxide and water. In contrast to anaerobic respiration, aerobic respiration provides a large amount of ATP per molecule of glucose (see Chapter 3 and figure 7.7*c*).

Excess Post-Exercise Oxygen Consumption (EPOC)

When a muscle fiber utilizes anaerobic respiration, such as during strenuous exercise, it accumulates lactic acid and depletes its ATP, CP, and oxygen stores. To restore resting conditions within a muscle fiber after activity ceases, respiratory and heart rates remain elevated to support **excess post-exercise oxygen consumption** or **EPOC** (formerly oxygen debt). EPOC is the amount of oxygen required to replenish myoglobin and to produce the ATP needed for the metabolism of the lactic acid in the liver, heart, and skeletal muscles and the restoration of ATP and creatine phosphate in the muscle fibers.

Fatigue

If a muscle is stimulated to contract for a long period, its contractions will gradually decrease until it no longer responds to stimulation. This condition is called **fatigue.** Although the exact mechanism is not known, several factors seem to be responsible for muscle fatigue. The most likely cause of fatigue in long term muscle activity is a lack of available nutrients, such as muscle glycogen and fatty acids, to utilize for ATP production.

Effects of Exercise on Muscles

Exercise has a profound effect on skeletal muscles. Strength training, which involves resistance exercise such as weight lifting, causes a muscle fiber to be repetitively stimulated to maximum contraction. Over time, the repetitive stimulation produces **hypertrophy**–an increase in muscle fiber size and strength. The number of muscle fibers cannot be increased after birth. Instead, hypertrophy results from an increase in the number of myofibrils in muscle fibers, which increases the diameter and strength of the muscle fibers and of the whole muscle itself. In comparison, lack of repetitive stimulation to maximum force causes muscular **atrophy,** which is the reduction in muscle size and strength due to loss of myofibrils. Atrophy can be caused by damage to the nerve stimulating the muscle or lack of use, such as when a limb is in a cast. Aerobic exercise, or endurance training, does not produce hypertrophy. Instead it enhances the efficiency of aerobic respiration in muscle fibers by increasing (1) the number of mitochondria, (2) the efficiency of obtaining oxygen from the blood, and (3) the concentration of myoglobin.

Heat Production

Heat production by muscular activity is an important mechanism in maintaining a normal body temperature. Muscles are active organs that form a large proportion of the body weight. Heat produced by muscles results from cellular respiration and other chemical reactions within the muscle fibers. Recall that 60% of the energy released by cellular respiration is heat energy. Muscle generates so much heat that exercise leads to an increase in body temperature that requires sweating to help remove heat from the body. On the other hand, the major response to a decrease in body temperature is shivering, which is involuntary muscle contractions.

Check My Understanding

3. What are the structure and function of a neuromuscular junction?
4. How do thin and thick myofilaments interact during muscle contraction?
5. What are the roles of ATP and creatine phosphate in muscle contraction?
6. What are the relationships among cellular respiration, lactic acid, and excess post-exercise oxygen consumption?

Contraction Characteristics

When studying muscle contraction, physiologists consider both single-fiber contraction and whole-muscle contraction.

Contraction of a Single Fiber

It is possible to remove a single muscle fiber in order to study its contraction in the laboratory. By using electrical stimuli to initiate contraction and by gradually increasing the strength (voltage) of each stimulus, it has been shown that the fiber will not contract until the stimulus reaches a certain minimal strength. This minimal stimulus is called the **threshold stimulus.**

Whenever a muscle fiber is stimulated by a threshold stimulus or by a stimulus of greater strength, it always contracts *completely*. Thus, a muscle fiber either contracts completely or not at all–contraction is *not* proportional to the strength of the stimulus. This characteristic of individual muscle fibers is known as the **all-or-none response.**

Contraction of Whole Muscles

Much information has been gained by studying the contraction of a whole muscle of an experimental animal. In such studies, electrical stimulation is used to cause contraction, and the contraction is recorded to produce a tracing called a *myogram*.

If a single threshold stimulus is applied, some of the muscle fibers will contract to produce a single, weak contraction (a muscle twitch) and then relax, all within a fraction of a second. The myogram will look like the one shown in figure 7.8. After the stimulus is applied, there is a brief interval before the muscle starts to contract. This interval is known as the *latent phase*. Then, the muscle contracts (shortens) during the *contraction phase* and relaxes (returns to its former length) during the *relaxation phase*. If a muscle is stimulated again after it has relaxed completely, it will contract and produce a similar myogram. A series of single stimuli applied in this manner will yield a myogram like the one in figure 7.9*a*.

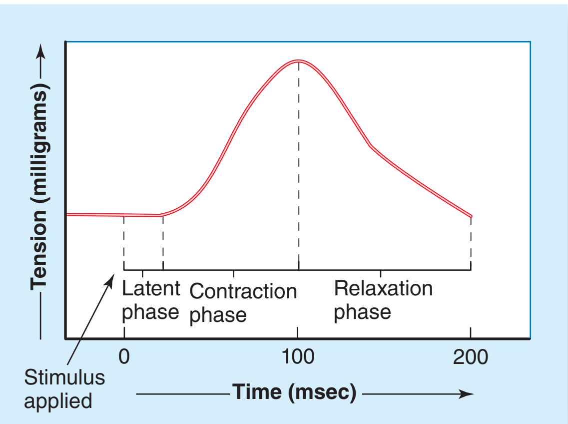


Figure 7.8 A myogram of a single muscle twitch. Note the brief latent phase, contraction phase, and longer relaxation phase.

If the interval between stimuli is shortened so that the muscle fibers cannot completely relax, the force of individual twitches combines by *summation*, which increases the force of contraction. Rapid summation produces incomplete tetany, a fluttering contraction (figure 7.9*b*). If stimuli are so frequent that relaxation is not possible, **tetany** results (figure 7.9*c*). Tetany is a state of sustained contraction without relaxation. In the body, tetany results from a rapid series of nerve impulses carried by somatic motor neurons to the muscle fibers that results in a prolonged state of contraction. Tetany for short time periods is the usual way in which muscles contract to produce body movements.

Graded Responses Unlike individual muscle fibers that exhibit all-or-none responses, whole muscles exhibit *graded responses*–that is, varying degrees of contraction. Graded responses enable the degree of muscle contraction to fit the task being performed. Obviously, more muscle fibers are required to lift a 14 kg (30 lb) weight than to lift a feather. Yet both activities can be performed by the same muscles.

Graded responses are possible because a muscle is composed of many different *motor units*, each responding to different thresholds of stimulation. In the laboratory, a weak stimulus that activates only low-threshold motor units produces a minimal contraction. As the strength of the stimulus is increased, the contractions get stronger as more motor units are activated until a **maximal stimulus** (one that activates all motor units) is applied, which produces a maximal contraction. Further increases in the strength of the stimulus (supramaximal) cannot produce a greater contraction. The same results occur in a normally functioning body. The nervous system provides the stimulation and controls the number of motor units activated in each muscle contraction. The activation of more and more motor units is known as *motor unit recruitment* (figure 7.9*d*).

Muscle Tone Even when a muscle is relaxed, some of its muscle fibers are contracting. At any given time, some of the muscle fibers in a muscle are involved in a sustained contraction that produces a constant partial, but slight, contraction of the muscle. This state of constant partial contraction, called **muscle tone,** keeps a muscle ready to respond. Muscle tone results from the alternating activation of different motor units by the nervous system so that some muscle fibers are always in sustained contraction, as seen in figure 7.10. Muscle tone of postural muscles plays an important role in maintaining erect posture.

Check My Understanding

7. What is meant by the all-or-none response?
8. How are muscles able to make graded responses?

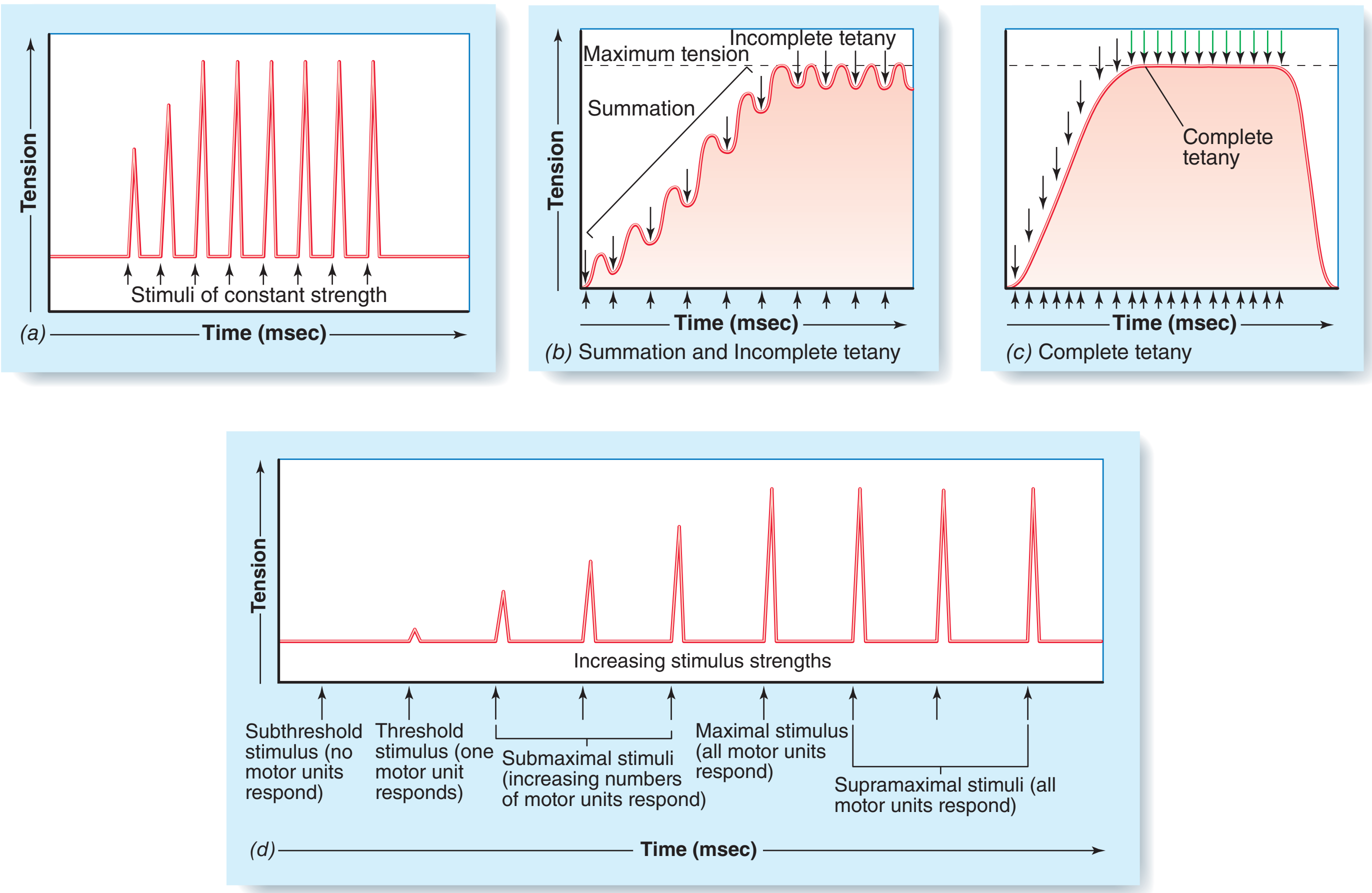


Figure 7.9 Myograms of *(a)* a series of simple twitches, *(b)* summation caused by incomplete relaxation between stimuli, *(c)* tetany, and *(d)* motor unit recruitment.

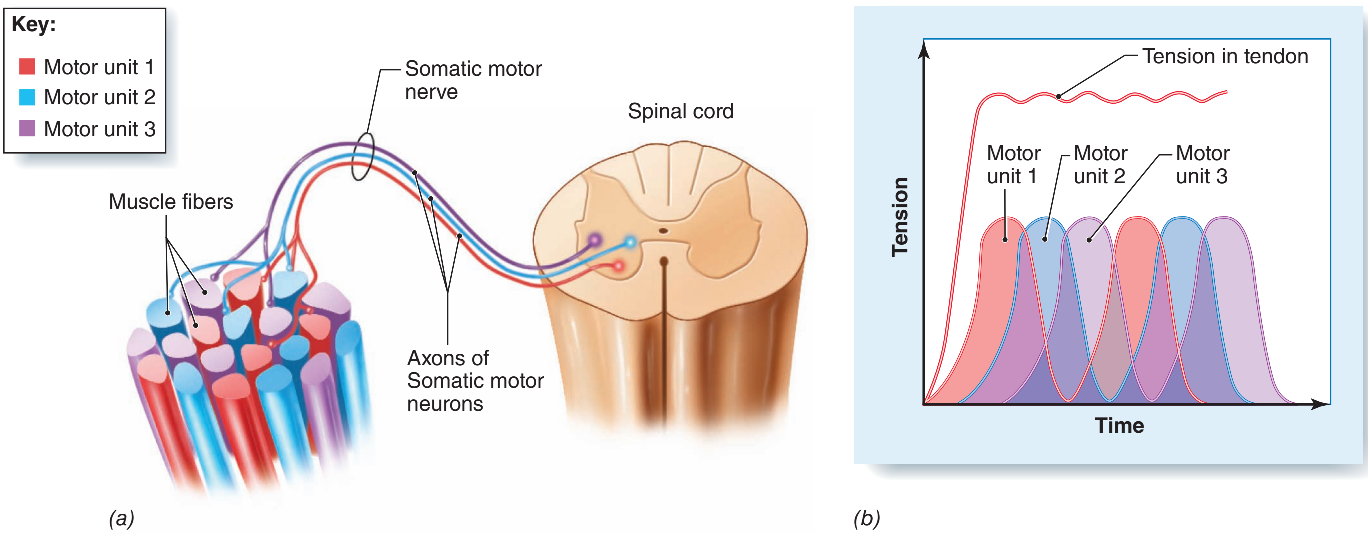


Figure 7.10 *(a)* Anatomy of motor units in a skeletal muscle. *(b)* Myogram showing mechanism of motor unit alternation in muscle tone.

7.3 Actions of Skeletal Muscles

Learning Objectives

10. Explain the relationship between a muscle's origin and insertion and its action.
11. Explain how agonists and antagonists function in the production of body movements.

Skeletal muscles are usually arranged so that the ends of a muscle are attached to bones on each side of a joint. Thus, a muscle usually extends across a joint. The type of movement produced depends upon the type of joint and the locations of the muscle attachments. Common movements at joints were discussed in chapter 6.

Origin and Insertion

During contraction, a bone to which one end of the muscle is attached moves, but the bone to which the other end is attached does not. The movable attachment of a muscle is called the **insertion,** and the immovable attachment is called the **origin.** When a muscle contracts, the insertion is pulled toward the origin.

Consider the *biceps brachii* in figure 7.11. It has two origins, and both are attached to the scapula. The insertion is on the radius, and the muscle lies along the anterior surface of the humerus. When the biceps brachii contracts, the insertion is pulled toward the origin, which results in the flexion of the forearm at the elbow.

Most muscle contractions are *isotonic contractions,* which cause movement at a joint. Walking and breathing are examples. However, some contractions may not produce movement but only increase tension within a muscle. Contractions that maintain body posture are good examples. Such contractions are *isometric contractions.*

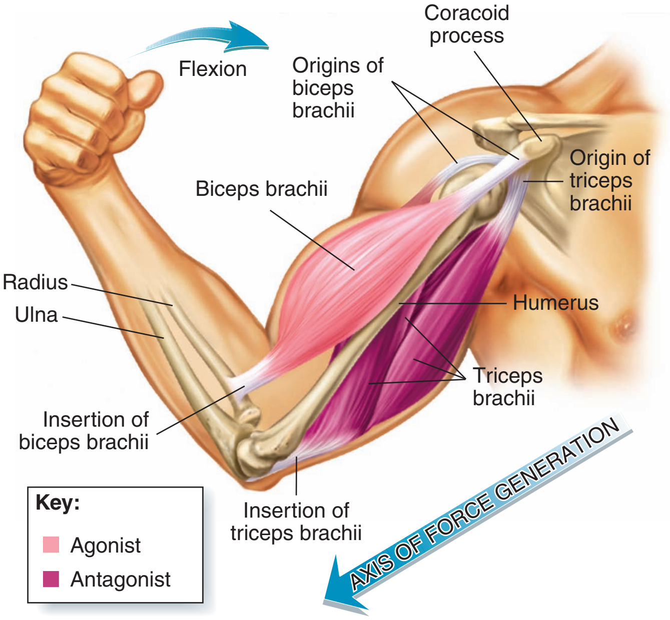


Figure 7.11 Demonstration of the actions of agonists and antagonists with origins and insertions labeled.

Muscle Interactions

Muscles function in groups rather than singly, and the groups are arranged to provide opposing movements. For example, if one group of muscles produces flexion, the opposing group produces extension. A group of muscles producing an action are called **agonists,** and the opposing group of muscles are called **antagonists.** When agonists contract, antagonists must relax, and vice versa, for movement to occur. If both groups contract simultaneously, the movable body part remains rigid. Figure 7.11 illustrates how the biceps brachii is the agonist of forearm flexion, while the triceps brachii is the antagonist.

7.4 Naming of Muscles

Learning Objective

12. List the criteria used for naming muscles.

Learning the complex names and functions of muscles can be confusing. However, the names of muscles are informative if their meaning is known. A few of the criteria used in naming muscles and examples of terms found in the names of muscles are listed below:

- **Function:** extensor, flexor, adductor, and pronator.
- **Shape:** trapezius (trapezoid), rhomboid (rhombus), deltoid (delta-shaped or triangular), biceps (two heads).
- **Relative position:** external, internal, abdominal, medial, lateral.
- **Location:** intercostal (between ribs), pectoralis (chest).
- **Site of attachment:** temporalis (temporal bone), zygomaticus (zygomatic bone).
- **Origin and insertion:** sternohyoid (sternum = origin; hyoid = insertion), sternocleidomastoid (sternum and clavicle = origins; mastoid process = insertion).
- **Size:** maximus (larger or largest), minimus (smaller or smallest), brevis (short), longus (long).
- **Orientation of fibers:** oblique (diagonal), rectus (straight), transversus (across).

7.5 Major Skeletal Muscles

Learning Objectives

13. Describe the location and action of the major muscles of the body.
14. Identify the major muscles on a diagram.

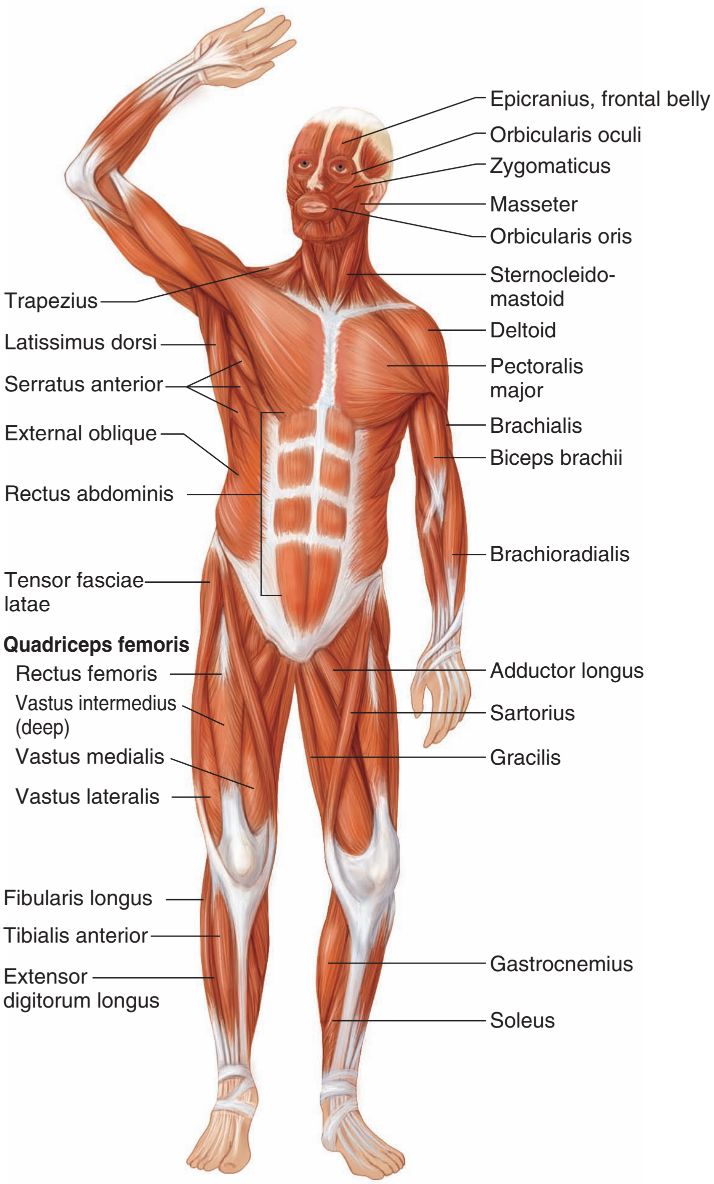


Figure 7.12 Anterior view of superficial skeletal muscles.

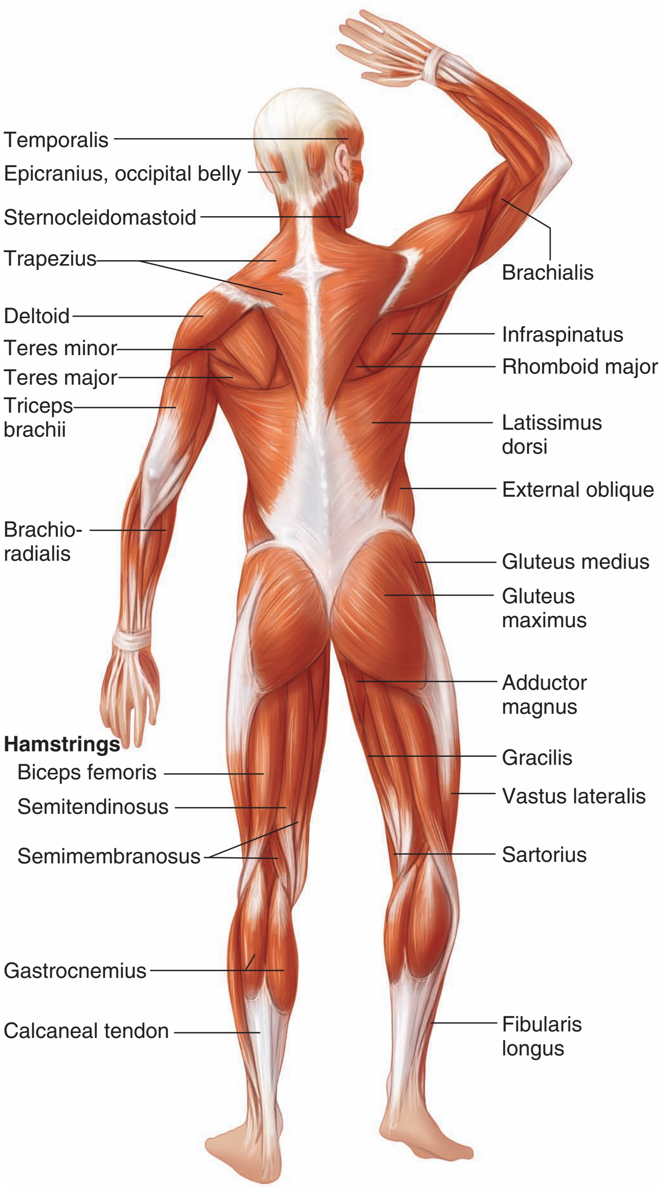


Figure 7.13 Posterior view of superficial skeletal muscles.

This section is concerned with the name, location, attachment, and action of the major skeletal muscles. There are more than 600 muscles in the body, but only a few of the major muscles are considered here. Most of this information is presented in tables and figures to aid your learning. The tables are organized according to the primary actions of the muscles. The pronunciation of each muscle is included, because being able to pronounce the names correctly will help you learn the names of the muscles.

As you study this section, locate each muscle listed in the tables on the related figures 7.12 to 7.25. This will help you visualize the location and action of each muscle. Also, if you visualize the locations of the origin and insertion of a muscle, its action can be determined because contraction pulls the insertion toward the origin. It may help to refresh your understanding of the skeleton by referring to appropriate figures in chapter 6. Begin your study by examining figures 7.12 and 7.13 to learn the major superficial muscles that will be considered in more detail as you progress through the chapter.

Muscles of Facial Expression and Mastication

Muscles of the face and scalp produce the facial expressions that help communicate feelings, such as anger, sadness, happiness, fear, disgust, pain, and surprise. Most have origins on skull bones and insertions on the dermis of the skin (table 7.3 and figure 7.14).

Table 7.3 Muscles of Facial Expression

Muscle	Origin	Insertion	Action
Buccinator (buk′-si-nā-tor)	Lateral surfaces of maxilla and mandible	Orbicularis oris	Compresses cheeks inward
Epicranius (ep-i-krā′-nē-us)	This muscle consists of two parts: the frontal belly and the occipital belly. They are joined by the epicranial aponeurosis, which covers the top of the skull.		
Frontal belly	Epicranial aponeurosis	Skin and muscles superior to the eyes	Elevates eyebrows and wrinkles forehead
Occipital belly	Base of occipital bone	Epicranial aponeurosis	Pulls scalp posteriorly
Orbicularis oculi (or-bik′-ū-lar-is ok′-ū-li)	Frontal bone and maxillae	Skin around eye	Closes eye
Orbicularis oris (or-bik′-ū-lar-is- o′-ris)	Muscles around mouth	Skin around lips	Closes and puckers lips; shapes lips during speech
Platysma (plah-tiz′-mah)	Fascia of superior chest	Mandible and muscles around mouth	Draws angle of mouth inferiorly
Zygomaticus (zī-gō-mat′-ik-us)	Zygomatic bone	Orbicularis oris at angle of the mouth	Elevates corners of mouth (smiling)

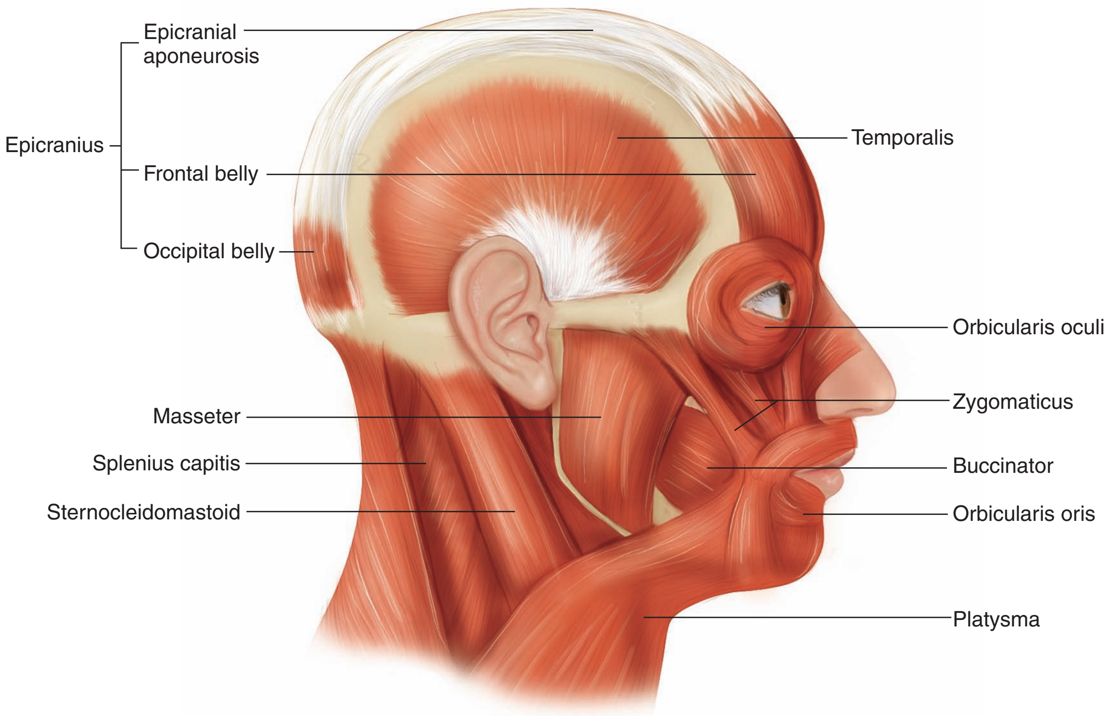


Figure 7.14 Muscles of facial expression and mastication.

The *epicranius* is an unusual muscle. It has a large *epicranial aponeurosis* that covers the top of the skull and two contractile portions: the *frontal belly* over the frontal bone and the *occipital belly* over the occipital bone.

Two major pairs of muscles elevate the mandible in the process of mastication (chewing): the *masseter* and the *temporalis* (table 7.4 and figure 7.14).

Muscles That Move the Head

Several pairs of neck muscles are responsible for flexing, extending, and rotating the head. Table 7.5 lists two of the major muscles that perform this function: the *sternocleidomastoid* and the *splenius capitis*. As noted in table 7.8, the *trapezius* can also extend the head, although this is not its major function (figures 7.14, 7.15, and 7.16).

Table 7.4 Muscles of Mastication

Muscle	Origin	Insertion	Action
Masseter (mas-se′-ter)	Zygomatic arch	Lateral surface of mandible	Elevates mandible
Temporalis (tem-po-ra′-lis)	Temporal bone	Coronoid process of mandible	Elevates mandible

Table 7.5 Muscles That Move the Head

Muscle	Origin	Insertion	Action
Sternocleidomastoid (ster-nō-klī-dō-mas′-toid)	Clavicle and sternum	Mastoid process of temporal bone	Contraction of both muscles flexes head toward chest; contraction of one muscle turns head away from contracting muscle
Splenius capitis (splē′-nē-us kap′-i-tis)	Inferior cervical and superior thoracic vertebrae	Mastoid process of temporal bone	Contraction of both muscles extends head; contraction of one muscle turns head toward same side as contracting muscle

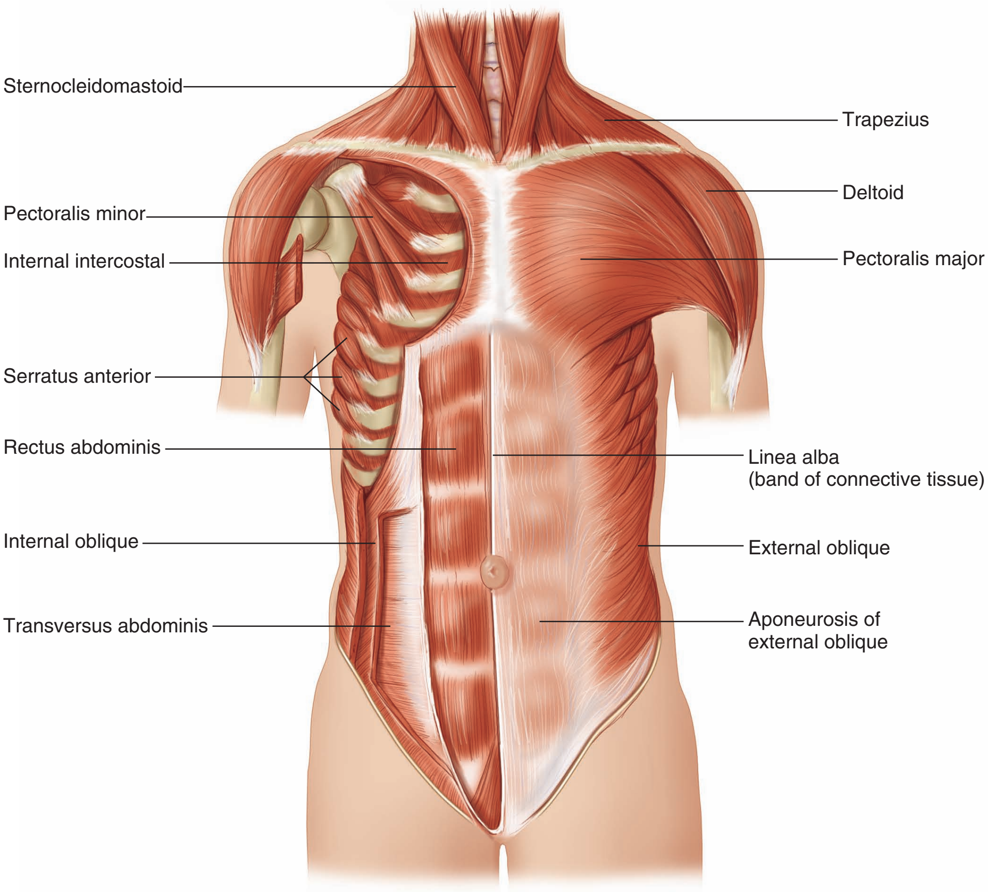


Figure 7.15 Muscles of the anterior chest and abdominal wall. The right pectoralis major is removed to show the deep muscles.

Muscle of the Abdominal Wall

The abdominal muscles are paired muscles that provide support for the anterior and lateral portions of the abdominal and pelvic regions, including support for the internal organs. The muscles are named for the direction of their muscle fibers: *rectus abdominis, external oblique, internal oblique,* and *transversus abdominis.* They are arranged in overlapping layers and are attached by larger

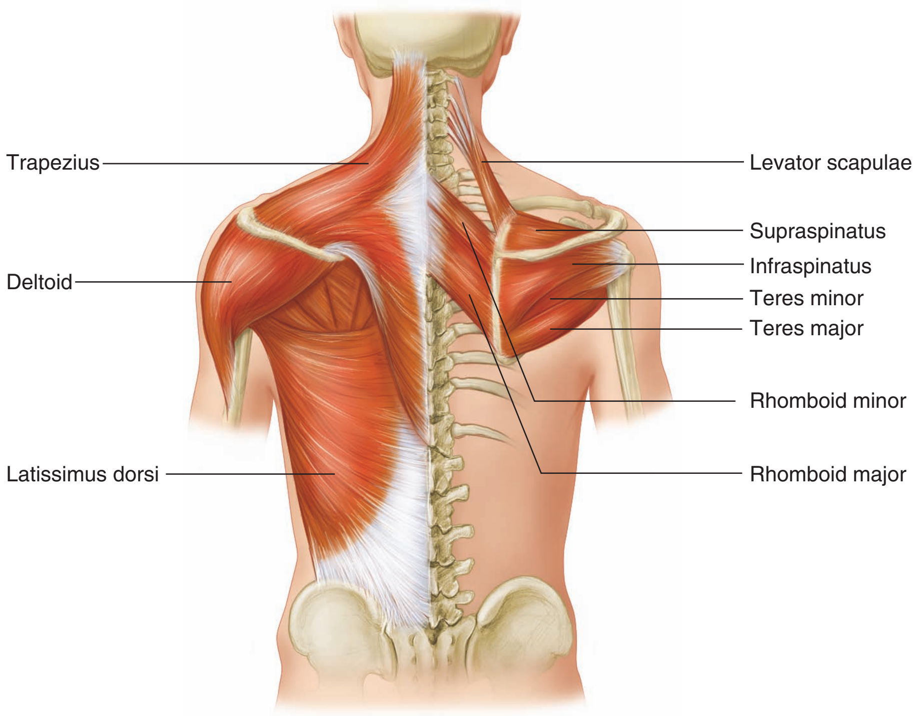


Figure 7.16 Muscles of the posterior shoulder. The right trapezius is removed to show deep muscles.

aponeuroses that merge at the anterior midline to form the *linea alba,* or white line (table 7.6 and figure 7.15).

Muscles of Breathing

Movement of the ribs occurs during breathing and is brought about by the contraction of two sets of muscles that are located between the ribs. The *external intercostals* elevate and protract the ribs during inspiration, and the *internal intercostals* depress and retract the ribs during expiration (table 7.7 and figure 7.15). The primary breathing muscle is the *diaphragm,* a thin sheet of muscle that separates the thoracic and abdominal cavities.

Muscles That Move the Pectoral Girdle

Pectoral girdle muscles originate on bones of the axial skeleton and insert on the scapula or clavicle. Because the scapula is supported mainly by muscles, it can be moved more freely than the clavicle. The *trapezius* is a superficial trapezoid-shaped muscle that covers much of the superior back. The *rhomboid major* and *minor* and the *levator scapulae* lie deep to the trapezius. Each *serratus anterior* is located on the lateral surface of the superior ribs near the axillary region. The *pectoralis minor* lies deep to the pectoralis major. It protracts and depresses the scapula (table 7.8 and figures 7.15 to 7.18).

Table 7.6 Muscles of the Abdominal Wall

Muscle	Origin	Insertion	Action
Rectus abdominis (rek′-tus ab-dom′-i-nis)	Pubic symphysis and pubis	Xiphoid process of sternum and costal cartilages of ribs 5 to 7	Tightens abdominal wall; flexes the vertebral column
External oblique (eks-ter′-nal o-blēk′)	Anterior surface of inferior eight ribs	Iliac crest and linea alba	Tightens abdominal wall; rotation and lateral flexion of the vertebral column
Internal oblique (in-ter′-nal o-blēk′)	Iliac crest and inguinal ligament	Cartilage of inferior four ribs, pubis, and linea alba	Same as above
Transversus abdominis (trans-ver′-sus ab-dom′-i-nis)	Iliac crest, cartilages of inferior six ribs, processes of lumbar vertebrae	Pubis and linea alba	Tightens abdominal wall

Table 7.7 Muscles of Breathing

Muscle	Origin	Insertion	Action
Diaphragm (dī-a-fram)	Lumbar vertebrae, costal cartilages of inferior ribs, xiphoid process	Central tendon located at midpoint of muscle	Forms floor of thoracic cavity; depresses during contraction, causing inspiration
External intercostals (eks-ter′-nal in-ter-kos′-tals)	Inferior border of rib above	Superior border of rib below	Elevates and protracts ribs during inspiration
Internal intercostals (in-ter′-nal in-ter-kos′-tals)	Superior border of rib below	Inferior border of rib above	Depresses and retracts ribs during expiration

Table 7.8 Muscles That Move the Pectoral Girdle

Muscle	Origin	Insertion	Action
Trapezius (trah-pē-zē′-us)	Occipital bone; cervical and thoracic vertebrae	Clavicle; spine and acromion of scapula	Elevates clavicle; adducts and elevates scapula; extends head
Rhomboid major and minor (rom-boid)	Superior thoracic vertebrae	Medial border of scapula	Adducts and elevates scapula
Levator scapulae (le-va′-tor skap′-ū-lē)	Cervical vertebrae	Superior medial margin of scapula	Elevates scapula
Serratus anterior (ser-ra′-tus)	Superior eight to nine ribs	Medial border of scapula	Depresses, protracts, and rotates scapula
Pectoralis minor (pek-to-rah′-lis)	Anterior surface of superior ribs	Coracoid process of scapula	Depresses and protracts scapula

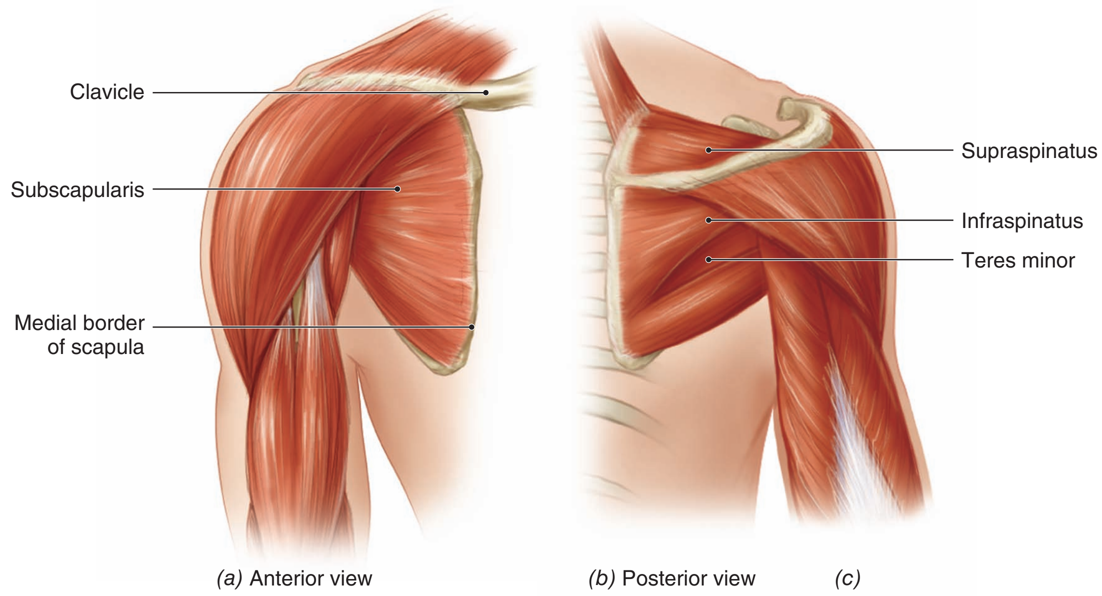


Figure 7.17 Muscles of the rotator cuff. *(a)* Anterior view showing subscapularis. *(b)* Posterior view showing supraspinatus, infraspinatus, and teres minor. *(c)* A gymnast on the rings must have a strong rotator cuff.

Muscles That Move the Arm and Forearm

Movement of the humerus is enabled by the muscles that originate on the pectoral girdle, ribs, or vertebrae and insert on the humerus. The arrangement of these muscles and the ball-and-socket joint between the humerus and scapula enable great freedom of movement for the arm. The *pectoralis major* is the large superficial muscle of the chest. The *deltoid* is the thick muscle that caps the shoulder joint. The *supraspinatus, infraspinatus,* and *teres minor* cover the posterior surface of the scapula. The anterior surface of each scapula is covered by the *subscapularis.* These four muscles and their tendons surround the head of the humerus at the shoulder joint, making up the **rotator cuff** (figure 7.17). The muscles and tendons of the rotator cuff are the only structures stabilizing the shoulder joint; thus the joint is fairly unstable compared to other joints. However, this relative lack of stability is what allows the shoulder's mobility. The *latissimus dorsi* is a broad, sheetlike muscle that covers the inferior back. The *teres major* assists the latissimus dorsi and is located just superior to it. (table 7.9 and figures 7.15 to 7.17).

Muscles moving the forearm originate on either the humerus or the scapula and insert on either the radius or the ulna. Three flexors occur on the anterior surface of the arm: the *biceps brachii, brachialis,* and *brachioradialis.* One extensor, the *triceps brachii,* is located on the posterior surface of the arm (table 7.10 and figures 7.15, 7.18, and 7.19).

Check My Understanding

9. What are the names and locations of the two parts of the epicranius muscle?
10. What muscles are involved in chewing your food?
11. What muscles turn your head to the side?
12. What muscle separates the abdominal and thoracic cavities?
13. What are the names of the abdominal muscles from deep to superficial?
14. What three muscles elevate the scapula?

Table 7.9 Muscles That Move the Arm

Muscle	Origin	Insertion	Action
Pectoralis major (pek-tō-rah′-lis)	Clavicle, sternum, and cartilages of superior ribs	Greater tubercle of humerus	Adducts, flexes, and medially rotates arm
Deltoid (del′-toid)	Clavicle and spine, and acromion of scapula	Deltoid tuberosity of humerus	Abducts, flexes, and extends arm
Latissimus dorsi (lah-tis′-i-mus dor′sī)	Inferior thoracic and lumbar vertebrae; sacrum; inferior ribs; iliac crest	Intertubercular sulcus of humerus	Adducts, extends, and medially rotates arm
Teres major (te′r-ez)	Inferior angle of scapula	Distal to lesser tubercle of humerus	Same as above
Rotator cuff muscles	These four muscles stabilize the shoulder joint		
Supraspinatus (su-prah-spī′-na-tus)	Superior to spine of scapula	Greater tubercle of humerus	Abducts arm
Infraspinatus (in-frah-spī′-na-tus)	Inferior to spine of scapula	Greater tubercle of humerus	Laterally rotates arm
Teres minor	Lateral border of scapula	Greater tubercle of humerus	Laterally rotates arm
Subscapularis (sŭ-skap-ŭ-lār′ris)	Anterior surface of scapula	Lesser tubercle of humerus	Medially rotates arm

Table 7.10 Muscles That Move the Forearm

Muscle	Origin	Insertion	Action
Biceps brachii (bī′-seps brā′-kē-ī)	Coracoid process and tubercle superior to glenoid cavity of scapula	Radial tuberosity of radius	Flexes forearm and supination, also flexes arm
Brachialis (brā′-kē-al-is)	Distal, anterior surface of humerus	Coronoid process of ulna	Flexes forearm
Brachioradialis (brā-kē-ō-rā-dē-a′-lis)	Lateral surface of distal end of humerus	Lateral surface of radius superior to styloid process	Flexes forearm
Triceps brachii (trī′-seps brā′-kē-ī)	Lateral and medial surfaces of humerus and tubercle inferior to glenoid cavity of scapula	Olecranon of ulna	Extends forearm, also extends arm

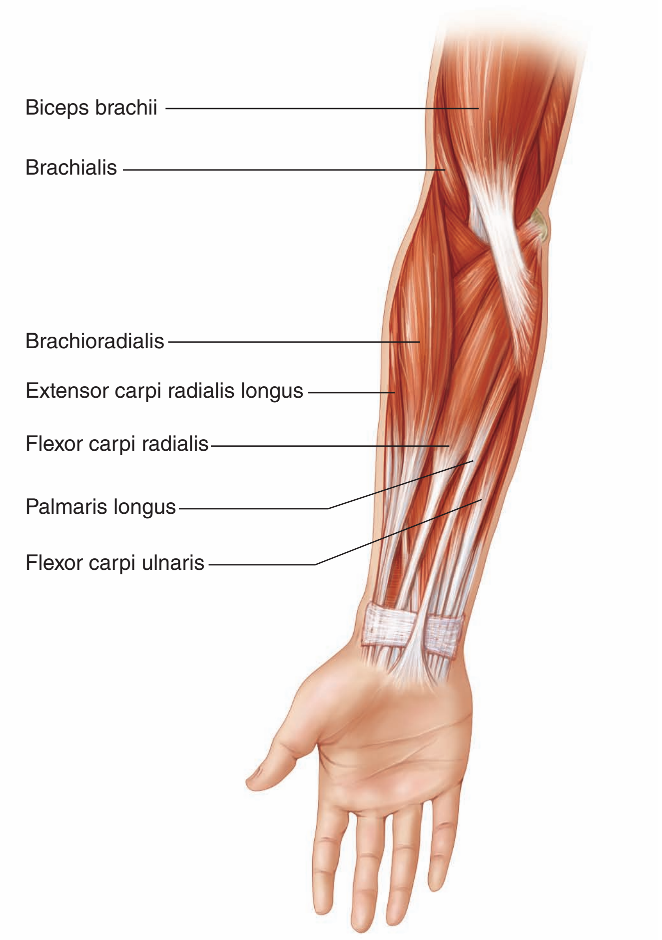


Figure 7.18 Muscles of the anterior forearm.

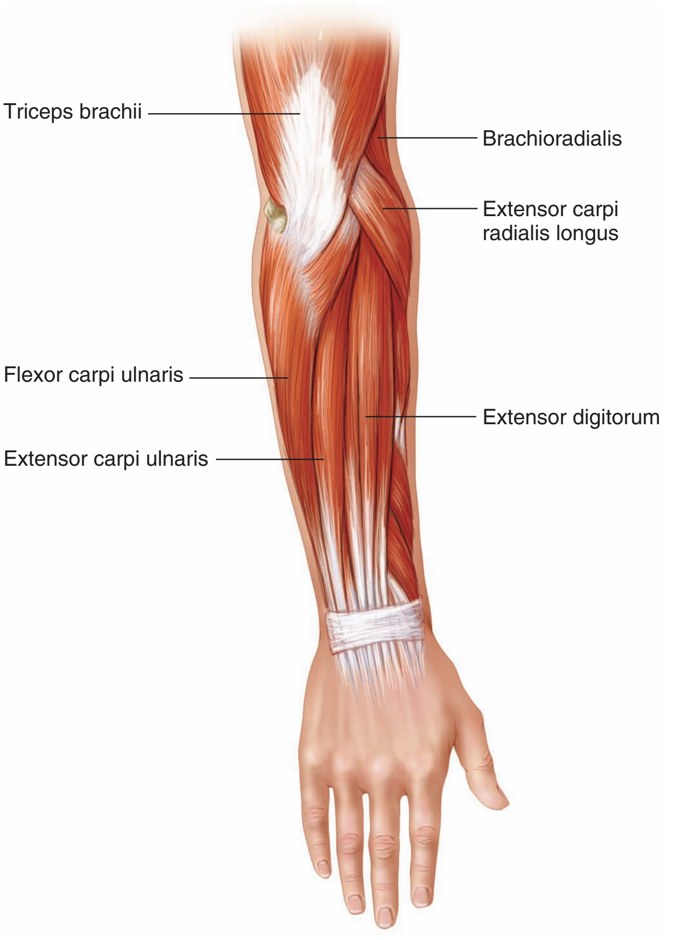


Figure 7.19 Muscles of the posterior forearm.

Muscles That Move the Wrist and Fingers

Many muscles that produce the various movements of the wrist and fingers are located in the forearm. Only a few of the larger superficial muscles are considered here. They originate from the distal end of the humerus and insert on carpal bones, metacarpals, or phalanges. Flexors on the anterior surface include the *flexor carpi radialis, flexor carpi ulnaris*, and *palmaris longus*. Extensors on the posterior surface include the *extensor carpi radialis longus, extensor carpi ulnaris*, and *extensor digitorum* (table 7.11; and figures 7.18 and 7.19). Note that the tendons of these muscles are held in position by a circular ligament at the wrist.

Check My Understanding

15. What muscle abducts and extends your arm?
16. What muscle extends your forearm?
17. What muscle extends your fingers?

Muscles That Move the Thigh and Leg

Muscles moving the thigh span the hip joint. They insert on the femur, and most originate on the pelvic girdle. The *iliacus* and *psoas major* are located anteriorly, the *gluteus maximus* is located posteriorly and forms the buttocks, the *gluteus medius* is located deep to the gluteus maximus posteriorly and extends laterally, and the *tensor fasciae latae* is located laterally. The *adductor longus* and *adductor magnus* are both located medially (table 7.12 and figures 7.20, 7.21, and 7.22).

The leg is moved by muscles located in the thigh. They span the knee joint and originate on the pelvic girdle or femur and insert on the tibia or fibula. The **quadriceps femoris** is composed of four muscles that have a common tendon that inserts on the patella. However, this tendon continues as the patellar ligament, which attaches to the tibial tuberosity–the functional insertion for these muscles. The *biceps femoris, semitendinosus*, and *semimembranosus* on the posterior surface of the thigh are often collectively called the **hamstrings.** The medially

Table 7.11 Muscles That Move the Wrist and Fingers

Muscle	Origin	Insertion	Action
Flexor carpi radialis (flek′-sor kar′-pī rā-dē-a′-lis)	Medial epicondyle of humerus	Metacarpals II and III	Flexes and abducts wrist
Flexor carpi ulnaris (flek′-sor kar′-pī ul-na′-ris)	Medial epicondyle of humerus and olecranon of ulna	Carpal bones and metacarpal V	Flexes and adducts wrist
Palmaris longus (pal-ma′-ris long′-gus)	Medial epicondyle of humerus	Fascia of palm	Flexes wrist
Extensor carpi radialis longus (eks-ten′-sor kar′-pī rā-dē-a′-lis long′-gus)	Lateral epicondyle of humerus	Metacarpal II	Extends and abducts wrist
Extensor carpi ulnaris (eks-ten′-sor kar′-pī ul-na′-ris)	Lateral epicondyle of humerus	Metacarpal V	Extends and adducts wrist
Extensor digitorum (eks-ten′-sor dij-i-to′-rum)	Lateral epicondyle of humerus	Posterior surfaces of phalanges II–V	Extends fingers

Table 7.12 Muscles That Move the Thigh

Muscle	Origin	Insertion	Action
Iliacus (il′-ē-ak-us)	Fossa of ilium	Lesser trochanter of femur	Flexes thigh
Psoas major (so′-as)	Lumbar vertebrae	Lesser trochanter of femur	Flexes thigh
Gluteus maximus (glū′-tē-us mak′-si-mus)	Posterior surfaces of ilium, sacrum, and coccyx	Posterior surface of femur and iliotibial tract	Extends and laterally rotates thigh
Gluteus medius (glū′-tē-us mē′-dē-us)	Lateral surface of ilium	Greater trochanter of femur	Abducts and medially rotates thigh
Tensor fasciae latae (ten′-sor fash′-ē-ē lah-tē′)	Anterior iliac crest	Iliotibial tract	Flexes and abducts thigh
Adductor longus (ad-duk′-tor long′-gus)	Pubis near pubic symphysis	Posterior surface of femur	Adducts, flexes, and laterally rotates thigh
Adductor magnus (ad-duk′-tor mag′-nus)	Inferior portion of ischium and pubis	Same as above	Same as above

Clinical Insight

Intramuscular injections are commonly used when quick absorption is desired. Such injections are given in three sites: (1) the lateral surface of the deltoid; (2) the gluteus medius in the superior, lateral portion of the buttock; and (3) the vastus lateralis near the midpoint of the lateral surface of the thigh. These injection sites are chosen because there are no major nerves or blood vessels present that could be damaged, and the muscles have a good blood supply to aid absorption. The site chosen may vary with the age and condition of the patient.

located *gracilis* has two insertions that give it dual actions. The long, straplike *sartorius* extends diagonally across the anterior surface of the thigh and spans both the hip and knee joints. Its contraction enables the legs to cross (tables 7.12, and 7.13 and figures 7.20, 7.21, and 7.22).

Muscles That Move the Foot and Toes

Many muscles are involved in the movement of the foot and toes. They are located in the leg and originate on the femur, tibia, or fibula and insert on the tarsal bones, metatarsals, or phalanges. The posterior leg muscles include the *gastrocnemius* and *soleus,* which insert through a common tendon, the calcaneal (Achilles) tendon, which attaches to the calcaneus. The *tibialis*

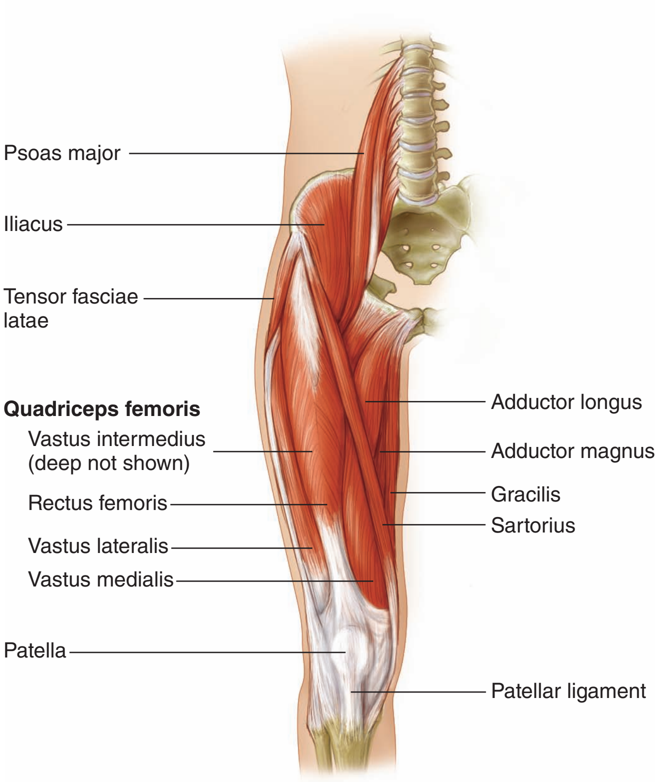


Figure 7.20 Muscles of the anterior right thigh. (Note that the vastus intermedius is deep to the rectus femoris and is not visible in this view.)

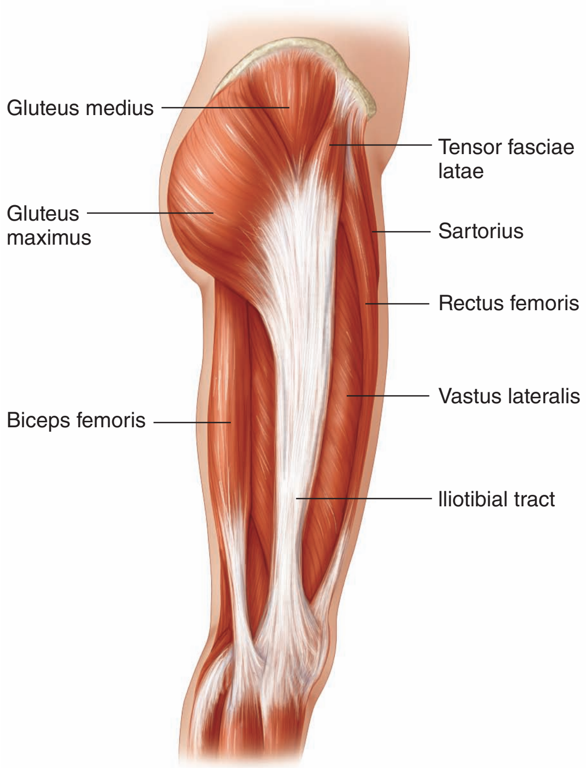


Figure 7.21 Muscles of the lateral right thigh.

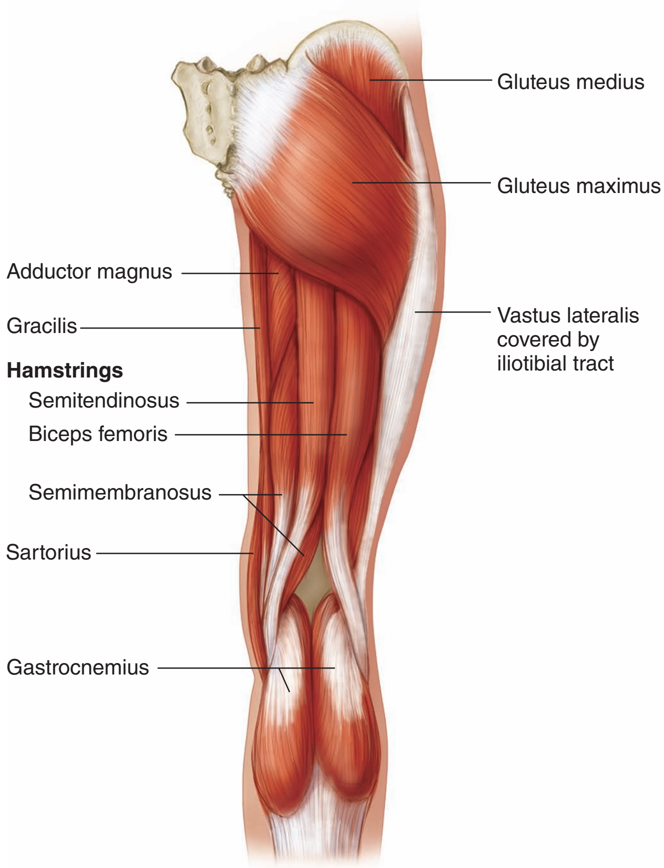


Figure 7.22 Muscles of the posterior right thigh.

anterior is anteriorly located, and the *extensor digitorum longus* lies lateral to it. Note that although the extensor digitorum extends the toes, as its name implies, it also dorsiflexes the foot. The *fibularis longus* is located on the lateral surface of the leg (table 7.14 and figures 7.23 to 7.25).

Note how the tendons are held in position by the bands of ligaments at the ankle.

Clinical Insight

Repeated stress from athletic activities may cause inflammation of a tendon, a condition known as *tendonitis*. Tendons associated with the shoulder, elbow, hip, and knee joints are most commonly affected.

Check My Understanding

18. Name the muscles that flex the thigh.
19. What are the four parts of the quadriceps femoris?
20. What is the action of muscles inserting on the calcaneus?

Table 7.13 Muscles That Move the Leg

Muscle	Origin	Insertion	Action
Quadriceps femoris (quad′-ri-seps fem′-or-is)	Four muscles of the anterior thigh that extend the leg.		
Rectus femoris (rek′-tus fem′-or-is)	Anterior inferior iliac spine and superior margin of acetabulum	Patella; tendon continues as patellar ligament, which attaches to tibial tuberosity	Extends leg and flexes thigh
Vastus lateralis (vas′-tus lat-er-a′lis)	Greater trochanter and posterior surface of femur	Same as above	Extends leg
Vastus medialis (vas′-tus me-de-a′lis)	Medial and posterior surfaces of femur	Same as above	Extends leg
Vastus intermedius (vas′-tus in-ter-mē′dē-us)	Anterior and lateral surfaces of femur	Same as above	Extends leg
Hamstrings	Three distinct muscles of the posterior thigh that flex leg and extend thigh.		
Biceps femoris (bi′-seps fem′-or-is)	Ischial tuberosity and posterior surface of femur	Head of fibula and lateral condyle of tibia	Flexes and laterally rotates leg; extends thigh
Semitendinosus (sem-ē-ten-di-nō′-sus)	Ischial tuberosity	Medial surface of tibia	Flexes and medially rotates leg; extends thigh
Semimembranosus (sem-ē-mem-brah-nō′-sus)	Ischial tuberosity	Medial condyle of tibia	Flexes and medially rotates leg; extends thigh
Gracilis (gras′-il-is)	Pubis near pubic symphysis	Medial surface of tibia	Adducts thigh; flexes leg and locks knee
Sartorius (sar-to′r-ē-us)	Anterior superior iliac spine	Medial surface of tibia	Flexes thigh and leg; abducts and laterally rotates thigh

Table 7.14 Muscles That Move the Foot and Toes

Muscle	Origin	Insertion	Action
Gastrocnemius (gas-trōk-nē′m-ē-us)	Medial and lateral condyles of femur	Calcaneus by the calcaneal tendon	Plantar flexes foot and flexes leg
Soleus (sō′l-ē-us)	Posterior surface of tibia and fibula	Calcaneus by the calcaneal tendon	Plantar flexes foot
Fibularis longus (fib-yu-lar-ris long′-gus)	Lateral condyle of tibia and head and body of fibula	Metatarsal I and tarsal bones	Plantar flexes and everts foot; supports arch
Tibialis anterior (tib-ē-a′l-is an-te′rē-or)	Lateral condyle and surface of tibia	Metatarsal I and tarsal bones	Dorsiflexes and inverts foot
Extensor digitorum longus (eks-ten′-sor dig-i-tor′-um long′-gus)	Lateral condyle of tibia and anterior surface of fibula	Phalanges of toes II-V	Dorsiflexes and everts foot; extends toes

7.6 Disorders of the Muscular System

Learning Objective

15. Describe the major disorders of the muscular system.

Some disorders of the muscle system may result from factors associated only with muscles, while others are caused by disorders of the nervous system. Certain neurological disorders are included here because of their obvious effect on muscle action.

Muscular Disorders

Cramps involve involuntary, painful tetany. The precise cause is unknown, but a cramp seems to result from chemical changes in the muscle, such as ionic imbalances or ATP deficiencies. Sometimes a severe blow to a muscle can produce a cramp.

Fibrosis (fī -brō′-sis) is an abnormal increase of connective tissue in a muscle. Usually, it results from connective tissue replacing dead muscle fibers following an injury.

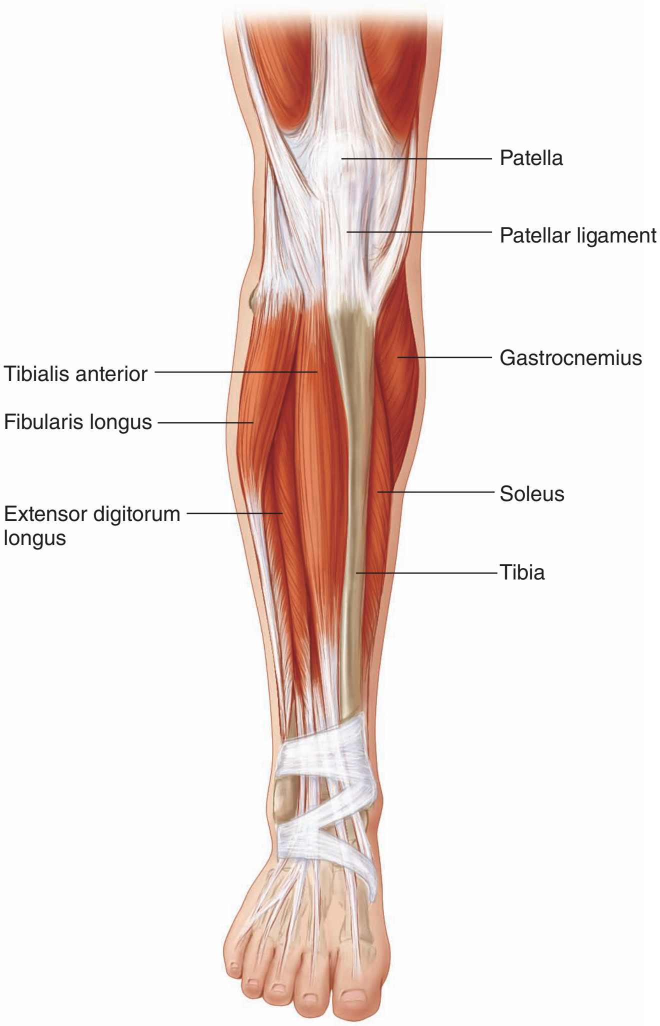


Figure 7.23 Muscles of the anterior right leg.

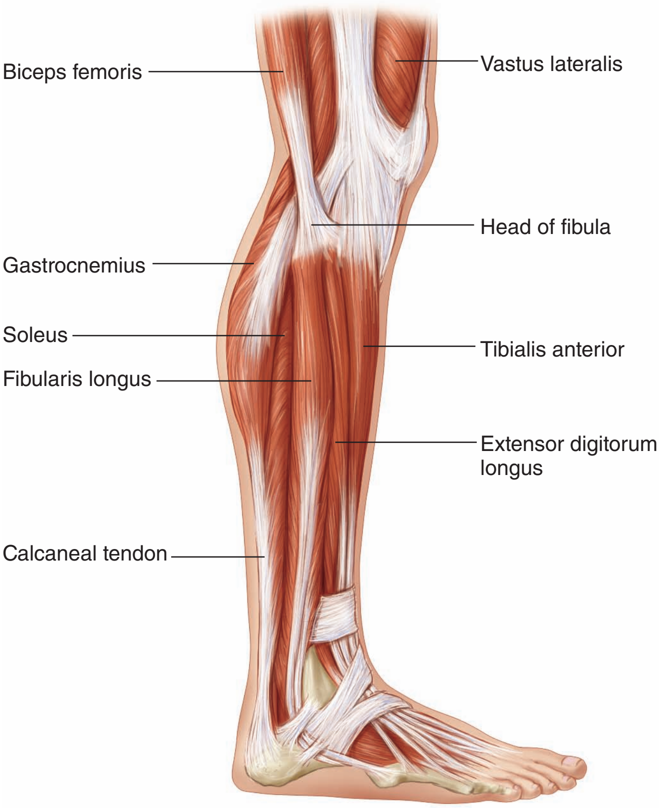


Figure 7.24 Lateral view of muscles of the right leg.

Fibromyalgia (fi-brō-mi-alj-a) is a painful condition of the muscles and joints with no known cause. Once thought to be a mental disorder, this is actually a musculoskeletal disorder that often leads to depression due to the helpless nature of the chronic symptoms.

Muscular dystrophy (dis′-trō-fē) is a general term for a number of inherited muscular disorders that are characterized by the progressive degeneration of muscles. The affected muscles gradually weaken and atrophy, producing a progressive crippling of the patient. There is no specific drug cure, but patients are encouraged to keep active and are given muscle-strengthening exercises.

Strains, or "pulled muscles," result when a muscle is stretched excessively. This usually occurs when an antagonist has not relaxed quickly enough as an agonist contracts. The hamstrings are a common site of muscle strains. In mild strains, only a few muscle fibers are damaged. In severe strains, both connective and muscle tissues are torn, and muscle function may be severely impaired.

Neurological Disorders Affecting Muscles

Botulism (boch′-ū-lizm) poisoning is caused by a neurotoxin produced by the bacterium *Clostridium botulinum.* The toxin prevents release of ACh from the terminal boutons of somatic motor axons. Without prompt treatment with an antitoxin, death may result from paralysis of breathing muscles. Poisoning results from eating improperly canned vegetables or meats that contain *C. botulinum* and the accumulated toxins.

Myasthenia gravis (mī-as-thē′-nē-ah grav′-i-is) is characterized by extreme muscular weakness caused by improper functioning of the neuromuscular junctions. It is an autoimmune disease in which antibodies are produced that attach to the ACh receptors on the motor end plate and reduce or block the stimulatory effect of ACh. Myasthenia gravis occurs most frequently in women between 20 and 40 years of age. Usually, it first affects ocular muscles and other muscles of the face and neck, which may lead to difficulty in chewing, swallowing, and talking. Other muscles of the body may be involved later. Treatment typically involves the use of acetylcholinesterase inhibitors and immunosuppressive drugs, such as the steroid prednisone.

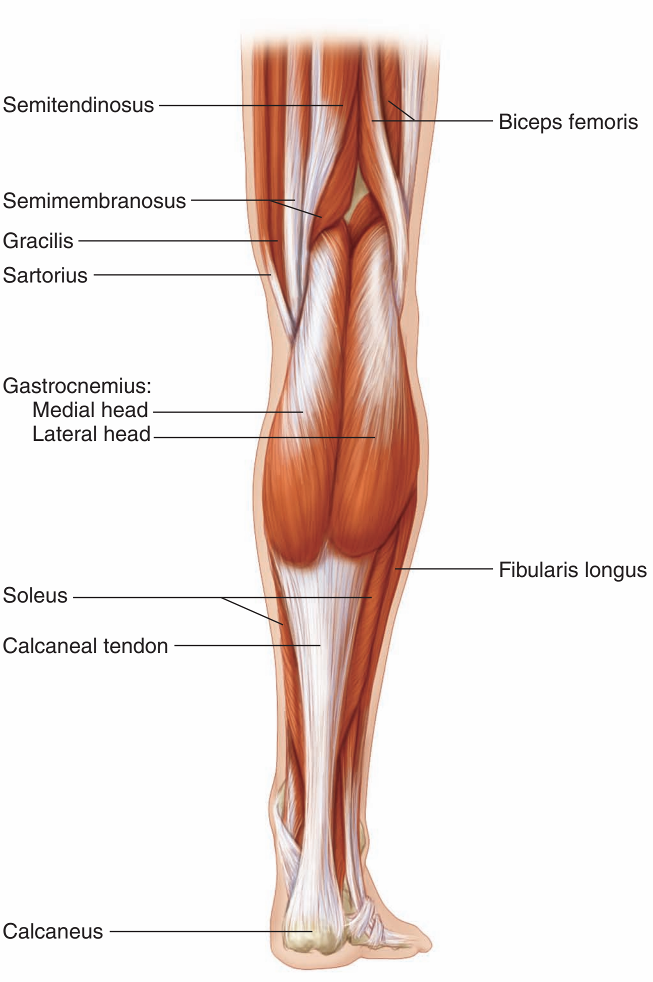


Figure 7.25 Muscles of the posterior right leg.

Poliomyelitis (pō-lē-ō-mī-e-lī′-tis) is a viral disease of somatic motor neurons in the spinal cord. Destruction of the somatic motor neurons leads to paralysis of skeletal muscles. It is now rare in industrialized countries due to the availability of a polio vaccine. Virtually all children in the United States receive this vaccine, which protects them from polio.

Spasms are sudden, involuntary contractions of a muscle or a group of muscles. They may vary from simple twitches to severe convulsions and may be accompanied by pain. Spasms may be caused by irritation of the motor neurons supplying the muscle, emotional stress, or neurological disorders. Spasms of smooth muscle in the walls of the digestive and respiratory tracts, or certain blood vessels can be hazardous. Hiccupping is a spasm of the diaphragm.

Tetanus (tet′-ah-nus) is a disease caused by the anaerobic bacterium *Clostridium tetani,* which is common in soil. Infection usually results from puncture wounds. *C. tetani* produces a neurotoxin that affects somatic motor neurons in the spinal cord, resulting in continuous stimulation and tetany of certain muscles. Because the first muscles affected are those that move the mandible, this disease is often called "lockjaw." Without prompt treatment, mortality is high. Young children usually receive vaccinations of tetanus toxoid to stimulate production of antibodies against the neurotoxin. Booster injections are given at regular intervals to keep the concentration of antibodies at a high level in order to prevent the disease.

Chapter Summary

- The three types of muscle tissue in the body are skeletal, smooth, and cardiac.
- Each type of muscle tissue has unique structural and functional characteristics.

7.1 Structure of Skeletal Muscle

- Each skeletal muscle is formed of many muscle fibers that are arranged in fascicles.
- Connective tissue envelops each muscle fiber, each fascicle, and the entire muscle.
- Muscles are attached to bones or other tissues by either tendons or aponeuroses.
- The sarcolemma is the plasma membrane of a muscle fiber, and the sarcoplasm (cytoplasm) contains the myofibrils, the contractile elements.
- Myofibrils consist of thick and thin myofilaments. The arrangement of the myofilaments produces the striations that are characteristic of muscle fibers.
- Each myofibril consists of many sarcomeres joined end-to-end. A sarcomere is bounded by a Z line at each end.
- I bands are light areas in a muscle tissue micrograph, and A bands are dark areas.
- The H band is the center of a sarcomere and contains only thick myofilaments.
- The terminal bouton of a somatic motor neuron is adjacent to each muscle fiber at the neuromuscular junction. The terminal bouton fits into depressions in the sarcolemma, called motor end plates. The synaptic cleft is the small space between the terminal bouton and motor end plate. The neurotransmitter ACh is contained in tiny vesicles in the terminal bouton.
- Each muscle fiber is innervated and controlled by a somatic motor neuron.
- A motor unit consists of a somatic motor neuron and all muscle fibers it innervates.

7.2 Physiology of Skeletal Muscle Contraction

- An activated terminal bouton releases ACh into the synaptic cleft. ACh attaches to ACh receptors of the motor end plate, which leads to the release of Ca^{2+} within the sarcoplasm. This, in turn, leads to the formation of cross-bridges between the heads of myosin molecules and the myosin binding sites on actin molecules. A series of ratchetlike movements pulls the thin myofilaments toward the center of the sarcomere, producing contraction.

- Acetylcholinesterase quickly breaks down ACh to prevent continued stimulation and to prepare the muscle fiber for the next stimulus.
- Energy for contraction comes from high-energy phosphate bonds in ATP.
- After cellular respiration has formed a muscle fiber's normal supply of ATP, excess energy is transferred to creatine to form creatine phosphate, which serves as a reserve supply of energy.
- Small amounts of oxygen are stored in combination with myoglobin, which gives muscle fibers a reserve of oxygen for aerobic respiration.
- Vigorous muscular activity quickly exhausts available oxygen, leading to the accumulation of lactic acid and causing excess post-exercise oxygen consumption. Heavy breathing after exercise provides the oxygen required to metabolize lactic acid and restore the pre-exercise state within the muscle fiber.
- Fatigue most likely results primarily from the lack of raw fuel in a muscle fiber.
- Large amounts of heat are produced by the chemical and physical processes of muscle contraction.
- When stimulated by a threshold stimulus, individual muscle fibers exhibit an all-or-none contraction response.
- A simple contraction consists of a latent phase, contraction phase, and relaxation phase.
- Whole muscles provide graded contraction responses, which are enabled by the number of motor units that are recruited.
- A sustained contraction of all motor units is tetany.
- Muscle tone is a state of partial contraction that results from alternating contractions of a few motor units.

7.3 Actions of Skeletal Muscles

- The origin is the immovable attachment, and the insertion is the movable attachment.
- Muscles are arranged in groups with opposing actions: agonists and antagonists.

7.4 Naming of Muscles

- Several criteria are used in naming muscles.
- These criteria include function, shape, relative position, location, site of attachment, origin and insertion, size, and orientation of fibers.

7.5 Major Skeletal Muscles

- Muscles of facial expression originate on skull bones and insert on the dermis of the skin. They include the epicranius, orbicularis oculi, orbicularis oris, buccinator, zygomaticus, and platysma.
- Muscles of mastication originate on fixed skull bones and insert on the mandible. They include the masseter and the temporalis.
- Muscles that move the head occur in the neck and superior back. They include the sternocleidomastoid and splenius capitis.
- Muscles of the abdominal wall connect the pelvic girdle, thoracic cage, and vertebral column. They include the rectus abdominis, external oblique, internal oblique, and transversus abdominis.
- The diaphragm is the major muscle of breathing.
- External intercostals and internal intercostals move the ribs, helping breathing.
- Muscles that move the pectoral girdle originate on the thoracic cage or vertebrae and insert on the pectoral girdle. They include the trapezius, rhomboid major and minor, levator scapulae, pectoralis minor, and serratus anterior.
- Muscles that move the arm originate on the thoracic cage, vertebrae, or pectoral girdle and insert on the humerus. They include the pectoralis major, deltoid, subscapularis, supraspinatus, infraspinatus, latissimus dorsi, teres major, and teres minor.
- Supraspinatus, infraspinatus, teres minor, and subscapularis make up the rotator cuff.
- Muscles that move the forearm originate on the scapula or humerus and insert on the radius or ulna. They include the biceps brachii, brachialis, brachioradialis, and triceps brachii.
- Muscles that move the wrist and fingers are the muscles of the forearm. They include the flexor carpi radialis, flexor carpi ulnaris, palmaris longus, extensor carpi radialis longus, extensor carpi ulnaris, and extensor digitorum.
- Muscles that move the thigh originate on the pelvic girdle and insert on the femur. They include the iliacus, psoas major, gluteus maximus, gluteus medius, tensor fasciae latae, adductor longus, and adductor magnus.
- Muscles that move the leg originate on the pelvic girdle or femur and insert on the tibia or fibula. They include the quadriceps femoris, biceps femoris, semitendinosus, semimembranosus, gracilis, and sartorius.
- Muscles that move the foot and toes are the muscles of the leg. They include the gastrocnemius, soleus, fibularis longus, tibialis anterior, and extensor digitorum longus.

7.6 Disorders of the Muscular System

- Disorders of muscles include cramps, fibrosis, fibromyalgia, muscular dystrophy, and strains.
- Neurological disorders that directly affect muscle action include botulism, myasthenia gravis, poliomyelitis, spasms, and tetanus.

Self-Review

Answers are located in appendix B.

1. A skeletal muscle consists of many ______, which are arranged in fascicles.
2. Muscles are attached to bones by ______.
3. A contractile unit of a myofibril is a ______.
4. A muscle contraction is triggered by ______ binding to its receptors on the motor end plate.
5. Contraction occurs when thick myofilaments pull ______ myofilaments toward the center of a sarcomere.
6. The movable attachment of a muscle is its ______.
7. The mandible is elevated by the contraction of the temporalis and the ______.
8. The abdominal muscle extending from the sternum to the pubis is the ______.
9. The broad muscle of the inferior back is the ______.
10. The shoulder muscle that abducts the arm is the ______.
11. The arm muscle that extends the forearm is the ______.
12. The large muscle that extends and laterally rotates the thigh is the ______.
13. The four-part thigh muscle that extends the leg is the ______.
14. The large superficial calf muscle that plantar flexes the foot is the ______.