Because flexing muscles look like mice scurrying beneath the skin, some scientist long ago dubbed them muscles, from the Latin word mus, meaning "little mouse." Indeed, the rippling muscles of professional boxers or weight lifters are often the first thing that comes to mind when someone hears the word muscle. But muscle is also the dominant tissue in the heart and in the walls of other hollow organs of the body. In all its forms, it makes up nearly half the body's mass.

The essential function of muscle is contraction, or shortening—a unique characteristic that sets it apart from any other body tissue. As a result of this ability, muscles are responsible for essentially all body movement and can be viewed as the "machines" of the body.

**Overview of Muscle Tissues**

6-1 Describe similarities and differences in the structure and function of the three types of muscle tissue, and indicate where they are found in the body.

6-2 Define muscular system.

6-3 Define and explain the role of the following: endomysium, perimysium, epimysium, tendon, and aponeurosis.

**Muscle Types**

There are three types of muscle tissue—skeletal, cardiac, and smooth (Table 6.1, p. 182). These differ in their cell structure, body location, and how they are stimulated to contract. But before we
### Table 6.1 Comparison of Skeletal, Cardiac, and Smooth Muscles

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Skeletal</th>
<th>Cardiac</th>
<th>Smooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body location</td>
<td>Attached to bones or, for some facial muscles, to skin</td>
<td>Walls of the heart</td>
<td>Mostly in walls of hollow visceral organs (other than the heart)</td>
</tr>
<tr>
<td>Cell shape and appearance</td>
<td>Single, very long, cylindrical, multinucleate cells with very obvious striations</td>
<td>Branching chains of cells; uninucleate, striations; intercalated discs</td>
<td>Single, fusiform, uninucleate; no striations</td>
</tr>
<tr>
<td>Connective tissue components</td>
<td>Epimysium, perimysium, and endomysium</td>
<td>Endomysium attached to the fibrous skeleton of the heart</td>
<td>Endomysium</td>
</tr>
<tr>
<td>Regulation of contraction</td>
<td>Voluntary; via nervous system controls</td>
<td>Involuntary; the heart has a pacemaker; also nervous system controls; hormones</td>
<td>Involuntary; nervous system controls; hormones, chemicals, stretch</td>
</tr>
<tr>
<td>Speed of contraction</td>
<td>Slow to fast</td>
<td>Slow</td>
<td>Very slow</td>
</tr>
<tr>
<td>Rhythmic contraction</td>
<td>No</td>
<td>Yes</td>
<td>Yes, in some</td>
</tr>
</tbody>
</table>
explore their differences, let’s look at some of the ways they are the same.

First, skeletal and smooth muscle cells are elongated. For this reason, these types of muscle cells (but not cardiac muscle cells) are called muscle fibers. Second, the ability of muscle to shorten, or contract, depends on two types of myofilaments, the muscle cell equivalents of the microfilaments of the cytoskeleton (studied in Chapter 3). A third similarity has to do with terminology. Whenever you see the prefixes myo- and mys- (“muscle”) and sarco- (“flesh”), you will know that muscle is being referred to. For example, in muscle cells the cytoplasm is called sarcoplasm (sar’ko-plaz’um).

Skeletal Muscle

Skeletal muscle fibers are packaged into the organs called skeletal muscles that attach to the body’s skeleton. As the skeletal muscles cover our bony “underpinnings,” they help form the much smoother contours of the body. Skeletal muscle fibers are huge, cigar-shaped, multinucleate cells. They are the largest of the muscle fiber types—some ranging up to 30 cm (nearly 1 foot) in length. Indeed, the fibers of large, hardworking muscles, such as the antigravity muscles of the hip, are so big and coarse that they can be seen with the naked eye.

Skeletal muscle is also known as striated muscle (because its fibers have obvious stripes) and as voluntary muscle (because it is the only muscle type subject to conscious control). However, it is important to recognize that skeletal muscles are often activated by reflexes (without our “willed command”) as well. When you think of skeletal muscle tissue, the key words to remember are skeletal, striated, and voluntary. Skeletal muscle tissue can contract rapidly and with great force, but it tires easily and must rest after short periods of activity.

Skeletal muscle fibers, like most cells, are soft and surprisingly fragile. Yet skeletal muscles can exert tremendous power—indeed, the force they generate in, say lifting a weight, is often much greater than that required to lift the weight. The reason they are not ripped apart as they exert force is that thousands of their fibers are bundled together by connective tissue, which provides strength and support to the muscle as a whole (Figure 6.1). Each muscle fiber is enclosed in a delicate connective tissue sheath called endomysium (en’do-mis’e-um). Several sheathed muscle fibers are then wrapped by a coarser fibrous membrane called perimysium to form a bundle of fibers called a fascicle (fas’t-kul). Many fascicles are bound together by an even tougher “overcoat” of connective tissue called an epimysium, which covers the entire muscle. The epimysia blend either into strong, cordlike tendons or into sheetlike aponeuroses (ap”o-nú-rou’séz), which attach muscles indirectly to bones, cartilages, or connective tissue coverings.

Besides simply acting to anchor muscles, tendons perform several other functions. The most important are providing durability and conserving space. Tendons are mostly tough collagenic fibers, so they can cross rough bony projections, which would tear the more delicate muscle tissues. Because of their relatively small size, more tendons than fleshy muscles can pass over a joint. Many people think of muscles as always having an enlarged “belly” that tapers down to a tendon at each end. However, muscles vary considerably.

**Q:** What is the meaning of epi? Of mys? How do these word roots relate to the role and position of the epimysium?

**A:** Ep = upon, over a muscle. The epi = upon or over a muscle. The mys = muscle. Thus, **epi** = upon or over a muscle.
in the way their fibers are arranged. Many are spindle-shaped as just described, but in others, the fibers are arranged in a fan shape or a circle (as described on pp. 202–203).

**Smooth Muscle**

*Smooth muscle* has no striations and is involuntary, which means that we cannot consciously control it. Found mainly in the walls of hollow visceral organs such as the stomach, urinary bladder, and respiratory passages, smooth muscle propels substances along a definite tract, or pathway, within the body. We can best describe smooth muscle using the terms *visceral*, *nonstriated*, and *involuntary*.

Smooth muscle cells are spindle-shaped, have a single nucleus, and are surrounded by scant endomysium (recall what you learned in Chapter 3; also see Table 6.1). They are arranged in layers and most often there are two such layers, one running circularly and the other longitudinally (as shown in Figure 6.2a). As the two layers alternately contract and relax, they change the size and shape of the organ. Moving food through the digestive tract and emptying the bowels and bladder are examples of "housekeeping" activities normally handled by smooth muscles. Smooth muscle contraction is slow and sustained. If skeletal muscle is like a speedy wind-up car that quickly runs down, then smooth muscle is like a steady, heavy-duty engine that lumbers along tirelessly.

**Cardiac Muscle**

*Cardiac muscle* is found in only one place in the body—the heart, where it forms the bulk of the heart walls. The heart serves as a pump, propelling blood into the blood vessels and to all tissues of the body. Cardiac muscle is like skeletal muscle in that it is striated, and like smooth muscle in that it is involuntary and cannot be consciously controlled by most of us. Important key words to jog your memory for this muscle type are *cardiac*, *striated*, and *involuntary*.

The cardiac cells are cushioned by small amounts of soft connective tissue (endomysium) and arranged in spiral or figure 8-shaped bundles (as shown in Figure 6.2b). When the heart contracts, its internal chambers become smaller, forcing the blood into the large arteries leaving the heart. Cardiac muscle fibers are branching cells joined by special junctions called *intercalated*
**Muscle Functions**

Producing movement is a common function of all muscle types, but skeletal muscle plays three other important roles in the body as well: it maintains posture, stabilizes joints, and generates heat. Let's take a look.

**Producing Movement**

Just about all movements of the human body result from muscle contraction. Skeletal muscles are responsible for mobility of the body as a whole, including all locomotion (walking, swimming, and cross-country skiing, for instance) and manipulating things with your agile upper limb. They enable us to respond quickly to changes in the external environment. For example, their speed and power enable us to jump out of the way of a runaway car and then follow its flight with our eyes. They also allow us to express our emotions with the silent language of smiles and frowns.

They are distinct from the smooth muscle of blood vessels walls and cardiac muscle of the heart, which work together to circulate blood and maintain blood pressure, and the smooth muscle of other hollow organs, which forces fluids (urine, bile) and other substances (food, a baby) through internal body channels.

**Maintaining Posture and Body Position**

We are rarely aware of the workings of the skeletal muscles that maintain body posture. Yet they function almost continuously, making one tiny adjustment after another so that we maintain an erect or seated posture despite the never-ending downward pull of gravity.

**Stabilizing Joints**

As the skeletal muscles pull on bones to cause movements, they also stabilize the joints of the skeleton. Indeed, muscle tendons are extremely important in reinforcing and stabilizing joints that have poorly fitting articulating surfaces (the shoulder joint, for example).

**Generating Heat**

Body heat is generated as a by-product of muscle activity. As ATP is used to power muscle contraction, nearly three-quarters of its energy escapes as heat. This heat is vital in maintaining normal body temperature. Skeletal muscle accounts for at least 40 percent of body mass, so it is the muscle type most responsible for generating heat.

**Additional Functions**

Some other roles are usually left off lists of major muscle functions: Skeletal muscles protect fragile internal organs by enclosure. Smooth muscles form valves to regulate the passage of substances through internal body openings, dilate and constrict the pupils of our eyes, and activate the arrector pili muscles that cause our hairs to stand on end.

**Did You Get It?**

1. How do cells of the three types of muscle tissues differ from one another anatomically?
2. Which muscle type has the most elaborate connective tissue wrappings?
3. What does striated mean relative to muscle cells?
4. How do the movements promoted by skeletal muscle differ from those promoted by smooth muscle?

(For answers, see Appendix D.)

**Microscopic Anatomy of Skeletal Muscle**

6-4 Describe the microscopic structure of skeletal muscle, and explain the role of actin- and myosin-containing myofilaments.

As mentioned previously, skeletal muscle cells are multinucleate (Figure 6.3a, p. 186). Many oval nuclei can be seen just beneath the plasma membrane, which is called the **sarclemma** (sar`ko-lem`ah; "muscle husk") in muscle cells. The nuclei are
pushed aside by long ribbonlike organelles, the myofibrils (mi"o-fi"brilz), which nearly fill the cytoplasm. Alternating light (I) and dark (A) bands along the length of the perfectly aligned myofibrils give the muscle cell as a whole its striped appearance. (Think of the second letter of light, I, and the second letter of dark, A, to help you remember which band is which.) A closer look at the banding pattern reveals that the light I band has a midline interruption, a darker area called the Z disc, and the dark A band has a lighter central area called the H zone (Figure 6.3b). The M line in the center of the H zone contains tiny protein rods that hold adjacent thick filaments together.

So why are we bothering with all these terms—dark this and light that? Because the banding pattern reveals the working structure of the myofibrils. First, we find that the myofibrils are actually chains of tiny
contractile units called sarcomeres (sar’ko-mer’z), which are aligned end to end like boxcars in a train along the length of the myofibrils. Second, it is the arrangement of even smaller structures (myofilaments) within sarcomeres that actually produces the banding pattern.

Let’s examine how the arrangement of the myofilaments leads to the banding pattern. There are two types of threadlike protein myofilaments within each of our “boxcar” sarcomeres (Figure 6.3c). The larger thick filaments, also called myosin filaments, are made mostly of bundled molecules of the protein myosin, but they also contain ATPase enzymes, which split ATP to generate the power for muscle contraction. Notice that the thick filaments extend the entire length of the dark A band. Also, notice that the midparts of the thick filaments are smooth, but their ends are studded with small projections (Figure 6.3c). These projections, or myosin beads, are called cross bridges when they link the thick and thin filaments together during contraction.

The thin filaments are composed of the contractile protein called actin, plus some regulatory proteins that play a role in allowing (or preventing) binding of myosin heads to actin. The thin filaments, also called actin filaments, are anchored to the Z disc (a disclike membrane). Notice that the light I band includes parts of two adjacent sarcomeres and contains only the thin filaments. Although they overlap the ends of the thick filaments, the thin filaments do not extend into the middle of a relaxed sarcomere, and thus the central region (the H zone) looks a bit lighter. When contraction occurs and the actin-containing filaments slide toward each other into the center of the sarcomeres, these light zones disappear because the actin and myosin filaments are completely overlapped. For now, however, just recognize that it is the precise arrangement of the myofilaments in the myofibrils that produces the banding pattern, or striations, in skeletal muscle cells.

Another very important muscle fiber organelle—the sarcoplasmic reticulum (SR), is a specialized smooth endoplasmic reticulum (not shown in Figure 6.3). The interconnecting tubules and sacs of the SR surround each and every myofibril just as the sleeve of a loosely crocheted sweater surrounds your arm. The major role of this elaborate system is to store calcium and to release it on demand when the muscle fiber is stimulated to contract. As you will see, calcium provides the final “go” signal for contraction.

Did You Get It?

5. Specifically, what is responsible for the banding pattern in skeletal muscle cells?

(For the answer, see Appendix D.)

**Skeletal Muscle Activity**

**Stimulation and Contraction of Single Skeletal Muscle Cells**

6-5 Describe how an action potential is initiated in a muscle cell.

Muscle cells have some special functional properties that enable them to perform their duties. The first of these is irritability, also termed responsiveness, which is the ability to receive and respond to a stimulus. The second, contractility, is the ability to shorten (forcibly) when adequately stimulated. This property sets muscle apart from all other tissue types. Extensibility is the ability of muscle cells to be stretched, whereas elasticity is their ability to recoil and resume their resting length after being stretched.

**The Nerve Stimulus and the Action Potential**

To contract, skeletal muscle cells must be stimulated by nerve impulses. One motor neuron (nerve cell) may stimulate a few muscle cells or hundreds of them, depending on the particular muscle and the work it does. One neuron and all the skeletal muscle cells it stimulates is called a motor unit (Figure 6.4, p. 188). When a long, threadlike extension of the neuron, called the nerve fiber or axon, reaches the muscle, it branches into a number of axon terminals, each of which forms junctions with the sarcolemma of a different muscle cell (Figure 6.5, p. 189). These junctions, called neuromuscular (literally, “nerve-muscle”) junctions, contain vesicles filled with a chemical referred to as a neurotransmitter. The specific neurotransmitter that stimulates skeletal muscle cells is acetylcholine (a’se-tēl-kō’lēn), or ACh. Although the nerve endings and the muscle cells’ membranes are very close, they never touch. The gap between them, the synaptic cleft, is filled with tissue (interstitial) fluid.
Figure 6.4 Motor units. Each motor unit consists of a motor neuron and all the muscle fibers it activates. (a) Portions of two motor units are shown. The motor neurons reside in the spinal cord, and their axons extend to the muscle. Within the muscle, each axon divides into a number of axon terminals, distributed to muscle fibers scattered throughout the muscle. (b) Photo of a portion of a motor unit (1,150×).

Did You Get It?

6. What two structures are closely associated at a neuromuscular junction?

(For the answer, see Appendix D.)

Now that we have described the structure of the neuromuscular junction, we are ready to examine what happens there. (As you read, refer to the numbered steps in Figure 6.5.) When a nerve impulse reaches the axon terminals 1, calcium channels open, and calcium (Ca²⁺) enters the terminal 2. Calcium entry causes some of the synaptic vesicles in the axon terminal to release acetylcholine 3, which then diffuses across the synaptic cleft and attaches to receptors (membrane proteins) that are located in highly folded regions of the sarcolemma 4. If enough acetylcholine is released, the sarcolemma at that point becomes temporarily even more permeable to sodium ions (Na⁺), which rush into the muscle cell, and to potassium ions (K⁺), which diffuse out of the cell. However, more Na⁺ enters than K⁺ leaves. This imbalance gives the cell interior an excess of positive ions, which reverses the electrical conditions of the sarcolemma. This event, called depolarization, opens more channels that allow Na⁺ entry only 5. This “upset” generates an electrical current called an action potential. Once begun, the action potential is unstoppable; it travels over the entire surface of the sarcolemma, conducting the electrical impulse from one end of the cell to the other. The result is contraction of the muscle cell.

Note that while the action potential is occurring, acetylcholine, which began the process, is broken down to acetic acid and choline by enzymes (acetylcholinesterase, or AChE) present on the sarcolemma and in the synaptic cleft 6. For
Figure 6.5 Events at the neuromuscular junction.

1. Action potential reaches axon terminal of motor neuron.

2. Calcium (Ca²⁺) channels open, and Ca²⁺ enters the axon terminal.

3. Ca²⁺ entry causes some synaptic vesicles to release their contents (acetylcholine, a neurotransmitter) by exocytosis.

4. Acetylcholine diffuses across the synaptic cleft and binds to receptors in the sarcolemma.

5. ACh binds and channels open that allow simultaneous passage of Na⁺ into the muscle fiber and K⁺ out of the muscle fiber. More Na⁺ ions enter than K⁺ ions leave, producing a local change in the electrical conditions of the membrane (depolarization). This eventually leads to an action potential.

6. The enzyme acetylcholinesterase breaks down ACh in the synaptic cleft, ending the process.
this reason, a single nerve impulse produces only one contraction. This prevents continued contraction of the muscle cell in the absence of additional nerve impulses. The muscle cell relaxes until stimulated by the next round of acetylcholine release.

Let’s compare this series of events to lighting a match under a small dry twig (Figure 6.6). The charring of the twig by the flame can be compared to the change in membrane permeability that allows sodium ions into the cell. When that part of the twig becomes hot enough (when enough sodium ions have entered the cell), the twig will suddenly burst into flame, and the flame will consume the twig (the action potential will be conducted along the entire length of the sarcolemma). We explain this series of events more fully in the discussion of nerve physiology (Chapter 7, pp. 234–237).

The events that return the cell to its resting state include (1) diffusion of potassium ions (K⁺) out of the cell and (2) operation of the sodium-potassium pump, the active transport mechanism that moves the sodium and potassium ions back to their initial positions.

### Did You Get It?

1. **What ions enter the muscle cell during action potential generation?**

(For the answer, see Appendix D.)

### Mechanism of Muscle Contraction: The Sliding Filament Theory

6-6 Describe the events of muscle cell contraction.

What causes the filaments to slide? This question brings us back to the myosin heads that protrude all around the ends of the thick filaments. When muscle fibers are activated by the nervous system as just described, the myosin heads attach to binding sites on the thin filaments, and the sliding begins. Each cross bridge attaches and detaches several times during a contraction, generating tension that helps to pull the thin filaments toward the center of the sarcomere. As this event occurs simultaneously in sarcomeres throughout the muscle cell, the cell shortens (Figure 6.7).

This “walking” of the myosin cross bridges, or heads, along the thin filaments during muscle shortening is much like a centipede’s gait. Some myosin heads (“legs”) are always in contact with actin (“the ground”), so that the thin filaments cannot slide backward as this cycle repeats again and again during contraction. Notice that the myofilaments themselves do not shorten during contraction; they simply slide past each other.

The attachment of the myosin cross bridges to actin requires calcium ions (Ca²⁺). So where does the calcium come from? Action potentials pass deep into the muscle cell along membranous
9. Which is a cross-bridge attachment more similar to: a precise rowing team or a person pulling a bucket on a rope out of a well?

(For answers, see Appendix D.)

Contraction of a Skeletal Muscle as a Whole

6-7 Define graded response, tetanus, isotonic and isometric contractions, and muscle tone as these terms apply to a skeletal muscle.

Graded Responses

In skeletal muscles, the “all-or-none” law of muscle physiology applies to the muscle cell, not to the whole muscle. It states that a muscle cell will contract to its fullest extent when it is stimulated adequately; it never partially contracts. However, the whole muscle reacts to stimuli with graded responses, or different degrees of shortening. In general, graded muscle contractions can be produced two ways: (1) by changing the frequency of muscle stimulation and (2) by changing the number of muscle cells being stimulated at one time. We briefly describe a muscle’s response to each of these next.

Muscle Response to Increasingly Rapid Stimulation Although muscle twitches (single, brief, jerky contractions) sometimes result from certain nervous system problems, this is not the way our muscles normally operate. In most types of muscle activity, nerve impulses are delivered to the muscle at a very rapid rate—so rapid that the muscle does not get a chance to relax completely between stimuli. As a result, the effects of the successive contractions are “summed” (added) together, and the contractions of the muscle get stronger and smoother. When the muscle is stimulated so rapidly that no evidence of relaxation is seen and the contractions are completely smooth and sustained, the muscle is said to be in fused, or complete, tetanus (tet’ah-nus), or in tetanic contraction.* Until this point is reached, the muscle

* Tetanic contraction is normal and desirable and is quite different from the pathological condition of tetanus (commonly called lockjaw), which is caused by a toxin made by bacteria. Lockjaw causes muscles to go into uncontrollable spasms, finally causing respiratory arrest.
In a relaxed muscle cell, the regulatory proteins forming part of the actin myofilaments prevent myosin binding (see a). When an action potential (AP) sweeps along its sarcolemma and a muscle cell is excited, calcium ions (Ca\(^{2+}\)) are released from intracellular storage areas (the sacs of the sarcoplasmic reticulum).

The flood of calcium acts as the final trigger for contraction, because as calcium binds to the regulatory proteins on the actin filaments, the proteins undergo a change in both their shape and their position on the thin filaments. This action exposes myosin-binding sites on the actin, to which the myosin heads can attach (see b), and the myosin heads immediately begin seeking out binding sites.

The free myosin heads are “cocked,” much like a set mousetrap. Myosin attachment to actin “springs the trap,” causing the myosin heads to snap (pivot) toward the center of the sarcomere. When this happens, the thin filaments are slightly pulled toward the center of the sarcomere (see c). ATP provides the energy needed to release and recock each myosin head so that it is ready to attach to a binding site farther along the thin filament. When the AP ends and calcium ions are returned to SR storage areas, the regulatory proteins resume their original shape and position, and again block myosin binding to the thin filaments. As a result, the muscle cell relaxes and settles back to its original length.

is said to be exhibiting **unfused**, or **incomplete**, tetanus (Figure 6.9).

**Muscle Response to Stronger Stimuli** Tetanus produces stronger (more forceful) muscle contractions, but its primary role is to produce smooth and prolonged muscle contractions. How forcefully a muscle contracts depends to a large extent on how many of its cells are stimulated. When only a few cells are stimulated, the contraction of the muscle as a whole is slight. When all the motor units are active and all the muscle cells are stimulated, the muscle contraction is as strong as it can get. Thus, muscle contractions can be slight or vigorous depending on what work has to be done. The same hand that gently soothes can also deliver a stinging slap!

**Providing Energy for Muscle Contraction**

Describe three ways in which ATP is regenerated during muscle activity.
As a muscle contracts, the bonds of ATP molecules are hydrolyzed to release the needed energy.

Recall that ATP can be compared to a tightly coiled spring that is ready to uncoil with tremendous energy when the "catch" is released (Chapter 2, p. 55). Remember that all bonds store energy, and the "catch" in this example is one of the characteristic high-energy bonds in ATP.

Surprisingly, muscles store very limited supplies of ATP—only a few seconds' worth, just enough to get you going. Because ATP is the only energy source that can be used directly to power muscle activity, ATP must be regenerated continuously if contraction is to continue.

Working muscles use three pathways for ATP regeneration:

1. **Direct phosphorylation of ADP by creatine phosphate** (Figure 6.10a, p. 194). The unique high-energy molecule creatine phosphate (CP) is found in muscle fibers but not other cell types. As ATP is being depleted, interactions between CP and ADP result in transfers of a high-energy phosphate group from CP to ADP, thus regenerating more ATP in a fraction of a second. Although muscle cells store perhaps five times as much CP as ATP, the CP supplies are also soon exhausted (in less than 15 seconds).

2. **Aerobic respiration** (Figure 6.10c). At rest and during light to moderate exercise, some 95 percent of the ATP used for muscle activity comes from aerobic respiration. Aerobic respiration occurs in the mitochondria and involves a series of metabolic pathways that use oxygen. These pathways are collectively referred to as oxidative phosphorylation. During aerobic respiration, glucose is broken down completely to carbon dioxide and water, and some of the energy released as the bonds are broken is captured in the bonds of ATP molecules. Although aerobic respiration provides a rich ATP harvest (about 32 ATP per 1 glucose), it is fairly slow and requires continuous delivery of oxygen and nutrient fuels to the muscle to keep it going.

3. **Anaerobic glycolysis and lactic acid formation** (Figure 6.10b). The initial steps of glucose breakdown occur via a pathway called glycolysis, which does not use oxygen and hence is anaerobic (literally "without oxygen"). During glycolysis, which occurs in the cytosol, glucose is broken down to pyruvic acid, and small amounts of energy are captured in ATP bonds (2 ATP per 1 glucose molecule). As long as enough oxygen is present, the pyruvic acid then enters the oxygen-requiring aerobic pathways that occur within the mitochondria to produce more ATP as described above. However, when muscle activity is intense, or oxygen and glucose delivery is temporarily inadequate to
meet the needs of the working muscles, the sluggish aerobic pathways cannot keep up with the demands for ATP. Under these conditions, the pyruvic acid generated during glycolysis is converted to lactic acid, and the overall process is referred to as anerobic glycolysis. Anaerobic glycolysis produces only about 5 percent as much ATP from each glucose molecule as aerobic respiration. However, it is some 2½ times faster, and it can provide most of the ATP needed for 30 to 40 seconds of strenuous muscle activity. The main shortcomings of anaerobic glycolysis are that it uses huge amounts of glucose for a small ATP harvest, and the accumulating lactic acid promotes muscle soreness.

**Did You Get It?**

10. What are the three energy sources for skeletal muscle contraction?

11. What is the immediate source of energy for muscle contraction?

(For answers, see Appendix D.)

**Muscle Fatigue and Oxygen Deficit**

6-9 Define oxygen deficit and muscle fatigue, and list possible causes of muscle fatigue.

If we exercise our muscles strenuously for a long time, muscle fatigue occurs. A muscle is fatigued when it is unable to contract even though it is still being stimulated. Without rest, a working muscle begins to tire and contracts more weakly until it finally ceases reacting and stops contracting. Factors that contribute to muscle fatigue are not fully known. Suspected causes are imbalances in ions (Ca²⁺, K⁺) and problems of the neuromuscular junction. However, many agree that the major factor is the oxygen deficit that occurs during prolonged muscle activity. Oxygen deficit is not a total lack of oxygen; rather, it happens when a
person is not able to take in oxygen fast enough to keep the muscles supplied with all the oxygen they need when they are working vigorously. Obviously, then, the work that a muscle can do and how long it can work without becoming fatigued depend on how good its blood supply is. When muscles lack oxygen, lactic acid begins to accumulate in the muscle via the anaerobic pathway described previously. We can recognize this event by the burning sensation we experience then. In addition, the muscle's ATP supply starts to run low, and ionic imbalance tends to occur. Together these factors cause the muscle to contract less and less effectively and finally to stop contracting altogether.

True muscle fatigue, in which the muscle quits entirely, rarely occurs in most of us because we feel fatigued long before it happens and we simply slow down or stop our activity. It does happen commonly in marathon runners. Many of them have literally collapsed when their muscles became fatigued and could no longer work.

Oxygen deficit, which always occurs to some extent during vigorous muscle activity, must be "paid back" whether fatigue occurs or not. During the recovery period after activity, the individual breathes rapidly and deeply. This continues until the muscles have received the amount of oxygen needed to get rid of the accumulated lactic acid and make ATP and creatine phosphate reserves.

**Types of Muscle Contractions—Isotonic and Isometric**

Until now, we have been discussing contraction in terms of shortening, but muscles do not always shorten when they contract. (I can hear you saying, "What kind of double-talk is that?"—but pay attention.) The event that is common to all muscle contractions is that tension develops in the muscle as the actin and myosin myofilaments interact and the myosin cross bridges attempt to slide the thin actin-containing filaments past the thick myosin myofilaments.

**Isotonic contractions** (literally, "same tone" or tension) are familiar to most of us. In isotonic contractions, the myofilaments are successful in their sliding movements, the muscle shortens, and movement occurs. Bending the knee, rotating the arms, and smiling are all examples of isotonic contractions.

Contractions in which the muscles do not shorten are called **isometric contractions** (literally, "same measurement" or length). In isometric contractions, the myosin myofilaments are "spinning their wheels," and the tension in the muscle keeps increasing. They are trying to slide, but the muscle is pitted against some more or less immovable object. For example, muscles are contracting isometrically when you try to lift a 400-pound dresser alone. When you straighten a bent elbow, the triceps muscle is contracting isotonically. But when you push against a wall with bent elbows, the wall doesn't move, and the triceps muscles, which cannot shorten to straighten the elbows, are contracting isometrically.

**Muscle Tone**

One aspect of skeletal muscle activity cannot be consciously controlled. Even when a muscle is voluntarily relaxed, some of its fibers are contracting—first one group and then another. Their contraction is not visible, but, as a result of it, the muscle remains firm, healthy, and constantly ready for action. This state of continuous partial contractions is called **muscle tone**. Muscle tone is the result of different motor units, which are scattered through the muscle, being stimulated by the nervous system in a systematic way.

**Homeostatic Imbalance 6.1**

If the nerve supply to a muscle is destroyed (as in an accident), the muscle is no longer stimulated in this manner, and it loses tone and becomes paralyzed. Soon after, it becomes **flaccid** (flak'sid), or soft and flabby, and begins to **atrophy** (waste away).

**Effect of Exercise on Muscles**

**6-10 Describe the effects of aerobic and resistance exercise on skeletal muscles and other body organs.**

The amount of work a muscle does is reflected in changes in the muscle itself. Muscle inactivity (due to a loss of nerve supply, immobilization, or whatever the cause) always leads to muscle weakness and wasting. Muscles are no exception to the saying "Use it or lose it!"

Conversely, regular exercise increases muscle size, strength, and endurance. However, not all types of exercise produce these effects—in fact, there are important differences in the benefits of exercise.
Aerobic, or endurance, types of exercise, such as participating in an aerobics class, jogging, or biking (Figure 6.11a), result in stronger, more flexible muscles with greater resistance to fatigue. These changes come about, at least partly, because the blood supply to the muscles increases, and the individual muscle cells form more mitochondria and store more oxygen. However, aerobic exercise benefits much more than the skeletal muscles. It makes overall body metabolism more efficient, improves digestion (and elimination), enhances neuromuscular coordination, and makes the skeleton stronger. The heart enlarges (hypertrophies) so that more blood is pumped out with each beat, fat deposits are cleared from the blood vessel walls, and the lungs become more efficient in gas exchange. These benefits may be permanent or temporary, depending on how often and how vigorously a person exercises.

Aerobic exercise does not cause the muscles to increase much in size, even though the exercise may go on for hours. The bulging muscles of a bodybuilder or professional weight lifter result mainly from resistance, or isometric, exercises (Figure 6.11b), which pit the muscles against some immovable object (or nearly immovable). Resistance exercises require very little time and little or no special equipment. A few minutes every other day is usually sufficient. You can push against a wall, and you can strongly contract buttock muscles even while standing in line at the grocery store. The key is forcing the muscles to contract with as much force as possible. The increased muscle size and strength that result are due mainly to enlargement of individual muscle cells (they make more contractile filaments) rather than to an increase in their number. The amount of connective tissue that reinforces the muscle also increases.

Because endurance and resistance exercises produce different patterns of muscle response, it is important to know what your exercise goals are. Lifting weights will not improve your endurance for a marathon. By the same token, jogging will do little to improve your muscle definition for competing in the Mr. or Ms. Muscle contest, nor will it make you stronger for moving furniture. Obviously, the best exercise program for most people is one that includes both types of exercise.

Did You Get It?

12. Gary is trying with all his might to pull a tree stump out of the ground. It does not budge. Which type of contraction are his muscles undergoing?

13. What is meant by the term oxygen deficit?

14. To develop big, beautiful skeletal muscles, you should focus on which type of exercise: aerobic or resistance exercise?

(For answers, see Appendix D.)

Muscle Movements, Types, and Names

6-11 Define origin, insertion, prime mover, antagonist, synergist, and fixator as they relate to muscles.

6-12 Demonstrate or identify the different types of body movements.

There are five very basic understandings about gross muscle activity. I call these the Five Golden Rules of skeletal muscle activity because they make it easier to understand muscle movements and appreciate muscle interactions (Table 6.2).

Types of Body Movements

Every one of our 600-odd skeletal muscles is attached to bone, or to other connective tissue structures, at no fewer than two points. One of these points, the origin, is attached to the immovable or
Table 6.2  The Five Golden Rules of Skeletal Muscle Activity

1. With a few exceptions, all skeletal muscles cross at least one joint.

2. Typically, the bulk of a skeletal muscle lies proximal to the joint crossed.

3. All skeletal muscles have at least two attachments: the origin and the insertion.

4. Skeletal muscles can only pull; they never push.

5. During contraction, a skeletal muscle insertion moves toward the origin.

less movable bone (Figure 6.12). The insertion is attached to the movable bone, and when the muscle contracts, the insertion moves toward the origin. Some muscles have interchangeable origins and insertions. For example, the rectus femoris muscle of the anterior thigh crosses both the hip and knee joints. Its most common action is to extend the knee, in which case the proximal pelvic attachment is the origin. However, when the knee is bent (by other muscles), the rectus femoris can flex the hip, and then its distal attachment on the leg is considered the origin.

Generally speaking, body movement occurs when muscles contract across joints. The type of movement depends on the mobility of the joint and on where the muscle is located in relation to the joint. The most obvious examples of the action of muscles on bones are the movements that occur at the joints of the limbs. However, less freely movable bones are also tugged into motion by the muscles, such as the vertebrae's movements when the torso is bent to the side.

Next we describe the most common types of body movements (Figure 6.13, p. 198). Try to demonstrate each movement as you read the following descriptions:

• **Flexion.** Flexion is a movement, generally in the sagittal plane, that decreases the angle of the joint and brings two bones closer together (Figure 6.13a and b). Flexion is typical of hinge joints (bending the knee or elbow), but it is also common at ball-and-socket joints (for example, bending forward at the hip).

Q: The other movement that the biceps brachii muscle (shown in this illustration) can bring about is to move the torso toward the bar when you chin yourself. Would the forearm still be the insertion for that movement?

![Muscle contracting](image)

**Figure 6.12 Muscle attachments (origin and insertion).** When a skeletal muscle contracts, its insertion moves toward its origin.

• **Extension.** Extension is the opposite of flexion, so it is a movement that increases the angle, or the distance, between two bones or parts of the body (straightening the knee or elbow). Extension that is greater than 180° (as when you move your arm posteriorly beyond its normal anatomical position, or tip your head so that your chin points toward the ceiling) is called hyperextension (Figure 6.13a and b).

• **Rotation.** Rotation is movement of a bone around its longitudinal axis (Figure 6.13c). Rotation is a common movement of ball-and-socket joints and describes the movement of the atlas around the dens of the axis (as in shaking your head "no").

• **Abduction.** Abduction is moving a limb away (generally on the frontal plane) from the midline, or median plane, of the body (Figure 6.13d).
(a) Flexion, extension, and hyperextension of the shoulder and knee

(b) Flexion, extension, and hyperextension

Figure 6.13 Body movements.

(c) Rotation
Figure 6.13 (continued)
The terminology also applies to the fanning movement of the fingers or toes when they are spread apart.

- **Adduction.** Adduction is the opposite of abduction, so it is the movement of a limb toward the body midline (Figure 6.13d).

- **Circumduction.** Circumduction is a combination of flexion, extension, abduction, and adduction commonly seen in ball-and-socket joints such as the shoulder. The proximal end of the limb is stationary, and its distal end moves in a circle. The limb as a whole outlines a cone (Figure 6.13d).

Special Movements

Certain movements do not fit into any of the previous categories and occur at only a few joints. (Some of these special movements are shown in Figure 6.13.)

- **Dorsiflexion and plantar flexion.** Up-and-down movements of the foot at the ankle are given special names. Lifting the foot so that its superior surface approaches the shin (standing on your heels) is called **dorsiflexion**, whereas depressing the foot (pointing the toes) is called **plantar flexion** (Figure 6.13e). Dorsiflexion of the foot corresponds to extension of the hand at the wrist, whereas plantar flexion of the foot corresponds to flexion of the hand.

- **Inversion and eversion.** Inversion and eversion are also special movements of the foot (Figure 6.13f). To invert the foot, turn the sole medially. To evert the foot, turn the sole laterally.

- **Supination and pronation.** The terms **supination** (sū̂p-i-nā́-shən; “turning backward”) and **pronation** (pro-nā́-shən; “turning forward”) refer to movements of the radius around the ulna (Figure 6.13g). Supination occurs when the forearm rotates laterally so that the palm faces anteriorly and the radius and ulna are parallel. Pronation occurs when the forearm rotates medially so that the palm faces posteriorly. Pronation brings the radius across the ulna so that the two bones form an X. A helpful memory trick: If you lift a cup of soup up to your mouth on your palm, you are supinating (“soup”-inating).

- **Opposition.** In the palm of the hand, the saddle joint between metacarpal 1 and the carpals allows opposition of the thumb (Figure 6.13h). This is the action by which you move your thumb to touch the tips of the other fingers on the same hand. This unique action makes the human hand a fine tool for grasping and manipulating things.

### Interactions of Skeletal Muscles in the Body

Muscles can’t push—they can only pull as they contract—so most often body movements result from two or more muscles acting together or against each other. Muscles are arranged in such a way that whatever one muscle (or group of muscles) can do, other muscles can reverse. In general, groups of muscles that produce opposite movements lie on opposite sides of a joint (Figure 6.14). Because of this arrangement, muscles are able to bring about an immense variety of movements.

The muscle that has the major responsibility for causing a particular movement is called the **prime mover.** (This physiological term has been borrowed by the business world to label a person who gets things done.) Muscles that oppose or reverse a movement are **antagonists** (an-tag’o-nists). When a prime mover is active, its antagonist is stretched and relaxed. Antagonists can be prime movers in their own right. For example, the biceps of the arm (prime mover of elbow flexion) is antagonized by the triceps (a prime mover of elbow extension).

**Synergists** (sin’er-jı̂TS; syn = together; erg = work) help prime movers by producing the same movement or by reducing undesirable movements. When a muscle crosses two or more joints, its contraction will cause movement in all the joints crossed unless synergists are there to stabilize them. For example, the flexor muscles of the fingers cross both the wrist and the finger joints. You can make a fist without bending your wrist because synergist muscles stabilize the wrist joints and allow the prime mover to act on the finger joints.

**Fixators** are specialized synergists. They hold a bone still or stabilize the origin of a prime mover so all the tension can be used to move the insertion bone. The postural muscles that stabilize the vertebral column are fixators, as are the muscles that anchor the scapulae to the thorax.
(a) A muscle that crosses on the **anterior side** of a joint produces **flexion**.

Example: Pectoralis major (anterior view)

(b) A muscle that crosses on the **posterior side** of a joint produces **extension**.

Example: Latissimus dorsi (posterior view)
The latissimus dorsi is the antagonist of the pectoralis major.

(c) A muscle that crosses on the **lateral side** of a joint produces **abduction**.

Example: Deltoid middle fibers (anterolateral view)

(d) A muscle that crosses on the **medial side** of a joint produces **adduction**.

Example: Teres major (postero-lateral view)
The teres major is the antagonist of the deltoid.

*These generalities do not apply to the knee and ankle because the lower limb is rotated during development. The muscles that cross these joints posteriorly produce flexion, and those that cross anteriorly produce extension.*

**Figure 6.14 Muscle action.** The action of a muscle can be inferred by the muscle’s position as it crosses a joint.
In summary, although prime movers seem to get all the credit for causing certain movements, the actions of antagonistic and synergistic muscles are also important in producing smooth, coordinated, and precise movements.

**Did You Get It?**

15. What action is being performed by a person who sticks out his thumb to hitch a ride?
16. What actions take place at the neck when you nod your head up and down as if saying "yes"?
17. In what way are fixators and synergist muscles important?

(For answers, see Appendix D.)

**Naming Skeletal Muscles**

6-13 List some criteria used in naming muscles.

Like bones, muscles come in many shapes and sizes to suit their particular tasks in the body. Muscles are named on the basis of several criteria, each of which focuses on a particular structural or functional characteristic. Paying close attention to these cues can greatly simplify your task of learning muscle names and actions:

- **Direction of the muscle fibers.** Some muscles are named in reference to some imaginary line, usually the midline of the body or the long axis of a limb bone. When a muscle's name includes the term *rectus* (straight), its fibers run parallel to that imaginary line. For example, the rectus femoris is the straight muscle of the thigh, or femur. Similarly, the term *oblique* as part of a muscle's name tells you that the muscle fibers run obliquely (at a slant) to the imaginary line.

- **Relative size of the muscle.** Such terms as *maximus* (largest), *minimus* (smallest), and *longus* (long) are sometimes used in the names of muscles—for example, the gluteus maximus is the largest muscle of the gluteal muscle group.

- **Location of the muscle.** Some muscles are named for the bone with which they are associated. For example, the temporalis and frontalis muscles overlie the temporal and frontal bones of the skull, respectively.

- **Number of origins.** When the term *biceps*, *triceps*, or *quadriceps* forms part of a muscle name, you can assume that the muscle has two, three, or four origins, respectively. For example, the biceps muscle of the arm has two heads, or origins, and the triceps muscle has three.

- **Location of the muscle's origin and insertion.** Occasionally, muscles are named for their attachment sites. For example, the sternocleidomastoid muscle has its origin on the sternum (sterno) and clavicle (cleido) and inserts on the mastoid process of the temporal bone.

- **Shape of the muscle.** Some muscles have a distinctive shape that helps to identify them. For example, the deltoid muscle is roughly triangular (*deltoid* means "triangular").

- **Action of the muscle.** When muscles are named for their actions, terms such as *flexor*, *extensor*, and *adductor* appear in their names. For example, the adductor muscles of the thigh all bring about its adduction, and the extensor muscles of the wrist all extend the wrist.

**Arrangement of Fascicles**

Skeletal muscles consist of fascicles, but fascicle arrangements vary, producing muscles with different structures and functional properties. We describe the most common patterns of fascicle arrangement next.

The pattern is **circular** when the fascicles are arranged in concentric rings (Figure 6.15a). Circular muscles are typically found surrounding external body openings which they close by contracting. A general term for such muscles is *spincters* ("squeezers"). Examples are the orbicularis muscles surrounding the eyes and mouth.

In a **convergent** muscle, the fascicles converge toward a single insertion tendon. Such a muscle is triangular or fan-shaped, such as the pectoralis major muscle of the anterior thorax (Figure 6.15b).

In a **parallel** arrangement, the length of the fascicles run parallel to the long axis of the muscle. These muscles are straplike (Figure 6.15d). A modification of the parallel arrangement, called *fusiform*, results in a spindle-shaped muscle with an expanded belly (midsection), such as the biceps brachii muscle of the arm (Figure 6.15c).

In a **pennate** (pen'ət; "feather") pattern, short fascicles attach obliquely to a central tendon. In the extensor digitorum muscle of the leg, the fascicles insert into only one side of the tendon and the muscle is *unipennate* (Figure 6.15g). If the fascicles insert into opposite sides of the tendon or
from several different sides, the muscle is bipennate (Figure 6.15f) or multipennate (Figure 6.15e), respectively.

A muscle’s fascicle arrangement determines its range of motion and power. The longer and the more nearly parallel the fascicles are to a muscle’s long axis, the more the muscle can shorten, but such muscles are not usually very powerful. Muscle power depends more on the total number of muscle cells in the muscle. The stocky bipennate and multipennate muscles, which pack in the most fibers, shorten very little but are very powerful.

**Did You Get It?**

18. Based on their names, deduce some characteristics of the following muscles: tibialis anterior, erector spinae, rectus abdominis.

19. What is the fascicle arrangement of the orbicularis oris muscle?

(For answers, see Appendix D.)

**Gross Anatomy of Skeletal Muscles**

6-14 Name and locate the major muscles of the human body (on a torso model, muscle chart, or diagram), and state the action of each.

It is beyond the scope of this book to describe the hundreds of skeletal muscles of the human body. We describe only the most important muscles here. All the superficial muscles we consider are summarized in the tables (Tables 6.3 and 6.4) and illustrated in the overall body views (Figures 6.22 and 6.23 on pp. 214 and 216) that accompany the tables (pp. 215 and 217).

**Head and Neck Muscles**

The head muscles (Figure 6.16, p. 204) are an interesting group. They have many specific functions but are usually grouped into two large categories—facial muscles and chewing muscles. Facial muscles are unique because they are inserted into soft tissues such as other muscles or skin. When they pull on the skin of the face, they permit us to smile faintly, grin widely, frown, pout, deliver a kiss, and so forth. The chewing muscles begin to break down food for the body. All head and neck muscles we describe are paired except for the platysma, the orbicularis oris, the frontalis, and the occipitalis.

**Facial Muscles**

**Frontalis** The frontalis, which covers the frontalis bone, runs from the cranial aponeurosis to the skin of the eyebrows, where it inserts. This muscle allows you to raise your eyebrows, as in surprise, and to
wrinkle your forehead. At the posterior end of the cranial aponeurosis is the small occipitalis muscle, which covers the posterior aspect of the skull and pulls the scalp posteriorly.*

**Orbicularis Oculi** The orbicularis oculi (or-bik'ə-ly'ə-ri) has fibers that run in circles around the eyes. It allows you to close your eyes, squint, blink, and wink.

**Orbicularis Oris** The orbicularis oris is the circular muscle of the lips. Because it closes the mouth and protrudes the lips, it is often called the "kissing" muscle.

**Buccinator** The fleshy buccinator (bu'si-nä'tor) muscle runs horizontally across the cheek and inserts into the orbicularis oris. It flattens the cheek (as in whistling or blowing a trumpet). It is also listed as a chewing muscle because it compresses the cheek to hold the food between the teeth during chewing.

**Zygomaticus** The zygomaticus (zi'go-mat'i-kus) extends from the corner of the mouth to the cheekbone. It is often referred to as the "smiling" muscle because it raises the corners of the mouth upward.

**Chewing Muscles**

The buccinator muscle, which is a member of this group, is described with the facial muscles.

**Masseter** As it runs from the zygomatic process of the temporal bone to the mandible, the masseter (mā-se'ter) covers the angle of the lower jaw. This muscle closes the jaw by elevating the mandible.

**Temporalis** The temporalis is a fan-shaped muscle overlying the temporal bone. It inserts into the mandible and acts as a synergist of the masseter in closing the jaw.

*Although the current references on anatomic terminology refer to the frontalis and occipitalis as the *frontal* and *occipital* bellies of the *epicranius* ("over the cranium") muscle, we will continue to use the terms *frontalis* and *occipitalis* here.*
A CLOSER LOOK Anabolic Steroids: Dying to Win?

Everyone loves a winner, and top athletes are popular and make lots of money. It is not surprising that some will grasp at anything to increase their performance— including “juice” (anabolic steroids). Anabolic steroids are variants of testosterone, the hormone responsible for the changes that occur during puberty and convert boys into men: most notably, the increase in bone and muscle mass. Pharmaceutical companies introduced anabolic steroids in the 1950s to treat certain muscle-wasting diseases, anemia, and muscle atrophy in patients immobilized after surgery.

Convinced that huge doses could enhance masculinizing effects in grown men, many athletes have turned to anabolic steroids. In 2004, allegations of rampant steroid abuse by Barry Bonds, formerly of the San Francisco Giants, and by other baseball players surfaced, stunning sports fans. In October 2007, Marion Jones admitted using performance-enhancing steroids when she won five gold medals in the 2000 Olympics, and in June 2010, Mark McGwire of the St. Louis Cardinals finally admitted steroid use.

It is estimated that one out of every 10 young men has tried steroids, and the practice is spreading rapidly among young women.

Although the use of these drugs has been banned by most international athletic competitions, underground suppliers keep producing new versions of designer steroids that evade antidoping tests. There is little question that many professional bodybuilders and athletes who require great muscle strength (such as discus throwers and weight lifters) are heavy users. Football players have also admitted to using steroids. Athletes claim that anabolic steroids increase muscle mass and strength, oxygen-carrying capacity of the blood, and aggressive behavior (the urge to “steamroller the other guy”).

But do the drugs do all that is claimed for them? Research studies have reported increases in isometric strength and body weight in steroid users. Although these are results weight lifters dream about, there is hot dispute over whether the drugs also enhance fine muscle coordination and endurance (which are important to runners and other athletes).

Do the claimed slight advantages conferred by steroid use outweigh the risks? Absolutely not! Physicians say that steroids cause bloated faces; shriveled testes and infertility; liver damage and liver cancer; and changes in blood cholesterol levels (which may place long-term users at risk for coronary disease). Additionally, about one-third of anabolic steroid users develop serious psychiatric problems, including depression, delusions, and manic behavior involving Jekyll-and-Hyde personality swings and extreme violence (the so-called ‘roid rage).

A more recent arrival on the scene, sold over the counter as a “nutritional performance enhancer,” is androstenedione, which is converted to testosterone in the body. It is taken orally, and much of it is destroyed by the liver soon after ingestion, but the few milligrams that survive temporarily boost testosterone levels. Reports of “wannabe” athletes from the fifth grade up sweeping the supplement off the drugstore shelves are troubling. Androstenedione is not regulated by the U.S. Food and Drug Administration (FDA), and its long-term effects are unpredictable. Studies at Massachusetts General Hospital in Boston have found that boys and men who took the supplement developed elevated levels of the female hormone estrogen as well as testosterone (raising their risk of feminizing effects such as enlarged breasts), early puberty, and stunted bone growth leading to shorter-than-normal adult height.

Some athletes say they are willing to do almost anything to win, short of killing themselves. Are those who use anabolic steroids unwittingly doing this as well?
Figure 6.17 Muscles of the anterior trunk, shoulder, and arm. (a) Muscles crossing the shoulder joint, causing movements of the arm. The platysma of the neck is removed. (b) Muscles of the abdominal wall. Portions of the superficial muscles of the right side of the abdomen are cut away to reveal the deeper muscles.

Neck Muscles
For the most part, the neck muscles, which move the head and shoulder girdle, are small and straplike. We consider only two neck muscles here.

Platysma The platysma is a single sheetlike muscle that covers the anterolateral neck (see Figure 6.16). It originates from the connective tissue covering of the chest muscles and inserts into the area around the mouth. Its action is to pull the corners of the mouth inferiorly, producing a downward sag of the mouth (the “sad clown” face).

Sternocleidomastoid The paired sternocleidomastoid (ster'no-klé-do-mas'toid) muscles are two-headed muscles, one found on each side of the neck. Of the two heads of each muscle, one arises from the sternum and the other arises from the clavicle (see Figure 6.22, p. 214). The heads fuse before inserting into the mastoid process of the temporal bone. When both sternocleidomastoid muscles contract together, they flex your neck. (It is this action of bowing the head that has led some people to call these muscles the “prayer” muscles.) If just one muscle contracts, the head is rotated toward the shoulder on the opposite side and tilts the head to its own side.

Homeostatic Imbalance 6.2
In some difficult births, one of the sternocleidomastoid muscles may be injured and develop spasms. A baby injured in this way has torticollis (tor'ti-kol'is), or wryneck.

Did You Get It?
20. Which muscle raises your eyebrow?
21. Which two muscles are synergists in jaw closure?

(For answers, see Appendix D.)
Trunk Muscles

The trunk muscles include (1) those that move the vertebral column (most of which are posterior anti-gravity muscles); (2) anterior thorax muscles, which move the ribs, head, and arms; and (3) muscles of the abdominal wall, which help to move the vertebral column and, most important, form the muscular "girdle" of the abdominal body wall.

Anterior Muscles (Figure 6.17)

Pectoralis Major The pectoralis (pek"to-ra'lis) major is a large fan-shaped muscle covering the upper part of the chest. Its origin is from the sternum, shoulder girdle, and the first six ribs. It inserts on the proximal end of the humerus. This muscle forms the anterior wall of the axilla and acts to adduct and flex the arm.

Intercostal Muscles The intercostal muscles are deep muscles found between the ribs. (Although they are not shown in Figure 6.17, which shows only superficial muscles, they are illustrated in Figure 6.22, p. 214.) The external intercostals are important in breathing because they help to raise the rib cage when you inhale. The internal intercostals, which lie deep to the external intercostals, depress the rib cage, helping to move air out of the lungs when you exhale forcibly.

Muscles of the Abdominal Girdle The anterior abdominal muscles (rectus abdominis, external and internal obliques, and transversus abdominis) form a natural "girdle" that reinforces the body trunk. Taken together, they resemble the structure of plywood because the fibers of each muscle or muscle pair run in a different direction. Just as plywood is exceptionally strong for its thickness, the abdominal muscles form a muscular wall that is well suited for its job of containing and protecting the abdominal contents.

* Rectus abdominis. The paired straplike rectus abdominis muscles are the most superficial muscles of the abdomen. They run from the pubis to the rib cage, enclosed in an aponeurosis. Their main function is to flex the vertebral column. They also compress the abdominal contents during defecation and childbirth and are involved in forced breathing.

* External oblique. The external oblique muscles are paired superficial muscles that make up the lateral walls of the abdomen. Their fibers run downward and medially from the last eight ribs and insert into the ilium. Like the rectus abdominis, they flex the vertebral column, but they also rotate the trunk and bend it laterally.

* Internal oblique. The internal oblique muscles are paired muscles deep to the external obliques. Their fibers run at right angles to those of the external obliques. They arise from the iliac crest and insert into the last three ribs. Their functions are the same as those of the external obliques.

* Transversus abdominis. The transversus abdominis is the deepest muscle of the abdominal wall and has fibers that run horizontally across the abdomen. It arises from the lower ribs and iliac crest and inserts into the pubis. This muscle compresses the abdominal contents.

Posterior Muscles (Figure 6.18, p. 208)

Trapezius The trapezius (trah-pe'ze-us) muscles are the most superficial muscles of the posterior neck and upper trunk. When seen together, they form a diamond- or kite-shaped muscle mass. Their origin is very broad. Each muscle runs from the occipital bone of the skull down the vertebral column to the end of the thoracic vertebrae. They then flare laterally to insert on the scapular spine and clavicle. The trapezius muscles extend the head (thus they are antagonists of the sternocleidomastoids). They also can elevate, depress, adduct, and stabilize the scapula.

Latissimus Dorsi The latissimus (lah-tis'is-mus) dorsi muscles are the two large, flat muscles that cover the lower back. They originate on the lower spine and ilium and then sweep superiorly to insert into the proximal end of the humerus. Each latissimus dorsi extends and adducts the humerus. These are very important muscles when the arm must be brought down in a power stroke, as when swimming or striking a blow.

Erector Spinae The erector spinae (e-rek'tor spi'ne) group is the prime mover of back extension. These paired muscles are deep muscles of the back (Figure 6.18b). Each erector spinae is a composite muscle consisting of three muscle columns (longissimus, iliocostalis, and spinalis) that
collectively span the entire length of the vertebral column. These muscles not only act as powerful back extensors ("erectors") but also provide resistance that helps control the action of bending over at the waist. Following injury to back structures, these muscles go into spasms, a common source of lower back pain.

**Quadratus Lumborum** The fleshy quadratus lumborum (quad-ra’tus lum-bor’um) muscles form part of the posterior abdominal wall. Acting separately, each muscle of the pair flexes the spine laterally. Acting together, they extend the lumbar spine. These muscles arise from the iliac crests and insert into the upper lumbar vertebrae (Figure 6.18b).

**Deltoid** The deltoids are fleshy, triangle-shaped muscles that form the rounded shape of your shoulders (see Figure 6.18a). Because they are so bulky, they are a favorite injection site (Figure 6.19) when relatively small amounts of medication (less than 5 ml) must be given intramuscularly (into muscle). The origin of each deltoid winds across the shoulder girdle from the spine of the scapula to the clavicle. It inserts into the proximal humerus. The deltoïds are the prime movers of arm abduction.

**Did You Get It?**

22. Which muscle group is the prime mover of back extension?

23. What structural feature makes the abdominal musculature especially strong for its thickness?

24. Which muscle of the posterior trunk is the synergist of the pectoralis major muscle in arm adduction?

(For answers, see Appendix D.)

**Muscles of the Upper Limb**

The upper limb muscles fall into three groups. The first group includes muscles that arise from the shoulder girdle and cross the shoulder joint to insert into the humerus (see Figures 6.17 and 6.18a). We have already considered these muscles, which move the arm—they are the pectoralis major, latissimus dorsi, and deltoïd.
**Muscles of the Humerus That Act on the Forearm**

All *anterior* arm muscles cause elbow flexion. In order of decreasing strength these are the brachialis, biceps brachii, and brachioradialis (Figures 6.17a and 6.22).

**Biceps Brachii** The biceps brachii (bra'kc-i) is the most familiar muscle of the arm because it bulges when the elbow is flexed (see Figure 6.17a). It originates by two heads from the shoulder girdle and inserts into the radial tuberosity. This muscle is the powerful prime mover for flexion of the forearm and acts to supinate the forearm. The best way to remember its action is to think of opening a bottle of wine. The biceps supinates the forearm to turn the corkscrew and then flexes the elbow to pull the cork.

**Brachialis** The brachialis lies deep to the biceps muscle and is as important as the biceps in elbow flexion. The brachialis lifts the ulna as the biceps lifts the radius.

**Brachioradialis** The brachioradialis is a fairly weak muscle that arises on the humerus and inserts into the distal forearm (see Figure 6.22, p. 214). Hence, it resides mainly in the forearm.

**Triceps Brachii** The triceps brachii is the only muscle fleshing out the posterior humerus (see Figure 6.18a). Its three heads arise from the shoulder girdle and proximal humerus, and it inserts into the olecranon process of the ulna. Being the powerful prime mover of elbow extension, it is the antagonist of the biceps brachii. This muscle is often called the "boxer's" muscle because it can deliver a straight-arm knockout punch.

**Muscles of the Lower Limb**

Muscles that act on the lower limb cause movement at the hip, knee, and foot joints. They are among the largest, strongest muscles in the body and are specialized for walking and balancing the body. Because the pelvic girdle is composed of heavy, fused bones that allow little movement, no special group of muscles is necessary to stabilize it. This is very different from the shoulder girdle, which requires several fixator muscles.

Many muscles of the lower limb span two joints and can cause movement at both of them. Therefore, the terms *origin* and *insertion* are often interchangeable in referring to these muscles.

Muscles acting on the thigh are massive muscles that help hold the body upright against the pull of gravity and cause various movements at the hip joint. Muscles acting on the leg form the flesh of the thigh. (In common usage, the term *leg*
Figure 6.20 Pelvic, hip, and thigh muscles of the right side of the body.
(a) Posterior view of hip and thigh muscles. (b) Diagram showing deep structures of the gluteal region and the proper site for administering an injection into the gluteus medius muscle.

refers to the whole lower limb, but anatomically the term refers only to that part between the knee and the ankle.) The thigh muscles cross the knee and cause its flexion or extension. Because many of the thigh muscles also have attachments on the pelvic girdle, they can cause movement at the hip joint as well.

Muscles originating on the leg cause assorted movements of the ankle and foot. We will consider only three muscles of this group, but there are many others that act to extend and flex the ankle and toe joints.

Muscles Causing Movement at the Hip Joint (Figure 6.20)

Gluteus Maximus The gluteus maximus (gloo’te-us max’i-mus) is a superficial muscle of the hip that forms most of the flesh of the buttock (Figure 6.20a). It is a powerful hip extensor that acts to bring the thigh in a straight line with the
pelvis. Although it is not very important in walking, it is probably the most important muscle for extending the hip when power is needed, as when climbing stairs and when jumping. It originates from the sacrum and iliac bones and inserts on the gluteal tuberosity of the femur and into the large tendinous *iliotibial* tract.

**Gluteus Medius** The gluteus medius runs from the ilium to the femur, beneath the gluteus maximus...
for most of its length. The gluteus medius is a hip abductor and is important in steadying the pelvis during walking. The gluteus medius is an important site for giving intramuscular injections, particularly when more than 5 ml is administered (see Figure 6.20b). Although it might appear that the large, fleshy gluteus maximus that forms the bulk of the buttock mass would be a better choice, notice that the medial part of each buttock overlies the large sciatic nerve; hence this area must be carefully avoided. This can be accomplished by mentally dividing the buttock into four equal quadrants (shown by the division lines on Figure 6.20b). The superolateral quadrant then overlies the gluteus medius muscle, which is usually a very safe site for an intramuscular injection.

**Iliopsoas** The iliopsoas (ill'-o-so'as; the p is silent) is a fused muscle composed of two muscles, the iliacus and the psoas major (Figure 6.20c). It runs from the iliac bone and lower vertebrae deep inside the pelvis to insert on the lesser trochanter of the femur. It is a prime mover of hip flexion. It also acts to keep the upper body from falling backward when we are standing erect.

**Adductor Muscles** The muscles of the adductor group form the muscle mass at the medial side of each thigh (Figure 6.20c). As their name indicates, they adduct, or press, the thighs together. However, because gravity does most of the work for them, they tend to become flabby very easily. Special exercises are usually needed to keep them toned. The adductors have their origin on the pelvis and insert on the proximal aspect of the femur.

**Muscles Causing Movement at the Knee Joint (Figure 6.20)**

**Hamstring Group** The muscles forming the muscle mass of the posterior thigh are the hamstrings (Figure 6.20a). The group consists of three muscles, the biceps femoris, semimembranosus, and semitendinosus, which originate on the ischial tuberosity and run down the thigh to insert on both sides of the proximal tibia. They are prime movers of thigh extension and knee flexion. Their name comes from the fact that butchers use their tendons to hang hams (consisting of thigh and hip muscles) for smoking. These tendons can be felt at the back of the knee.

**Sartorius** Compared with other thigh muscles described here, the thin, straplike sartorius (sart'o-re-us) muscle is not too important. However, it is the most superficial muscle of the thigh and so is rather hard to miss (Figure 6.20c). It runs obliquely across the thigh from the anterior iliac crest to the medial side of the tibia. It is a weak thigh flexor. The sartorius is commonly referred to as the "tailor's" muscle because it acts as a synergist to bring about the cross-legged position in which old-time tailors are often shown.

**Quadriceps Group** The quadriceps (kwod'ris-seps) group consists of four muscles—the rectus femoris and three vastus muscles—that flesh out the anterior thigh. (Only two vastus muscles are visible in Figure 6.20c. The third, the vastus intermedius, is obscured by the rectus femoris muscle, which lies over it.) The vastus muscles originate from the femur; the rectus femoris originates on the pelvis. All four muscles insert into the tibial tuberosity via the patellar ligament. The group as a whole acts to extend the knee powerfully, as when kicking a football. Because the rectus femoris crosses two joints, the hip and the knee, it can also help to flex the hip. The vastus lateralis and rectus femoris are sometimes used as intramuscular injection sites (Figure 6.20d), particularly in infants, who have poorly developed gluteus muscles.

**Muscles Causing Movement at the Ankle and Foot (Figure 6.21)**

**Tibialis Anterior** The tibialis anterior is a superficial muscle on the anterior leg. It arises from the upper tibia and then parallels the anterior crest as it runs to the tarsal bones, where it inserts by a long tendon. It acts to dorsiflex and invert the foot.

**Extensor Digitorum Longus** Lateral to the tibialis anterior, the extensor digitorum longus muscle arises from the lateral tibial condyle and proximal three-quarters of the fibula and inserts into the phalanges of toes 2 to 5. It is a prime mover of toe extension.

**Fibularis Muscles** The three fibularis muscles—longus, brevis, and tertius—are found on the lateral part of the leg. They arise from the fibula and insert into the metatarsal bones of the foot.
The group as a whole plantar flexes and everts the foot.

**Gastrocnemius** The gastrocnemius (gas"trok-ne'ime-us) muscle is a two-bellied muscle that forms the curved calf of the posterior leg. It arises by two heads, one from each side of the distal femur, and inserts through the large calcaneal (Achilles) tendon into the heel of the foot. It is a prime mover for plantar flexion of the foot; for this reason it is often called the "toe dancer's" muscle. If its insertion tendon is cut, walking is very difficult. The foot drags because the heel cannot be lifted.

**Soleus** Deep to the gastrocnemius is the fleshy soleus muscle. Because it arises on the tibia and fibula (rather than the femur), it does not affect knee movement, but like the gastrocnemius, it inserts into the calcaneal tendon and is a strong plantar flexor of the foot.

Most of the superficial muscles previously described are shown in anterior and posterior views of the body as a whole (Figure 6.22, p. 214 and Figure 6.23, p. 216) and are summarized in the tables (Table 6.3, p. 215 and Table 6.4, p. 217). Take the time to review these muscles again before continuing with this chapter.

(Text continues on page 218.)
Figure 6.22 Major superficial muscles of the anterior surface of the body.
<table>
<thead>
<tr>
<th>Name</th>
<th>Origin</th>
<th>Insertion</th>
<th>Primary action(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Head/neck muscles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontalis</td>
<td>Cranial aponeurosis</td>
<td>Skin of eyebrows</td>
<td>Raises eyebrows</td>
</tr>
<tr>
<td>Orbicularis oculi</td>
<td>Frontal bone and maxilla</td>
<td>Tissue around eyes</td>
<td>Blinks and closes eye</td>
</tr>
<tr>
<td>Orbicularis oris</td>
<td>Mandible and maxilla</td>
<td>Skin and muscle around mouth</td>
<td>Closes and protrudes lips</td>
</tr>
<tr>
<td>Temporalis</td>
<td>Temporal bone</td>
<td>Mandible</td>
<td>Closes jaw</td>
</tr>
<tr>
<td>Zygomatricus</td>
<td>Zygomatic bone</td>
<td>Skin and muscle at corner of lips</td>
<td>Raises corner of mouth</td>
</tr>
<tr>
<td>Masseter</td>
<td>Temporal bone</td>
<td>Mandible</td>
<td>Closes jaw</td>
</tr>
<tr>
<td>Buccinator</td>
<td>Maxilla and mandible near molars</td>
<td>Orbicularis oris</td>
<td>Compresses cheek (as in sucking), holds food between teeth during chewing</td>
</tr>
<tr>
<td>Sternocleidomastoid</td>
<td>Sternum and clavicle</td>
<td>Temporal bone (mastoid process)</td>
<td>Flexes neck; laterally rotates head</td>
</tr>
<tr>
<td>Platysma</td>
<td>Connective tissue covering of superior chest muscles</td>
<td>Tissue around mouth</td>
<td>Tenses skin of neck (as in shaving)</td>
</tr>
<tr>
<td><strong>Trunk muscles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pectoralis major</td>
<td>Sternum, clavicle, and first to sixth ribs</td>
<td>Proximal humerus</td>
<td>Adducts and flexes humerus</td>
</tr>
<tr>
<td>Rectus abdominis</td>
<td>Pubis</td>
<td>Sternum and fifth to seventh ribs</td>
<td>Flexes vertebral column</td>
</tr>
<tr>
<td>External oblique</td>
<td>Lower eight ribs</td>
<td>Iliac crest</td>
<td>Flexes and rotates vertebral column</td>
</tr>
<tr>
<td><strong>Arm/shoulder muscles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>Scapula of shoulder girdle</td>
<td>Proximal radius</td>
<td>Flexes elbow and supinates forearm</td>
</tr>
<tr>
<td>Brachialis</td>
<td>Distal humerus</td>
<td>Proximal ulna</td>
<td>Flexes elbow</td>
</tr>
<tr>
<td>Deltoid</td>
<td>(See Table 6.4)</td>
<td></td>
<td>Abducts arm</td>
</tr>
<tr>
<td><strong>Hip/thigh/leg muscles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iliopsoas</td>
<td>Ilium and lumbar vertebrae</td>
<td>Femur (lesser trochanter)</td>
<td>Flexes hip</td>
</tr>
<tr>
<td>Adductor muscles</td>
<td>Pelvis</td>
<td>Proximal femur</td>
<td>Adduct and medially rotate thigh</td>
</tr>
<tr>
<td>Sartorius</td>
<td>Ilium</td>
<td>Proximal tibia</td>
<td>Flexes thigh on hip</td>
</tr>
<tr>
<td>Quadriceps group</td>
<td>Vasti: femur</td>
<td>Tibial tuberosity via patellar ligament</td>
<td>All extend knee; rectus femoris also flexes hip on thigh</td>
</tr>
<tr>
<td>(vastus medialis, intermedius, and lateralis; and the rectus femoris)</td>
<td></td>
<td>Tibial tuberosity via patellar ligament</td>
<td></td>
</tr>
<tr>
<td>Rectus femoris: pelvis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tibialis anterior</td>
<td>Proximal tibia</td>
<td>First cuneiform (tarsal) and first metatarsal of foot</td>
<td>Dorsiflexes and inverts foot</td>
</tr>
<tr>
<td>Extensor digitorum longus</td>
<td>Proximal tibia and fibula</td>
<td>Distal toes 2–5</td>
<td>Extends toes</td>
</tr>
<tr>
<td>Fibularis muscles</td>
<td>Fibula</td>
<td>Metatarsals of foot</td>
<td>Plantar flex and evert foot</td>
</tr>
</tbody>
</table>
Figure 6.23 Major superficial muscles of the posterior surface of the body.

Arm
- Triceps brachii
- Brachialis

Forearm
- Brachioradialis
- Extensor carpi radialis longus
- Flexor carpi ulnaris
- Extensor carpi ulnaris
- Extensor digitorum

Hip
- Gluteus medius
- Gluteus maximus

Thigh
- Adductor muscle
- Hamstrings:
  - Biceps femoris
  - Semitendinosus
  - Semimembranosus

Leg
- Gastrocnemius
- Soleus
- Fibularis longus

Calcaneal (Achilles) tendon
<table>
<thead>
<tr>
<th>Name</th>
<th>Origin</th>
<th>Insertion</th>
<th>Primary action(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neck/trunk/shoulder muscles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trapezius</td>
<td>Occipital bone and all cervical and thoracic vertebrae</td>
<td>Scapular spine and clavicle</td>
<td>Raises, retracts, and rotates scapula</td>
</tr>
<tr>
<td>Latissimus dorsi</td>
<td>Lower spine and iliac crest</td>
<td>Proximal humerus</td>
<td>Extends and adducts humerus</td>
</tr>
<tr>
<td>Erector spinae*</td>
<td>Iliac crests, ribs 3–12, and vertebrae</td>
<td>Ribs, thoracic and cervical vertebrae</td>
<td>Extends and laterally flexes spine</td>
</tr>
<tr>
<td>Quadratus lumborum*</td>
<td>Iliac crest, lumbar fascia</td>
<td>Transverse processes of upper lumbar vertebrae</td>
<td>Flexes spine laterally; extends spine</td>
</tr>
<tr>
<td>Deltoid</td>
<td>Scapular spine and clavicle</td>
<td>Humerus (deltoid tuberosity)</td>
<td>Abducts humerus</td>
</tr>
<tr>
<td><strong>Arm/forearm muscles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>Shoulder girdle and proximal humerus</td>
<td>Olecranon process of ulna</td>
<td>Extends elbow</td>
</tr>
<tr>
<td>Flexor carpi radialis</td>
<td>Distal humerus</td>
<td>Second and third metacarpals</td>
<td>Flexes wrist and abducteds hand (see Figure 6.22)</td>
</tr>
<tr>
<td>Flexor carpi ulnaris</td>
<td>Distal humerus and posterior ulna</td>
<td>Carpals of wrist and fifth metacarpal</td>
<td>Flexes wrist and adducts hand</td>
</tr>
<tr>
<td>Flexor digitorum superficialis†</td>
<td>Distal humerus, ulna and radius</td>
<td>Middle phalanges of second to fifth fingers</td>
<td>Flexes wrist and fingers</td>
</tr>
<tr>
<td>Extensor carpi radialis</td>
<td>Humerus</td>
<td>Base of second and third metacarpals</td>
<td>Extends wrist and abducts hand</td>
</tr>
<tr>
<td>Extensor digitorum</td>
<td>Distal humerus</td>
<td>Distal phalanges of second to fifth fingers</td>
<td>Extends fingers</td>
</tr>
<tr>
<td><strong>Hip/thigh/leg muscles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>Sacrum and ilium</td>
<td>Proximal femur (gluteal tuberosity)</td>
<td>Extends hip (when forceful extension is required)</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>Ilium</td>
<td>Proximal femur</td>
<td>Abducts thigh; steadies pelvis during walking</td>
</tr>
<tr>
<td>Hamstring muscles (semitendinosus, semimembranosus, biceps femoris)</td>
<td>Ischial tuberosity</td>
<td>Proximal tibia (head of fibula in the case of biceps femoris)</td>
<td>Flex knee and extend hip</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>Distal femur</td>
<td>Calcaneus (heel via calcaneal tendon)</td>
<td>Plantar flexes foot and flexes knee</td>
</tr>
<tr>
<td>Soleus</td>
<td>Proximal tibia and fibula</td>
<td>Calcaneus</td>
<td>Plantar flexes foot</td>
</tr>
</tbody>
</table>

*Erector spinae and quadratus lumborum are deep muscles (they are not shown in Figure 6.23; see Figure 6.18b).

†Although its name indicates that it is a superficial muscle, the flexor digitorum superficialis lies deep to the flexor carpi radialis and is not visible in a superficial view.
Did You Get It?

25. Which muscle is the antagonist of the biceps brachii when the biceps flexes the elbow?
26. Which muscle group is the antagonist of the hamstring muscles?
27. What are two good sites for intramuscular injections in adults?
28. Which two muscles insert into the calcaneal tendon? What movement do they effect?

(For answers, see Appendix D.)

Developmental Aspects of the Muscular System

6-15 Explain the importance of a nerve supply and exercise in keeping muscles healthy.

6-16 Describe the changes that occur in aging muscles.

In the developing embryo, the muscular system is laid down in segments (much like the structural plan of an earthworm), and then each segment is invaded by nerves. The muscles of the thoracic and lumbar regions become very extensive because they must cover and move the bones of the limbs. The muscles and their control by the nervous system develop rather early in pregnancy. The expectant mother is often astonished by the first movements (called the quickening) of the fetus, which usually occur by the 16th week of pregnancy.

Homeostatic Imbalance 6.3

Very few congenital muscular problems occur. The exception to this is muscular dystrophy—a group of inherited muscle-destroying diseases that affect specific muscle groups. The muscles enlarge because of fat and connective tissue deposit, but the muscle fibers degenerate and atrophy.

The most common and serious form is Duchenne's muscular dystrophy, which is expressed almost exclusively in boys. This tragic disease is usually diagnosed between the ages of 2 and 7 years. Active, normal-looking children become clumsy and fall frequently as their muscles weaken. The disease progresses from the extremities upward, finally affecting the head and chest muscles. Children with this disease rarely live beyond their early twenties and generally die of respiratory failure. Although the cause of muscular dystrophy has been pinned down—the diseased muscle fibers lack a protein (called dystrophin) that helps maintain the sarcolemma—a cure is still elusive.

Initially after birth, a baby's movements are all gross reflex types of movements. Because the nervous system must mature before the baby can control muscles, we can trace the increasing efficiency of the nervous system by observing a baby's development of muscle control. This development proceeds in a cephalic/caudal direction, and gross muscular movements precede fine ones. Babies can raise their heads before they can sit up and can sit up before they can walk. Muscular control also proceeds in a proximal/distal direction; that is, babies can perform the gross movements like waving "bye-bye" and pulling objects to themselves before they can use the pincer grasp to pick up a pin. All through childhood, the nervous system's control of the skeletal muscles becomes more and more precise. By midadolescence, we have reached the peak level of development of this natural control and can simply accept it or bring it to a fine edge by athletic training.

Because of its rich blood supply, skeletal muscle is amazingly resistant to infection throughout life, and given good nutrition, relatively few problems affect skeletal muscles. We repeat, however, that muscles, like bones, will atrophy, even with normal tone, if they are not used continually. A lifelong program of regular exercise keeps the whole body operating at its best possible level.

Homeostatic Imbalance 6.4

One rare disease that can affect muscles during adulthood is myasthenia gravis (mi"ras-the'-ne-ah gra'vis; asthen = weakness; gravis = heavy), a disease characterized by drooping of the upper eyelids, difficulty in swallowing and talking, and generalized muscle weakness and fatigability. The disease involves a shortage of acetylcholine receptors at neuromuscular junctions. The blood of many of these patients contains antibodies to acetylcholine receptors, which suggests that myasthenia gravis is an autoimmune disease. Although the receptors may initially be present in normal numbers, they appear to be destroyed as the disease progresses. Whatever the case, the muscle cells are not stimulated properly and get progressively weaker. Death usually occurs as a result of the inability of the respiratory muscles to function (respiratory failure).
A female patient with myasthenia gravis. Notice the effect on the patient’s eyelid muscles.

As we age, the amount of connective tissue in the muscles increases, and the amount of muscle tissue decreases; thus the muscles become stringer, or more sinewy. Because the skeletal muscles represent so much of the body mass, body weight begins to decline in the older person as this natural loss in muscle mass occurs. Another result of the loss in muscle mass is a decrease in muscle strength; strength decreases by about 50 percent by the age of 80. Regular exercise can help offset the effects of aging on the muscular system, and frail older people who begin to “pump iron” (use leg and hand weights) can rebuild muscle mass and dramatically increase their strength.

**Did You Get It?**

29. What must happen before babies can control their muscles?

30. How does lifelong exercise affect our skeletal muscles and muscle mass in old age?

(For answers, see Appendix D.)

**SUMMARY**

For more chapter study tools, go to the Study Area of MasteringA&P. There you will find:
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- A&P Flash
- Practice Anatomy Lab
- Get Ready for A&P
- Flashcards, Quizzes, Crossword Puzzles, Art-labeling Activities, Practice Tests, and more!

**Overview of Muscle Tissues** (pp. 181–185)

1. Skeletal muscle forms the muscles attached to the skeleton, which move the limbs and other body parts. Its cells are long, striated and multinucleate, and they are subject to voluntary control. Connective tissue coverings (endomysium, perimysium, and epimysium) enclose and protect the muscle fibers and increase the strength of skeletal muscles. Skeletal muscles make up the muscular system.

2. Smooth muscle cells are uninucleate, spindle-shaped, and arranged in opposing layers in the walls of hollow organs. When they contract, substances (food, urine, a baby) are moved along internal pathways. Smooth muscle control is involuntary.

3. Cardiac muscle cells are striated, branching cells that fit closely together and are arranged in spiral bundles in the heart. Their contraction pumps blood through the blood vessels. Control is involuntary.

4. The sole function of muscle tissue is to contract or shorten. As it contracts, it causes movement, maintains posture, stabilizes joints, and generates heat.

**Microscopic Anatomy of Skeletal Muscle** (pp. 185–187)

1. The multinucleate cylindrical skeletal muscle fibers are packed with unique organelles called myofibrils. The banding pattern (striations) of the myofibrils and the cell as a whole reflects the regular arrangement of thin (actin-containing) and thick (myosin) filaments within the sarcomeres, the contractile units composing the myofibrils.

*(Chapter Summary continues on page 221.)*
SYSTEMS IN SYNC

Homeostatic Relationships between the **Muscular System** and Other Body Systems

**Endocrine System**
- Growth hormone and androgens influence skeletal muscle strength and mass

**Lymphatic System/Immunity**
- Physical exercise may enhance or depress immunity depending on its intensity
- Lymphatic vessels drain leaked tissue fluids; immune system protects muscles from disease

**Digestive System**
- Physical activity increases gastrointestinal mobility when at rest
- Digestive system provides nutrients needed for muscle health; liver metabolizes lactic acid

**Urinary System**
- Physical activity promotes normal voiding behavior; skeletal muscle forms the voluntary sphincter of the urethra
- Urinary system disposes of nitrogen-containing wastes

**Nervous System**
- Facial muscle activity allows emotions to be expressed
- Nervous system stimulates and regulates muscle activity

**Respiratory System**
- Muscular exercise increases respiratory capacity
- Respiratory system provides oxygen and disposes of carbon dioxide

**Cardiovascular System**
- Skeletal muscle activity increases efficiency of cardiovascular functioning; helps prevent atherosclerosis and causes cardiac hypertrophy
- Cardiovascular system delivers oxygen and nutrients to muscles; carries away wastes

**Reproductive System**
- Skeletal muscle helps support pelvic organs (e.g., uterus in females); assists erection of penis and clitoris
- Testicular androgen promotes increased skeletal muscle size

**Integumentary System**
- Muscular exercise enhances circulation to skin and improves skin health; exercise also increases body heat, which the skin helps dissipate
- Skin protects the muscles by external enclosure

**Skeletal System**
- Skeletal muscle activity maintains bone health and strength
- Bones provide levers for muscle activity
2. Each myofibril is loosely enclosed by a specialized ER, called the sarcoplasmic reticulum (SR), which plays an important role in storing and releasing calcium ions. Calcium ions are the final trigger for muscle fiber contraction.

**Skeletal Muscle Activity** (pp. 187–196)

1. All skeletal muscle cells are stimulated by motor neurons. When the neuron releases a neurotransmitter (acetylcholine), the permeability of the sarcolemma changes, allowing sodium ions to enter the muscle cell. This produces an electrical current (action potential), which flows across the entire sarcolemma, resulting in release of calcium ions from the SR.

2. Calcium binds to regulatory proteins on the thin filaments and exposes myosin-binding sites, allowing the myosin heads on the thick filaments to attach. The attached heads pivot, sliding the thin filaments toward the center of the sarcomere, and contraction occurs. ATP provides the energy for the sliding process, which continues as long as ionic calcium is present.

3. Although individual muscle cells contract completely when adequately stimulated, a muscle (which is an organ) responds to stimuli to different degrees, that is, it exhibits graded responses.

4. Most skeletal muscle contractions are tetanic (smooth and sustained) because rapid nerve impulses are reaching the muscle, and the muscle cannot relax completely between contractions. The strength of muscle contraction reflects the relative number of muscle cells contracting (more = stronger).

5. ATP, the immediate source of energy for muscle contraction, is stored in muscle fibers in small amounts that are quickly used up. ATP is regenerated via three routes. From the fastest to the slowest, these are via a coupled reaction of creatine phosphate with ADP, via anaerobic glycolysis and lactic acid formation, and via aerobic respiration. Only aerobic respiration requires oxygen.

6. If muscle activity is strenuous and prolonged, muscle fatigue occurs because ionic imbalances occur, lactic acid accumulates in the muscle, and the energy (ATP) supply decreases. After exercise, the oxygen deficit is repaid by rapid, deep breathing.

7. Muscle contractions are isotonic (the muscle shortens, and movement occurs) or isometric (the muscle does not shorten, but its tension increases).

8. Muscle tone keeps muscles healthy and ready to react. It is a result of a staggered series of nerve impulses delivered to different cells within the muscle. If the nerve supply is destroyed, the muscle loses tone, becomes paralyzed, and atrophies.

9. Inactive muscles atrophy. Muscles challenged almost beyond their ability by resistance exercise will increase in size and strength. Muscles subjected to regular aerobic exercise become more efficient and stronger and can work longer without tiring. Aerobic exercise also benefits other body organ systems.

**Muscle Movements, Types, and Names** (pp. 196–203)

1. All muscles are attached to bones at two points. The origin is the immovable attachment; the insertion is the movable bony attachment. When contraction occurs, the insertion moves toward the origin.

2. Body movements include flexion, extension, abduction, adduction, circumduction, rotation, pronation, supination, inversion, eversion, dorsiflexion, plantar flexion, and opposition.

3. On the basis of their general functions in the body, muscles are classified as prime movers, antagonists, synergists, and fixators.

4. Muscles are named according to several criteria, including muscle size, shape, number and location of origins, associated bones, and action of the muscle.

5. Muscles have several fascicle arrangements that influence their force and degree of shortening.

**Gross Anatomy of Skeletal Muscles** (pp. 203–218)

1. Muscles of the head fall into two groups. The muscles of facial expression include the frontalis, orbicularis oris and oculi, and zygomaticus. The chewing muscles are the masseter, temporalis, and buccinator (which is also a muscle of facial expression).
2. Muscles of the trunk and neck move the head, shoulder girdle, and trunk and form the abdominal girdle. Anterior neck and trunk muscles include the sternocleidomastoid, pectoralis major, intercostals, rectus abdominis, external and internal obliques, and transversus abdominis. Posterior trunk and neck muscles include the trapezius, latissimus dorsi, and deltoid. Deep muscles of the back are the erector spinae muscles.

3. Muscles of the upper limb include muscles that cause movement at the shoulder joint, elbow, and hand. Muscles causing movement at the elbow include the brachialis, biceps brachii, brachioradialis, and triceps brachii.

4. Muscles of the lower extremity cause movement at the hip, knee, and foot. They include the iliopectos, gluteus maximus and medius, adductors, quadriceps and hamstring groups, gastrocnemius, tibialis anterior, flexor muscles, soleus, and extensor digitorum longus.

**Developmental Aspects of the Muscular System** (pp. 218–220)

1. Increasing muscular control reflects the maturation of the nervous system. Muscle control is achieved in a cephalic/caudal and proximal/distal direction.

2. To remain healthy, muscles must be regularly exercised. Without exercise, they atrophy; with extremely vigorous exercise, they hypertrophy.

3. As we age, muscle mass decreases, and the muscles become more sinewy. Exercise helps to retain muscle mass and strength.

**REVIEW QUESTIONS**

**Multiple Choice**

*More than one choice may apply.*

1. If you compare electron micrographs of a relaxed skeletal muscle fiber and a fully contracted muscle fiber, which would you see only in the *relaxed* fiber?
   a. Z discs
d. A bands
   b. Triads
e. H zones
   c. I bands

2. After ACh attaches to its receptors at the neuromuscular junction, what is the next step?
   a. Sodium channels open.
b. Calcium binds to regulatory proteins on the thin filaments.
c. Cross bridges attach.
d. ATP is hydrolyzed.

3. Your ability to lift that heavy couch would be increased by which type of exercise?
   a. Aerobic
c. Resistance
   b. Endurance
   d. Swimming

4. Doing the pincer grasp is an _____ movement.
   a. extending
c. adducting
   b. abducting
d. opposing

5. Which are ways in which muscle names have been derived?
   a. Attachments
   b. Size
c. Function
d. Location

6. Which of the following muscles attach to the hip bones?
   a. Rectus abdominis
   b. Rectus femoris
c. Vastus medialis
d. Vastus lateralis

7. Which of these thigh muscles causes movement at the hip joint?
   a. Rectus femoris
   b. Biceps femoris
c. Vastus lateralis
d. Semitendinosus

8. Which of the following insert on the arm?
   a. Biceps brachii
   b. Triceps brachii
c. Trapezius
d. Latissimus dorsi

**Short Answer Essay**

9. What is the major function of muscle?

10. Compare skeletal, smooth, and cardiac muscles in regard to their microscopic anatomy, location and arrangement in body organs, and function in the body.

11. What two types of muscle tissue are striated?

12. Why are the connective tissue wrappings of skeletal muscles important? Name these connective tissue
coverings, beginning with the finest and ending with the most coarse.

13. What is the function of tendons?

14. Define neuromuscular junction, motor unit, tetanus, graded response, aerobic respiration, anaerobic glycolysis, muscle fatigue, and neurotransmitter.

15. Describe the events that occur from the time a motor neuron releases acetylcholine at the neuromuscular junction until muscle cell contraction occurs.

16. How do isotonic and isometric contractions differ?

17. Muscle tone keeps muscles healthy. What is muscle tone, and what causes it? What happens to a muscle that loses its tone?

18. A skeletal muscle is attached to bones at two points. Name each of these attachment points, and indicate which is movable and which is immovable.

19. List the 12 body movements studied in this chapter, and demonstrate each.

20. How is a prime mover different from a synergist muscle? How can a prime mover also be considered an antagonist?

21. If you were alternately contracting and relaxing your masseter muscle, what would you be doing? Name three other muscles of the face, and give the location and function of each.

22. The sternocleidomastoid muscles help to flex the neck. What are their antagonists?

23. Name two muscles that reverse the movement of the deltoid muscle.

24. Name the prime mover of elbow flexion. Name its antagonist.

25. Other than acting to flex the spine and compress the abdominal contents, the abdominal muscles are extremely important in protecting and containing the abdominal viscera. What is it about the arrangement of these muscles that makes them so well suited for their job?

26. The hamstring and quadriceps muscle groups are antagonists of each other, and each group is a prime mover in its own right. What action does each muscle group perform?

27. What two-bellied muscle makes up the calf region of the leg? What is its function?

28. What happens to muscles when they are exercised regularly? Exercised vigorously as in weight lifting? Not used?

29. What is the effect of aging on skeletal muscles?

30. Should a triathlete engage in aerobic or resistance training? Explain.

CRITICAL THINKING AND CLINICAL APPLICATION QUESTIONS

31. Name three muscles or muscle groups used as sites for intramuscular injections. Which is most often used in babies?

32. Mr. Ahmadi was advised by his physician to lose weight and start jogging. He began to jog daily. On the sixth day, he was forced to jump out of the way of a speeding car. He heard a snapping sound that was immediately followed by pain in his right lower calf. A gap was visible between his swollen calf and his heel, and he was unable to plantar flex that foot. What do you think happened?

33. While painting her house, Susan fell off the ladder and fractured her right clavicle. Treatment prescribed by the emergency room physician included using a sling for her right arm to immobilize the clavicle and speed its healing. What muscles are temporarily "put out of business" by the sling?

34. When Eric returned from jogging, he was breathing heavily and sweating profusely, and he complained that his legs ached and felt weak. His wife poured him a sport drink and urged him to take it easy until he could "catch his breath." On the basis of what you have learned about muscle energy metabolism, respond to the following questions:
   a. Why is Eric breathing heavily?
   b. What ATP-harvesting pathway have his working muscles been using that leads to such a breathing pattern?
   c. What metabolic product(s) might account for his sore muscles and his feeling of muscle weakness?

35. Chemical A binds and blocks acetylcholine receptors of muscle cells. Chemical B floods the cytoplasm of muscle cells with calcium ions. Which chemical would make the best muscle relaxant and why?
36. Mr. Adams has had colon surgery. Now he is experiencing weakness of the muscles on his right side only, the side in which the incision was made through the abdominal musculature. Consequently, the abdominal muscles on his left side contract more strongly, throwing his torso into a lateral flexion. Mr. Adams needs physical therapy. What abnormal spinal curvature will result if he doesn’t get it, and why?

37. When a person dies, rigor mortis sets in as ATP synthesis ceases. Explain why the lack of ATP in muscle cells would cause the muscles to become rigid rather than limp soon after death.

38. Harry was pondering an exam question that said, “What muscle type has elongated cells and is found in the walls of the urinary bladder?” What should he have responded?