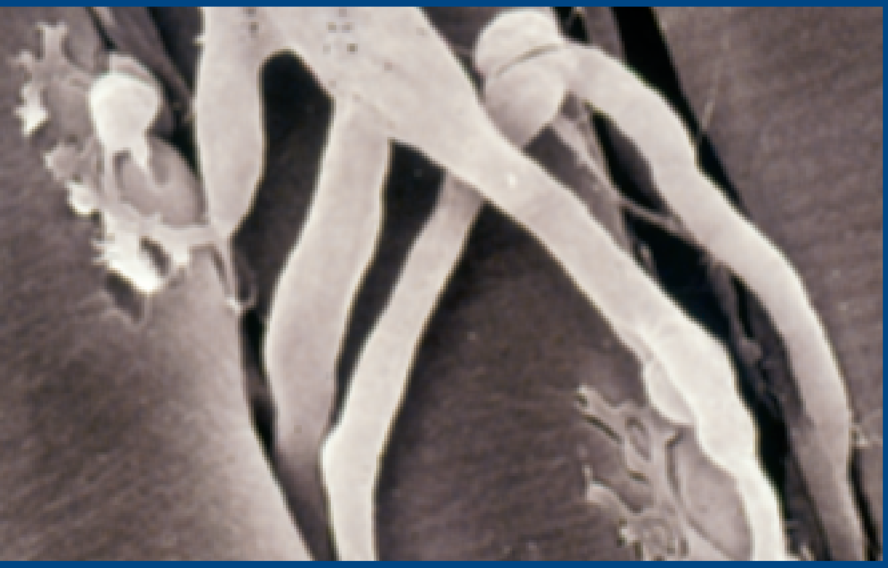
chapter 7

The Muscular System



Scanning electron micrograph of motor neurons terminating at muscle fibers. A muscle fiber receives the stimulus to contract at a neuromuscular junction.

chapter outline & learning objectives

After you have studied this chapter, you should be able to:

7.1 Functions and Types of Muscles (p. 114)

- Distinguish between the three types of muscles, and tell where they are located in the body.
- Describe the connective tissues of a skeletal muscle.
- Name and discuss five functions of skeletal muscles.

7.2 Microscopic Anatomy and Contraction of Skeletal Muscle (p. 116)

- Name the components of a skeletal muscle fiber, and describe the function of each.
- Explain how skeletal muscle fibers are innervated and how they contract.
- Describe how ATP is made available for muscle contraction.

7.3 Muscle Responses (p. 122)

- Contrast the responses of a muscle fiber and whole muscle in the laboratory with their responses in the body.
- Contrast slow-twitch and fast-twitch muscle fibers.

7.4 Skeletal Muscles of the Body (p. 124)

- Discuss how muscles work together to achieve the movement of a bone.
- Give examples to show how muscles are named.
- Describe the locations and actions of the major skeletal muscles of each body region.

7.5 Effects of Aging (p. 134)

- Describe the anatomical and physiological changes that occur in the muscular system as we age.

7.6 Homeostasis (p. 136)

- Describe how the muscular system works with other systems of the body to maintain homeostasis.
- Describe some common muscle disorders and some of the serious diseases that can affect muscles.

Visual Focus

Anatomy of a Muscle Fiber (p. 117)

Medical Focus

Benefits of Exercise (p. 135)

7.1 Functions and Types of Muscles

All muscles, regardless of the particular type, can contract—that is, shorten. When muscles contract, some part of the body or the entire body moves. Humans have three types of muscles: smooth, cardiac, and skeletal (Fig. 7.1). The contractile cells of these tissues are elongated and therefore are called **muscle fibers.**

Smooth Muscle

Smooth muscle is located in the walls of hollow internal organs, and its involuntary contraction moves materials through an organ. Smooth muscle fibers are spindle-shaped cells, each with a single nucleus (uninucleated). The cells are usually arranged in parallel lines, forming sheets. Smooth muscle does not have the striations (bands of light and dark) seen in cardiac and skeletal muscle. Although smooth muscle is slower to contract than skeletal muscle, it can sustain prolonged contractions and does not fatigue easily.

Cardiac Muscle

Cardiac muscle forms the heart wall. Its fibers are uninucleated, striated, tubular, and branched, which allows the fibers to interlock at intercalated disks. Intercalated disks permit contractions to spread quickly throughout the heart. Cardiac fibers relax completely between contractions, which prevents fatigue. Contraction of cardiac muscle fibers is rhythmical; it occurs without outside nervous stimulation or control. Thus, cardiac muscle contraction is involuntary.

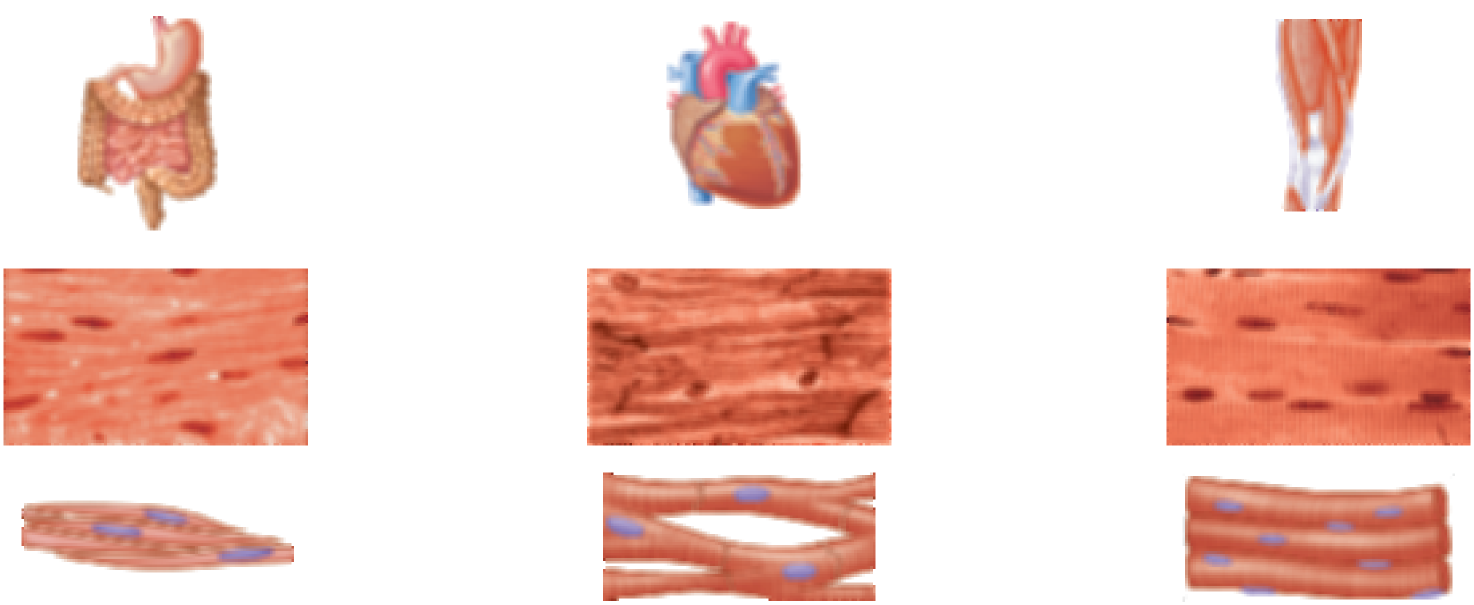
Skeletal Muscle

Skeletal muscle fibers are tubular, multinucleated, and striated. They make up the skeletal muscles attached to the skeleton. Skeletal muscle fibers can run the length of a muscle and therefore can be quite long. Skeletal muscle is voluntary because its contraction is always stimulated and controlled by the nervous system. In this chapter, we will explore why skeletal muscle (and cardiac muscle) is striated.

Connective Tissue Coverings

Muscles are organs, and as such they contain other types of tissues, such as nervous tissue, blood vessels, and connective tissue. Connective tissue is essential to the organization of the fibers within a muscle (Fig. 7.2). First, each fiber is surrounded by a thin layer of areolar connective tissue called the *endomysium.* Blood capillaries and nerve fibers reach each muscle fiber by way of the endomysium. Second, the muscle fibers are grouped into bundles called *fascicles.* The fascicles have a sheath of connective tissue called the *perimysium.* Finally, the

Figure 7.1 Types of muscles. The three types of muscles in the body have the appearance and characteristics shown here.



Smooth muscle
- has spindle-shaped, nonstriated, uninucleated fibers.
- occurs in walls of internal organs.
- is involuntary.

Cardiac muscle
- has striated, tubular, branched, uninucleated fibers.
- occurs in walls of heart.
- is involuntary.

Skeletal muscle
- has striated, tubular, multinucleated fibers.
- is usually attached to skeleton.
- is voluntary.

muscle itself is covered by a connective tissue layer called the *epimysium*. The epimysium becomes a part of the *fascia*, a layer of fibrous tissue that separates muscles from each other (deep fascia) and from the skin (superficial fascia). Collagen fibers of the epimysium continue as a strong, fibrous **tendon** that attaches the muscle to a bone. The epimysium merges with the periosteum of the bone.

Functions of Skeletal Muscles

This chapter concerns the skeletal muscles, and therefore it is fitting to consider their functions independent of the other types of muscles:

Skeletal muscles support the body. Skeletal muscle contraction opposes the force of gravity and allows us to remain upright. Some skeletal muscles are serving this purpose even when you think you are relaxed.

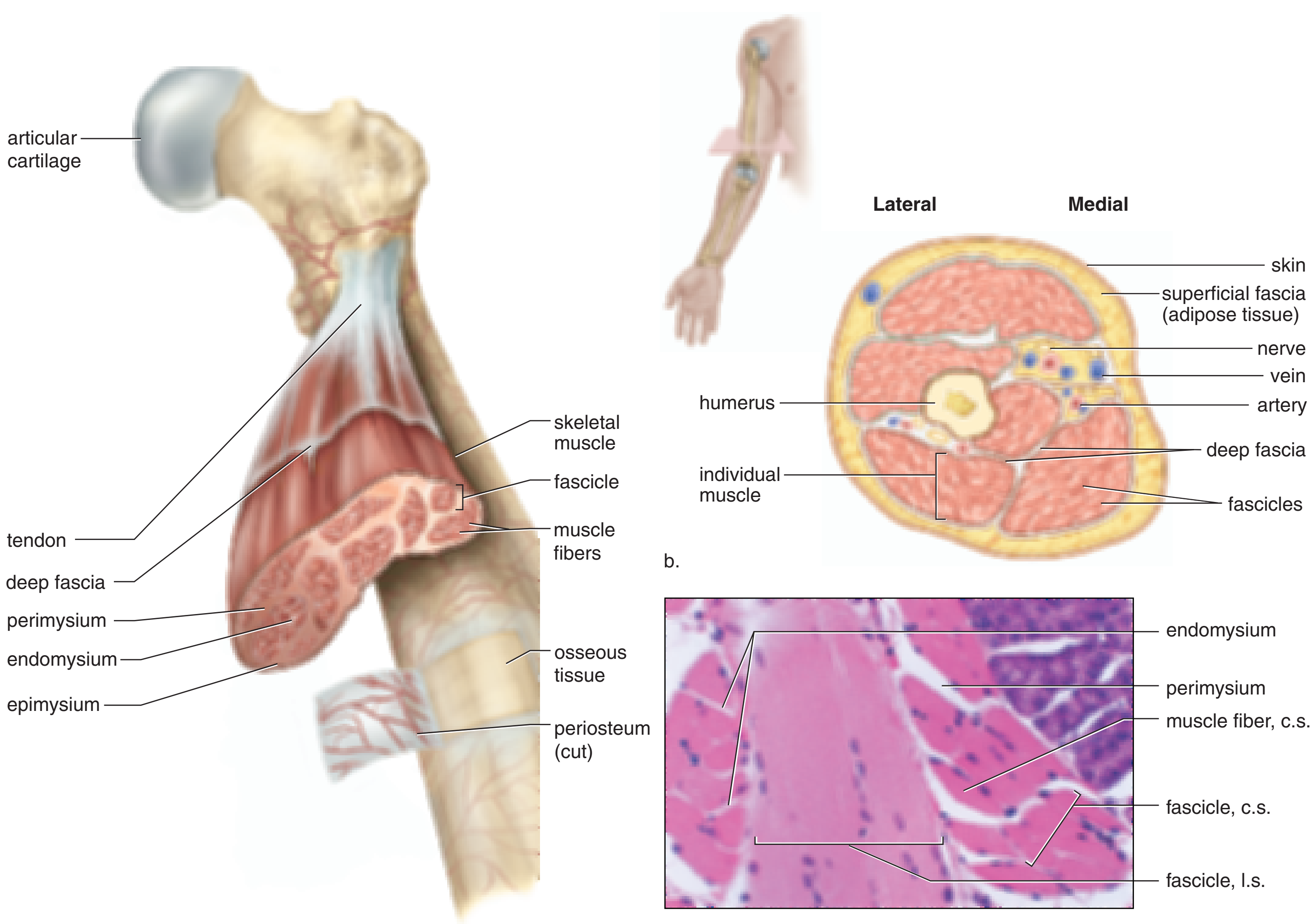
Skeletal muscles make bones and other body parts move. Muscle contraction accounts not only for the movement of limbs but also for eye movements, facial expressions, and breathing.

Skeletal muscles help maintain a constant body temperature. Skeletal muscle contraction causes ATP to break down, releasing heat that is distributed about the body.

Skeletal muscle contraction assists movement in cardiovascular and lymphatic vessels. The pressure of skeletal muscle contraction keeps blood moving in cardiovascular veins and lymph moving in lymphatic vessels.

Skeletal muscles help protect internal organs and stabilize joints. Muscles pad the bones that protect organs, and they have tendons that help hold bones together at joints.

Figure 7.2 **Connective tissue of a skeletal muscle. a. Trace the connective tissue of a muscle from the endomysium to the perimysium to the epimysium, which becomes a part of the deep fascia and from which the tendon extends to attach a muscle to the periosteum of a bone. b. Cross section of the arm showing the arrangement of the muscles, which are separated from the skin by fascia. The superficial fascia contains adipose tissue. c. Photomicrograph of muscle fascicles from the tongue where the fascicles run in different directions. (c.s. = cross section; l.s. = longitudinal section.)**



7.2 Microscopic Anatomy and Contraction of Skeletal Muscle

We have already examined the structure of skeletal muscle as seen with the light microscope. As you know, skeletal muscle tissue has alternating light and dark bands, giving it a striated appearance. The electron microscope shows that these bands are due to the arrangement of myofilaments in a muscle fiber.

Muscle Fiber

A muscle fiber contains the usual cellular components, but special names have been assigned to some of these components (Table 7.1 and Figure 7.3). The plasma membrane is called the *sarcolemma*; the cytoplasm is the sarcoplasm; and the endoplasmic reticulum is the *sarcoplasmic reticulum*. A muscle fiber also has some unique anatomical characteristics. One feature is its T (for transverse) system; the sarcolemma forms **T (transverse) tubules** that penetrate, or dip down, into the cell so that they come into contact—but do not fuse—with expanded portions of the sarcoplasmic reticulum. The expanded portions of the sarcoplasmic reticulum are calcium storage sites. Calcium ions (Ca^{2+}), as we shall see, are essential for muscle contraction.

The sarcoplasmic reticulum encases hundreds and sometimes even thousands of **myofibrils**, each about 1 μm in diameter, which are the contractile portions of the muscle fibers. Any other organelles, such as mitochondria, are located in the sarcoplasm between the myofibrils. The sarcoplasm also contains glycogen, which provides stored energy for muscle contraction, and the red pigment **myoglobin**, which binds oxygen until it is needed for muscle contraction.

Table 7.1 Microscopic Anatomy of a Muscle

Name	Function
Sarcolemma	Plasma membrane of a muscle fiber that forms T tubules
Sarcoplasm	Cytoplasm of a muscle fiber that contains organelles, including myofibrils
Glycogen	A polysaccharide that stores energy for muscle contraction
Myoglobin	A red pigment that stores oxygen for muscle contraction
T tubule	Extension of the sarcolemma that extends into the muscle fiber and conveys impulses that cause Ca^{2+} to be released into the sarcoplasmic reticulum
Sarcoplasmic reticulum	The smooth ER of a muscle fiber that stores Ca^{2+}
Myofibril	A bundle of myofilaments that contracts
Myofilament	Actin filaments and myosin filaments whose structure and functions account for muscle striations and contractions

Myofibrils and Sarcomeres

Myofibrils are cylindrical in shape and run the length of the muscle fiber. The striations of skeletal muscle fibers are formed by the placement of myofilaments within units of myofibrils called **sarcomeres.** A sarcomere extends between two dark lines called the Z lines. A sarcomere contains two types of protein myofilaments. The thick filaments are made up of a protein called **myosin,** and the thin filaments are made up of a protein called **actin.** Other proteins are also present. The I band is light colored because it contains only actin filaments attached to a Z line. The dark regions of the A band contain overlapping actin and myosin filaments, and its H zone has only myosin filaments.

Myofilaments

The thick and thin filaments differ in the following ways:

Thick Filaments A thick filament is composed of several hundred molecules of the protein myosin. Each myosin molecule is shaped like a golf club, with the straight portion of the molecule ending in a double globular head, or *cross-bridge*. Cross-bridges are slanted away from the middle of a sarcomere.

Thin Filaments Primarily, a thin filament consists of two intertwining strands of the protein actin. Two other proteins, called tropomyosin and troponin, are also present, as we will discuss later in this section.

Sliding Filaments We will also see that when muscles are innervated, impulses travel down a T tubule, and calcium is released from the sarcoplasmic reticulum. Now the muscle fiber contracts as the sarcomeres within the myofibrils shorten. When a sarcomere shortens, the actin (thin) filaments slide past the myosin (thick) filaments and approach one another. This causes the I band to shorten and the H zone to almost or completely disappear. The movement of actin filaments in relation to myosin filaments is called the **sliding filament theory** of muscle contraction. During the sliding process, the sarcomere shortens even though the filaments themselves remain the same length. ATP supplies the energy for muscle contraction. Although the actin filaments slide past the myosin filaments, it is the myosin filaments that do the work. Myosin filaments break down ATP and have cross-bridges that pull the actin filaments toward the center of the sarcomere.

visual focus

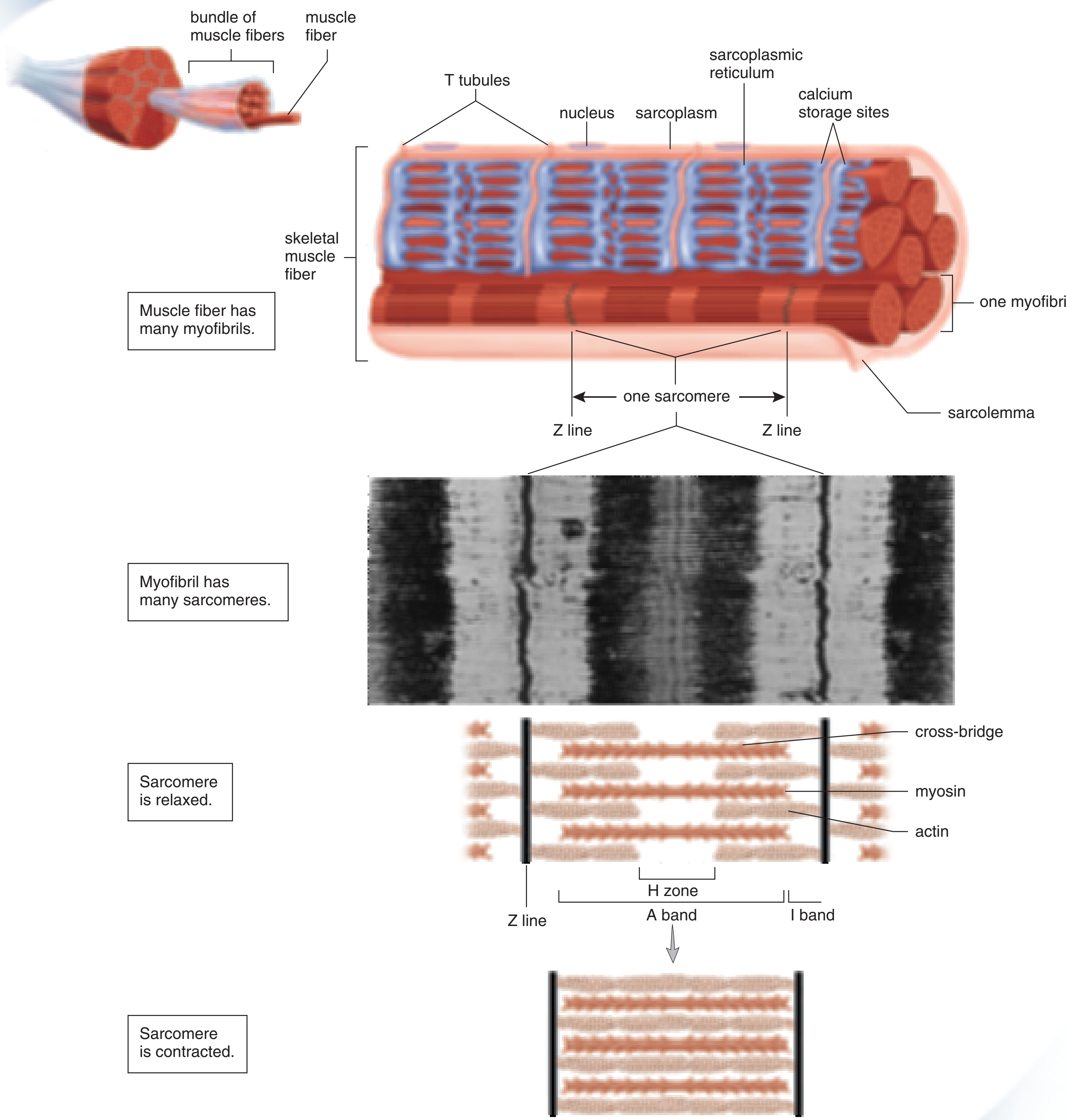


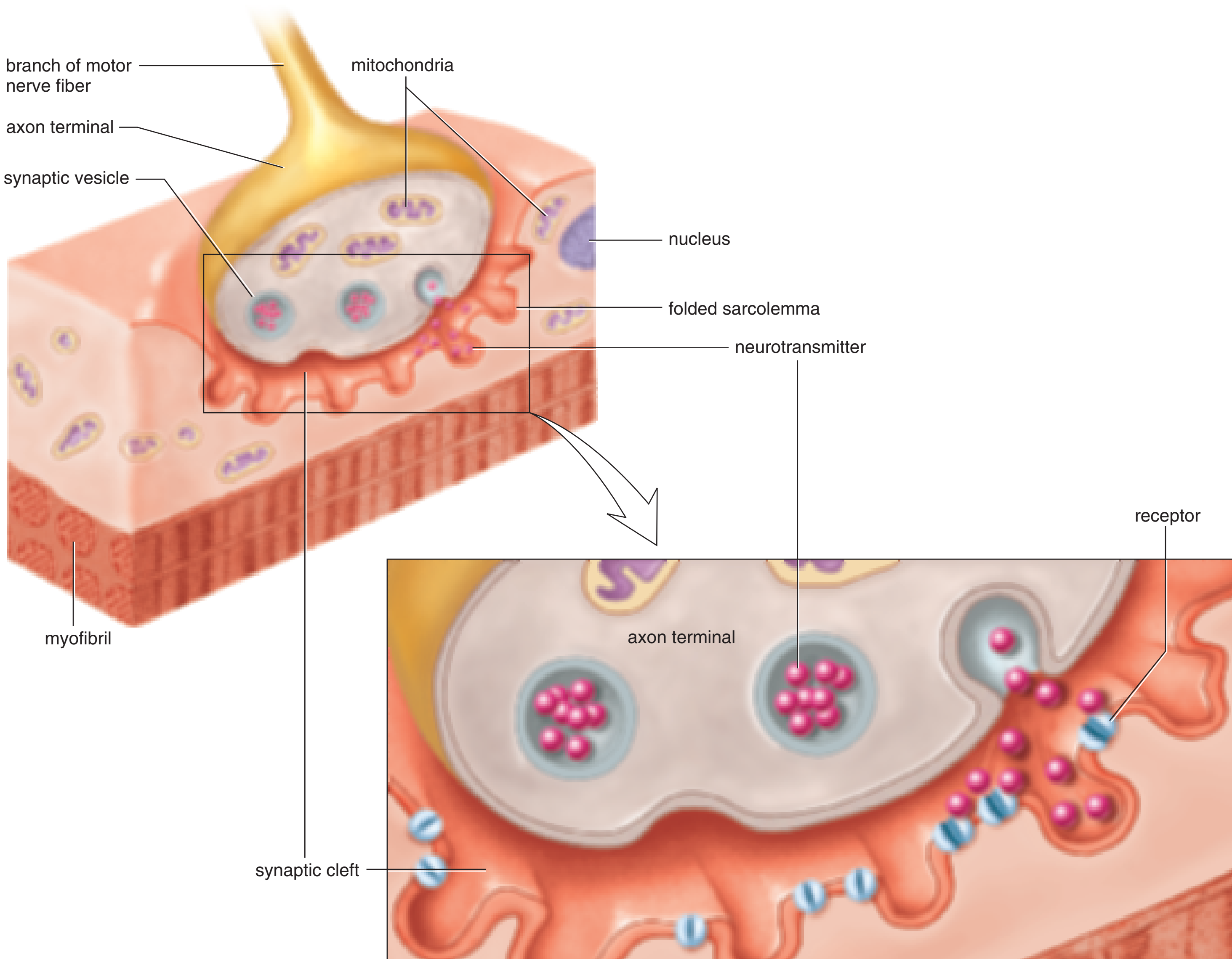
Figure 7.3 Anatomy of a muscle fiber. A muscle fiber contains many myofibrils with the components shown. A myofibril has many sarcomeres that contain myosin and actin filaments whose arrangement gives rise to the striations so characteristic of skeletal muscle. Muscle contraction occurs when sarcomeres contract and actin filaments slide past myosin filaments.

Skeletal Muscle Contraction

Muscle fibers are innervated—that is, they are stimulated to contract by motor neurons whose axons are found in nerves. The axon of one motor neuron has several branches and can stimulate from a few to several muscle fibers of a particular muscle. Each branch of the axon ends in an axon terminal that lies in close proximity to the sarcolemma of a muscle fiber. A small gap, called a synaptic cleft, separates the axon bulb from the sarcolemma. This entire region is called a **neuromuscular junction** (Fig. 7.4).

Axon terminals contain synaptic vesicles that are filled with the neurotransmitter acetylcholine (ACh). When nerve impulses traveling down a motor neuron arrive at an axon terminal, the synaptic vesicles release a neurotransmitter into the synaptic cleft. It quickly diffuses across the cleft and binds to receptors in the sarcolemma. Now the sarcolemma generates impulses that spread over the sarcolemma and down T tubules to the sarcoplasmic reticulum. The release of calcium from the sarcoplasmic reticulum causes the filaments within the sarcomeres to slide past one another. Sarcomere contraction results in myofibril contraction, which in turn results in muscle fiber, and finally muscle, contraction.

Figure 7.4 **Neuromuscular junction. The branch of an axon ends in an axon terminal that meets but does not touch a muscle fiber. A synaptic cleft separates the axon terminal from the sarcolemma of the muscle fiber. Nerve impulses traveling down an axon cause synaptic vesicles to discharge acetylcholine, which diffuses across the synaptic cleft. When the neurotransmitter is received by the sarcolemma of a muscle fiber, impulses begin and lead to muscle fiber contractions.**



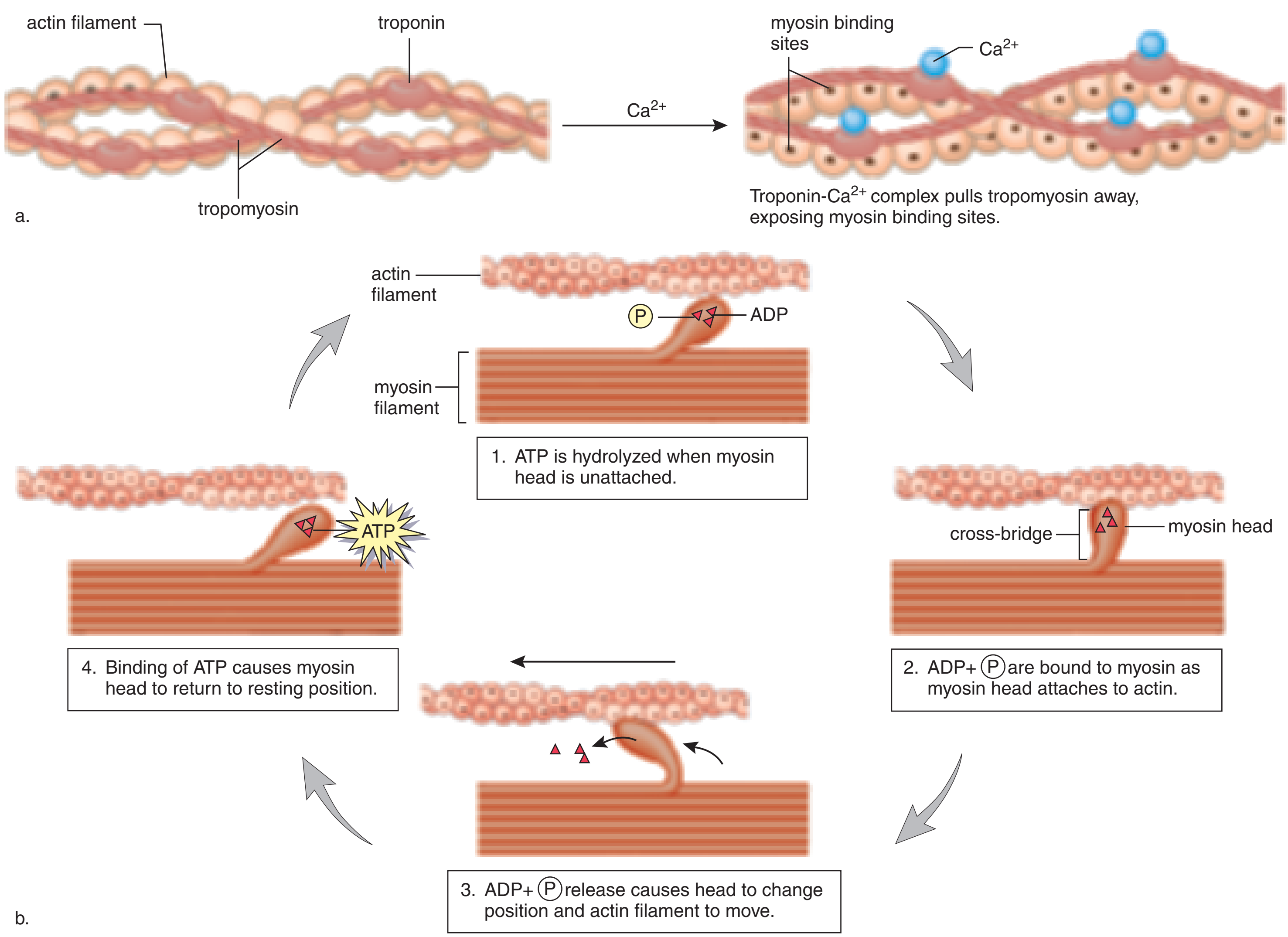
The Role of Actin and Myosin

Figure 7.5 shows the placement of two other proteins associated with an actin filament, which you will recall is composed of a double row of twisted actin molecules. Threads of *tropomyosin* wind about an actin filament, and *troponin* occurs at intervals along the threads. Calcium ions (Ca^{2+}) that have been released from the sarcoplasmic reticulum combine with troponin. After binding occurs, the tropomyosin threads shift their position, and myosin binding sites are exposed.

The double globular heads of a myosin filament have ATP binding sites. The heads function as ATPase enzymes, splitting ATP into ADP and Ⓟ. This reaction activates the head so that it will bind to actin. The ADP and Ⓟ remain on the myosin heads until the heads attach to actin, forming a cross-bridge. Now, ADP and Ⓟ are released, and this causes the cross-bridges to change their positions. This is the power stroke that pulls the thin filaments toward the middle of the sarcomere. When another ATP molecule binds to a myosin head, the cross-bridge is broken as the head detaches from actin. The cycle begins again; the actin filaments move nearer the center of the sarcomere each time the cycle is repeated.

Contraction continues until nerve impulses cease and calcium ions are returned to their storage sites. The membranes of the sarcoplasmic reticulum contain active transport proteins that pump calcium ions back into the sarcoplasmic reticulum.

Figure 7.5 **The role of calcium and myosin in muscle contraction. a.** Upon release, calcium binds to troponin, exposing myosin binding sites. **b.** After breaking down ATP, myosin heads bind to an actin filament, and later, a power stroke causes the actin filament to move.

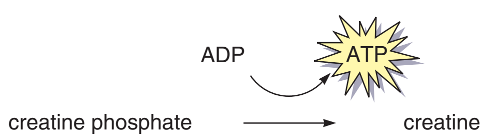


Energy for Muscle Contraction

ATP produced previous to strenuous exercise lasts a few seconds, and then muscles acquire new ATP in three different ways: creatine phosphate breakdown, cellular respiration, and fermentation (Fig. 7.6). Creatine phosphate breakdown and fermentation are anaerobic, meaning that they do not require oxygen.

Creatine Phosphate Breakdown

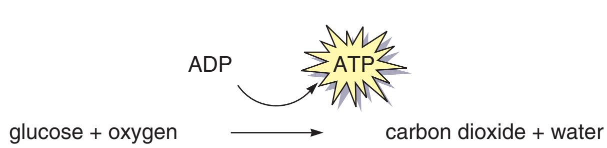
Creatine phosphate is a high-energy compound built up when a muscle is resting. Creatine phosphate cannot participate directly in muscle contraction. Instead, it can regenerate ATP by the following reaction:



This reaction occurs in the midst of sliding filaments, and therefore is the speediest way to make ATP available to muscles. Creatine phosphate provides enough energy for only about eight seconds of intense activity, and then it is spent. Creatine phosphate is rebuilt when a muscle is resting by transferring a phosphate group from ATP to creatine.

Cellular Respiration

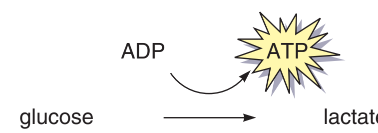
Cellular respiration completed in mitochondria usually provides most of a muscle's ATP. Glycogen and fat are stored in muscle cells. Therefore, a muscle cell can use glucose from glycogen and fatty acids from fat as fuel to produce ATP if oxygen is available:



Myoglobin, an oxygen carrier similar to hemoglobin, is synthesized in muscle cells, and its presence accounts for the reddish-brown color of skeletal muscle fibers. Myoglobin has a higher affinity for oxygen than does hemoglobin. Therefore, myoglobin can pull oxygen out of blood and make it available to muscle mitochondria that are carrying on cellular respiration. Then, too, the ability of myoglobin to temporarily store oxygen reduces a muscle's immediate need for oxygen when cellular respiration begins. The end products (carbon dioxide and water) are usually no problem. Carbon dioxide leaves the body at the lungs, and water simply enters the extracellular space. The by-product, heat, keeps the entire body warm.

Fermentation

Fermentation, like creatine phosphate breakdown, supplies ATP without consuming oxygen. During fermentation, glucose is broken down to lactate (lactic acid):



The accumulation of lactate in a muscle fiber makes the cytoplasm more acidic, and eventually enzymes cease to function well. If fermentation continues longer than two or three minutes, cramping and fatigue set in. Cramping seems to be due to lack of the ATP needed to pump calcium ions back into the sarcoplasmic reticulum and to break the linkages between the actin and myosin filaments so that muscle fibers can relax.

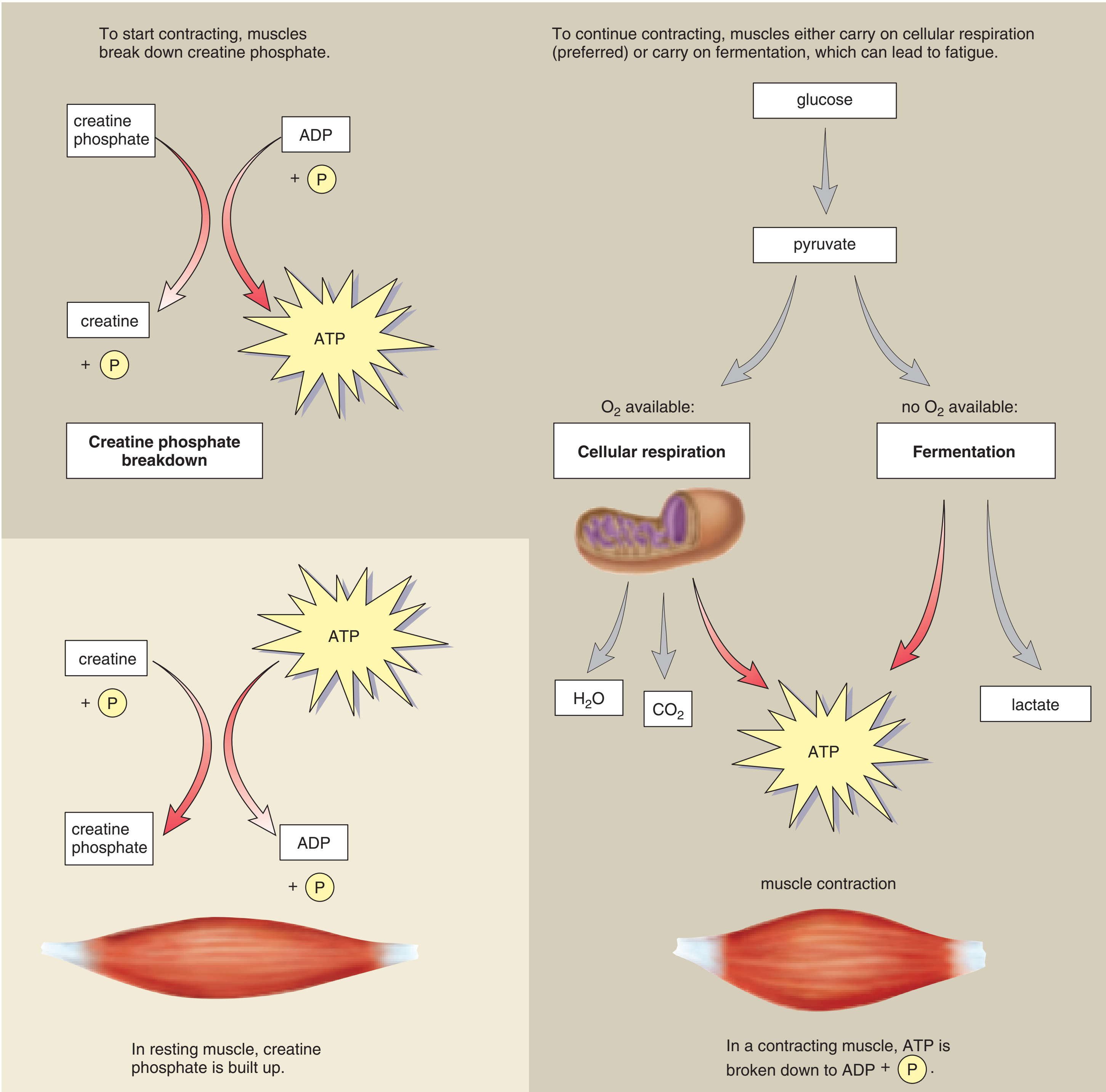
Oxygen Deficit

When a muscle uses fermentation to supply its energy needs, it incurs an **oxygen deficit.** Oxygen deficit is obvious when a person continues to breathe heavily after exercising. The ability to run up an oxygen deficit is one of muscle tissue's greatest assets. Brain tissue cannot last nearly as long without oxygen as muscles can.

Repaying an oxygen deficit requires replenishing creatine phosphate supplies and disposing of lactic acid. Lactic acid can be changed back to pyruvic acid and metabolized completely in mitochondria, or it can be sent to the liver to reconstruct glycogen. A marathon runner who has just crossed the finish line is not exhausted due to oxygen deficit. Instead, the runner has used up all the muscles', and probably the liver's, glycogen supply. It takes about two days to replace glycogen stores on a high-carbohydrate diet.

People who train rely more heavily on cellular respiration than do people who do not train. In people who train, the number of muscle mitochondria increases, and so fermentation is not needed to produce ATP. Their mitochondria can start consuming oxygen as soon as the ADP concentration starts rising during muscle contraction. Because mitochondria can break down fatty acid, instead of glucose, blood glucose is spared for the activity of the brain. (The brain, unlike other organs, can only utilize glucose to produce ATP.) Because less lactate is produced in people who train, the pH of the blood remains steady, and there is less of an oxygen deficit.

Figure 7.6 Energy sources for muscle contraction.



7.3 Muscle Responses

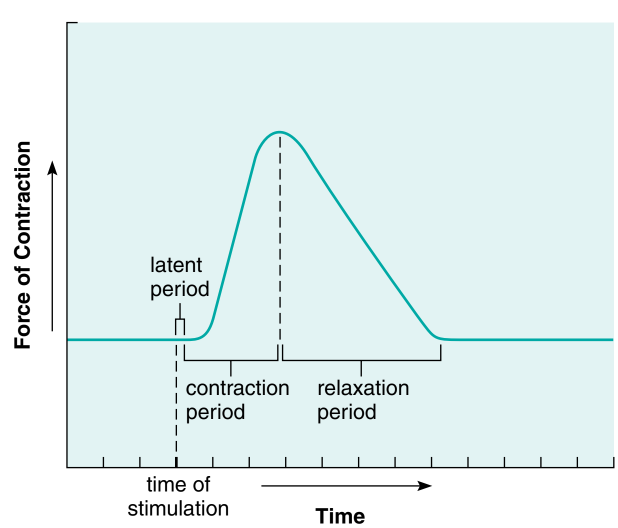
Muscles can be studied in the laboratory in an effort to understand how they respond when in the body.

In the Laboratory

When a muscle fiber is isolated, placed on a microscope slide, and provided with ATP plus the various electrolytes it requires, it contracts completely along its entire length. This observation has resulted in the **all-or-none law:** A muscle fiber contracts completely or not at all. In contrast, a whole muscle shows degrees of contraction. To study whole muscle contraction in the laboratory, an isolated muscle is stimulated electrically, and the mechanical force of contraction is recorded as a visual pattern called a *myogram*. When the strength of the stimulus is above a threshold level, the muscle contracts and then relaxes. This action—a single contraction that lasts only a fraction of a second—is called a **muscle twitch.** Figure 7.7 is a myogram of a muscle twitch, which is customarily divided into three stages: the latent period, or the period of time between stimulation and initiation of contraction; the contraction period, when the muscle shortens; and the relaxation period, when the muscle returns to its former length. It's interesting to use our knowledge of muscle fiber contraction to understand these events. From our study thus far, we know that a muscle fiber in an intact muscle contracts when calcium leaves storage sacs and relaxes when calcium returns to storage sacs.

But unlike the contraction of a muscle fiber, a muscle has degrees of contraction, and a twitch can vary in height (strength) depending on the degree of stimulation. Why should that be? Obviously, a stronger stimulation causes more individual fibers to contract than before.

Figure 7.7 A myogram showing a single muscle twitch.

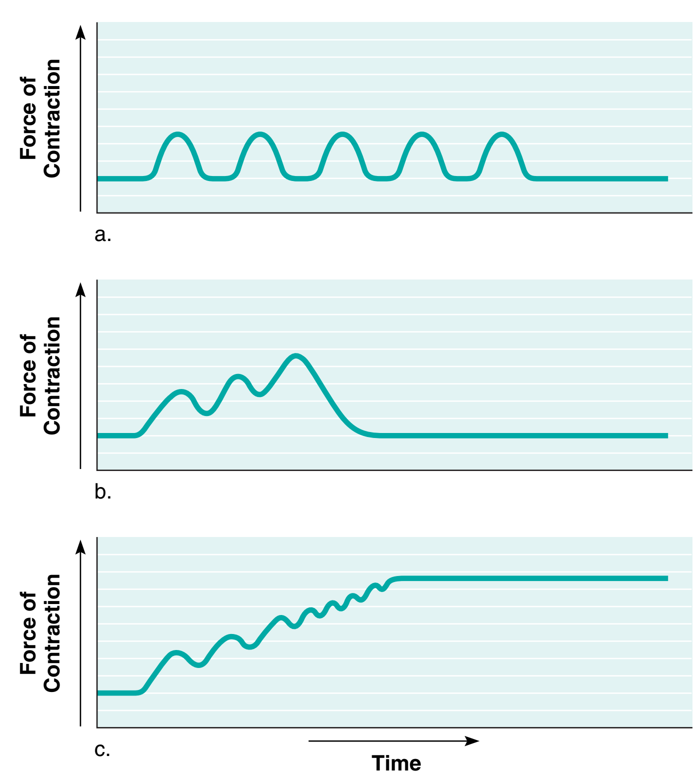


If a whole muscle is given a rapid series of stimuli, it can respond to the next stimulus without relaxing completely. **Summation** is increased muscle contraction until maximal sustained contraction, called a **tetanic contraction,** is achieved (Fig. 7.8). The myogram no longer shows individual twitches; rather, the twitches are fused and blended completely into a straight line. Tetanus continues until the muscle *fatigues* due to depletion of energy reserves. Fatigue is apparent when a muscle relaxes even though stimulation continues.

In the Body

In the body, muscles are innervated to contract by nerves. As mentioned, each axon within a nerve stimulates a number of muscle fibers. A nerve fiber together with all of the muscle fibers it innervates is called a **motor unit.** A motor unit obeys the all-or-none law. Why? Because all the muscle fibers in a motor unit are stimulated at once, and they all either contract or do not contract. A variable of interest is the number of muscle fibers within a motor unit. For example, in the ocular muscles that move the eyes, the innervation ratio is one motor axon per 23 muscle fibers, while in the gastrocnemius muscle of the lower leg, the ratio is about one motor axon per 1,000 muscle fibers. No doubt, moving the eyes requires finer control than moving the legs.

Figure 7.8 Myograms showing **(a)** a series of twitches, **(b)** summation, and **(c)** a tetanic contraction. Note that an increased frequency of stimulations has resulted in these different responses.



Tetanic contractions ordinarily occur in the body because, as the intensity of nervous stimulation increases, more and more motor units are activated. This phenomenon, known as **recruitment,** results in stronger and stronger muscle contractions. But while some muscle fibers are contracting, others are relaxing. Because of this, intact muscles rarely fatigue completely. Even when muscles appear to be at rest, they exhibit **tone,** in which some of their fibers are always contracting. Muscle tone is particularly important in maintaining posture. If all the fibers within the muscles of the neck, trunk, and legs were to suddenly relax, the body would collapse.

Athletics and Muscle Contraction

Athletes who excel in a particular sport, and much of the general public as well, are interested in staying fit by exercising. The Medical Focus on page 135 gives suggestions for exercise programs according to age.

Exercise and Size of Muscles Muscles that are not used or that are used for only very weak contractions decrease in size, or atrophy. **Atrophy** can occur when a limb is placed in a cast or when the nerve serving a muscle is damaged. If nerve stimulation is not restored, muscle fibers are gradually replaced by fat and fibrous tissue. Unfortunately, atrophy can cause muscle fibers to shorten progressively, leaving body parts contracted in contorted positions.

Forceful muscular activity over a prolonged period causes muscle to increase in size as the number of myofibrils within the muscle fibers increases. Increase in muscle size, called **hypertrophy,** occurs only if the muscle contracts to at least 75% of its maximum tension.

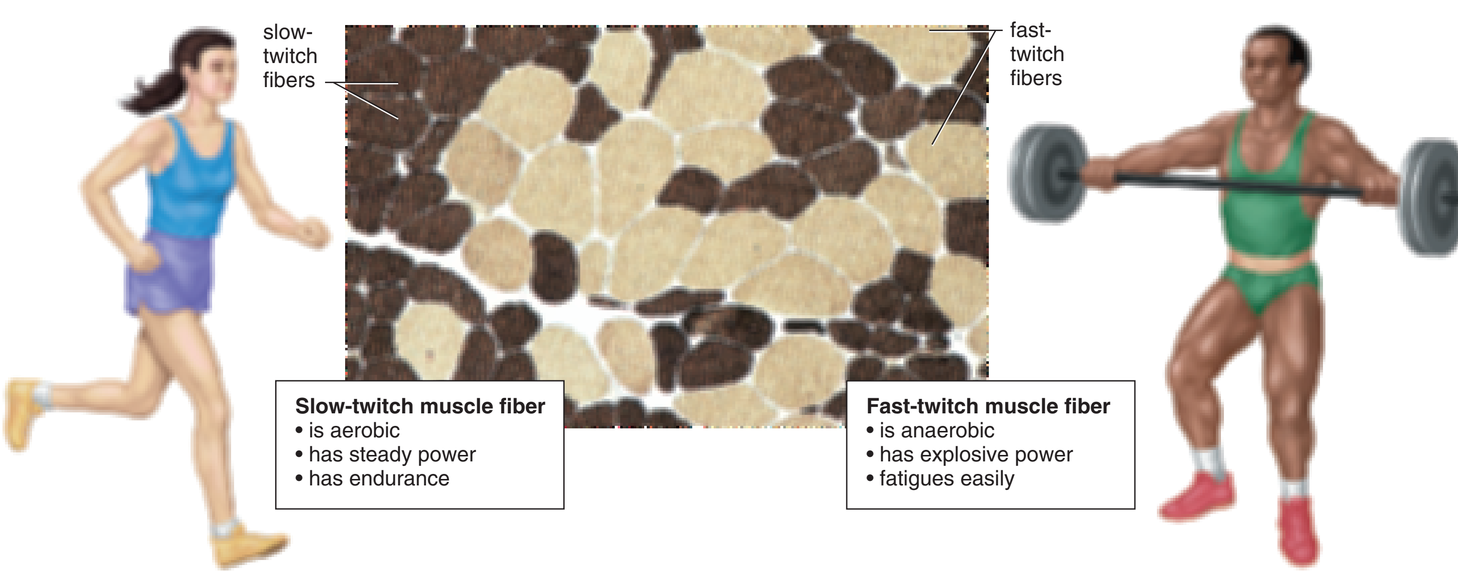
Some athletes take anabolic steroids, either testosterone or related chemicals, to promote muscle growth. This practice has many undesirable side effects as discussed in the Medical Focus on page 199.

Slow-Twitch and Fast-Twitch Muscle Fibers We have seen that all muscle fibers metabolize both aerobically and anaerobically. Some muscle fibers, however, utilize one method more than the other to provide myofibrils with ATP. Slow-twitch fibers tend to be aerobic, and fast-twitch fibers tend to be anaerobic (Fig. 7.9).

Slow-twitch fibers have a steadier tug and more endurance, despite having motor units with a smaller number of fibers. These muscle fibers are most helpful in sports such as long-distance running, biking, jogging, and swimming. Because they produce most of their energy aerobically, they tire only when their fuel supply is gone. Slow-twitch fibers have many mitochondria and are dark in color because they contain myoglobin, the respiratory pigment found in muscles. They are also surrounded by dense capillary beds and draw more blood and oxygen than fast-twitch fibers. Slow-twitch fibers have a low maximum tension, which develops slowly, but these muscle fibers are highly resistant to fatigue. Because slow-twitch fibers have a substantial reserve of glycogen and fat, their abundant mitochondria can maintain a steady, prolonged production of ATP when oxygen is available.

Fast-twitch fibers tend to be anaerobic and seem to be designed for strength because their motor units contain many fibers. They provide explosions of energy and are most helpful in sports activities such as sprinting, weight lifting, swinging a golf club, or throwing a shot. Fast-twitch fibers are light in color because they have fewer mitochondria, little or no myoglobin, and fewer blood vessels than slow-twitch fibers do. Fast-twitch fibers can develop maximum tension more rapidly than slow-twitch fibers can, and their maximum tension is greater. However, their dependence on anaerobic energy leaves them vulnerable to an accumulation of lactic acid that causes them to fatigue quickly.

Figure 7.9 **Slow- and fast-twitch fibers. If your muscles contain many slow-twitch fibers (dark color), you would probably do better at a sport like cross-country running. But if your muscles contain many fast-twitch fibers (light color), you would probably do better at a sport like weight lifting.**



7.4 Skeletal Muscles of the Body

The human body has some 600 skeletal muscles, but this text will discuss only some of the most significant of these. First, let us consider certain basic principles of muscle contraction.

Basic Principles

When a muscle contracts, one bone remains fairly stationary, and the other one moves. The **origin** of a muscle is on the stationary bone, and the **insertion** of a muscle is on the bone that moves.

Frequently, a body part is moved by a group of muscles working together. Even so, one muscle does most of the work, and this muscle is called the **prime mover.** For example, in flexing the elbow, the prime mover is the biceps brachii (Fig. 7.10) The assisting muscles are called the **synergists.** The brachialis (see Fig. 7.12) is a synergist that helps the biceps brachii flex the elbow. A prime mover can have several synergists.

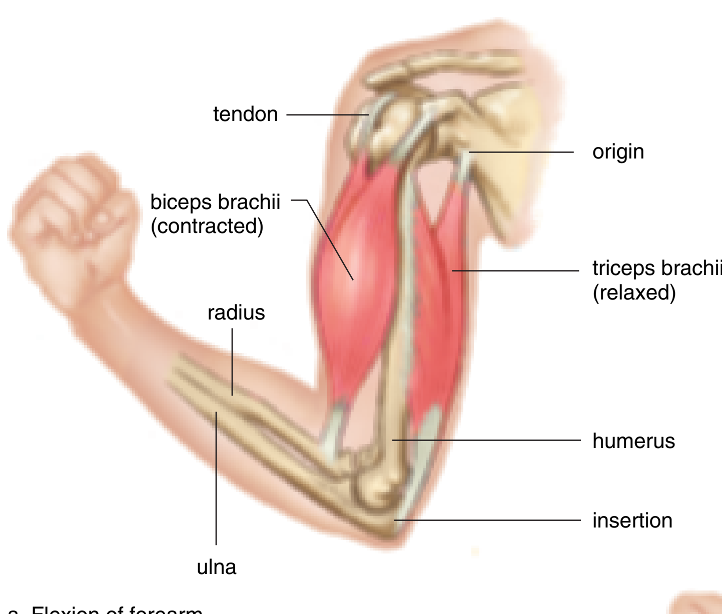
When muscles contract, they shorten. Therefore, muscles can only pull; they cannot push. However, muscles have **antagonists,** and antagonistic pairs work opposite one another to bring about movement in opposite directions. For example, the biceps brachii and the triceps brachii are antagonists; one flexes the forearm, and the other extends the forearm (Fig. 7.10). Later on in our discussion, we will encounter other antagonistic pairs.

Naming Muscles

When learning the names of muscles, considering what the name means will help you remember it. The names of the various skeletal muscles are often combinations of the following terms used to characterize muscles:

1. **Size.** For example, the *gluteus maximus* is the largest muscle that makes up the buttocks. The *gluteus minimus* is the smallest of the gluteal muscles. Other terms used to indicate size are vastus (huge), longus (long), and brevis (short).
2. **Shape.** For example, the *deltoid* is shaped like a delta, or triangle, while the *trapezius* is shaped like a trapezoid. Other terms used to indicate shape are latissimus (wide) and teres (round).
3. **Direction of fibers.** For example, the *rectus abdominis* is a longitudinal muscle of the abdomen (*rectus* means straight). The *orbicularis* is a circular muscle around the eye. Other terms used to indicate direction are transverse (across) and oblique (diagonal).
4. **Location.** For example, the *frontalis* overlies the frontal bone. The *external obliques* are located outside the internal obliques. Other terms used to indicate location are pectoralis (chest), gluteus (buttock), brachii (arm), and sub (beneath). You should also review these directional terms: anterior, posterior, lateral, medial, proximal, distal, superficial, and deep.

Figure 7.10 **The origin of a muscle is on a bone that remains stationary, and the insertion of a muscle is on a bone that moves when a muscle contracts. Two of the muscles shown here are antagonistic. a. When the biceps brachii contracts, the lower arm flexes. b. When the triceps brachii contracts, the lower arm extends.**



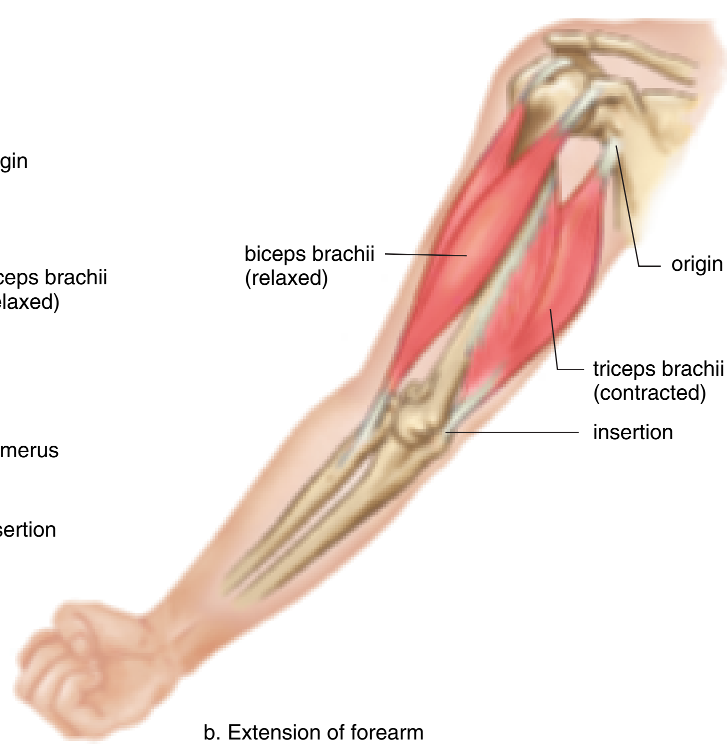


Figure 7.11 Anterior view of the body's superficial skeletal muscles.

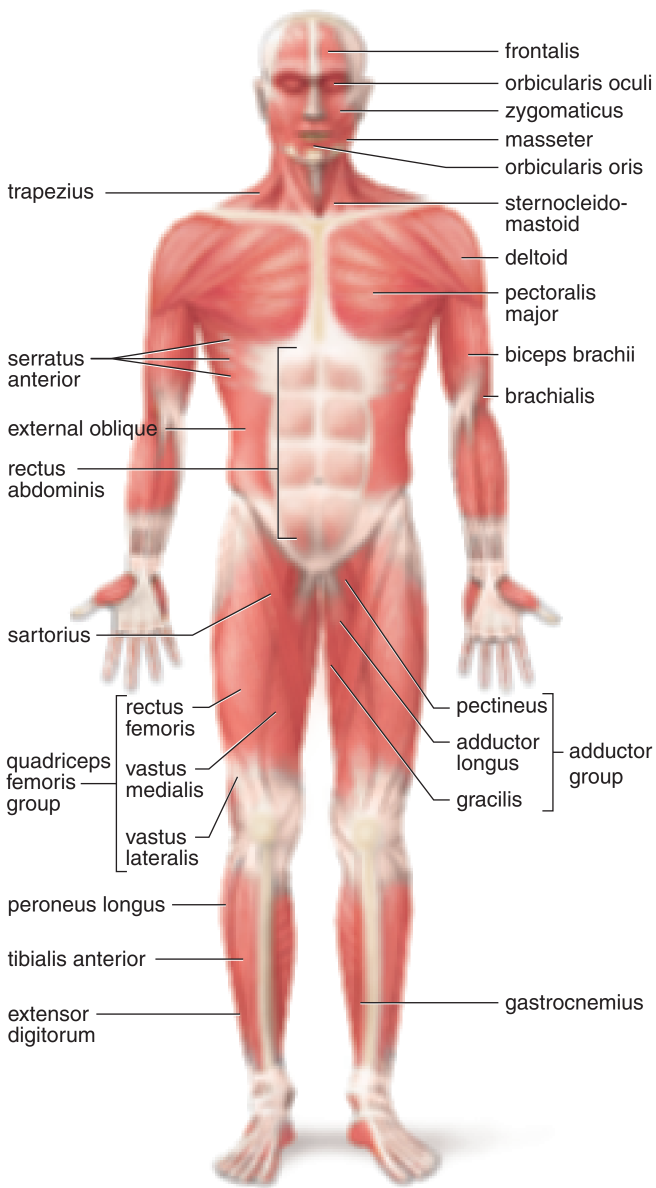
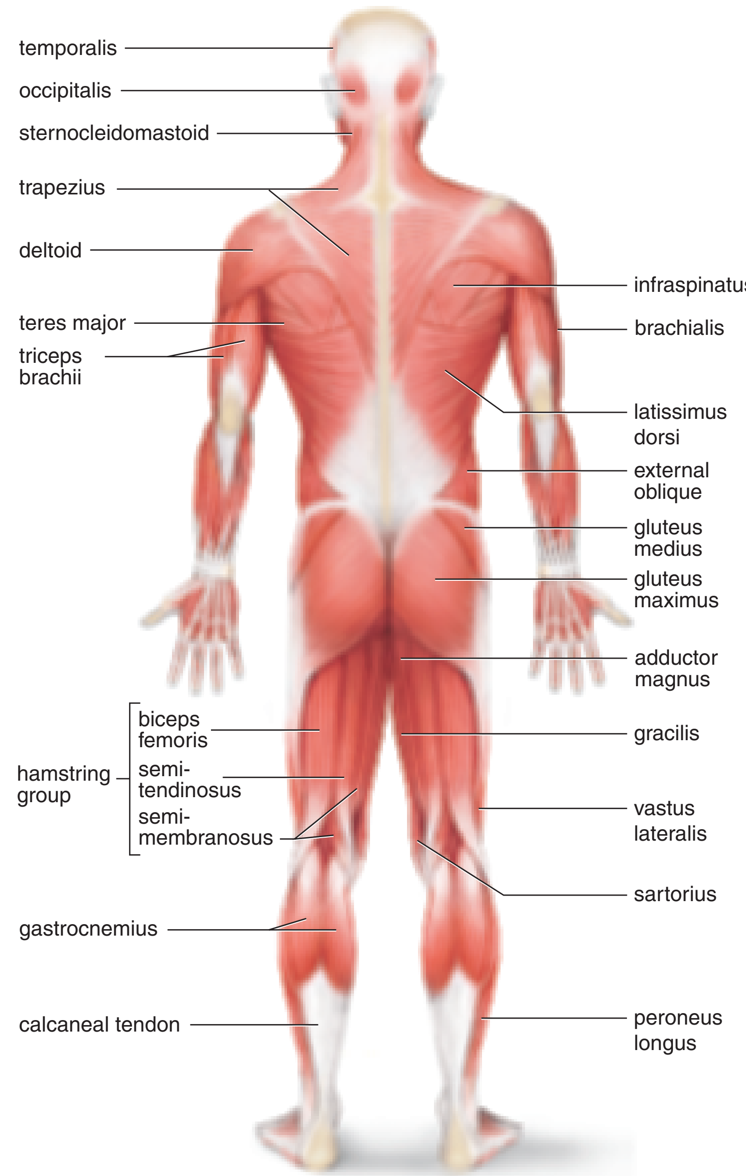


Figure 7.12 Posterior view of the body's superficial skeletal muscles.



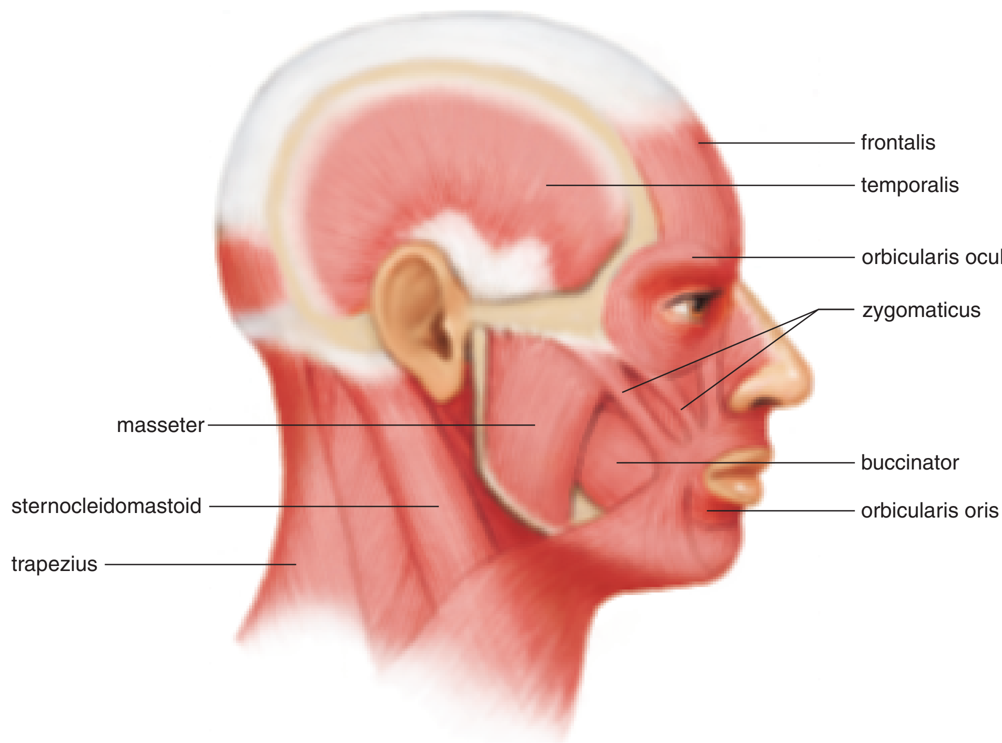
5. **Attachment.** For example, the *sternocleidomastoid* is attached to the sternum, clavicle, and mastoid process. The *brachioradialis* is attached to the brachium (arm) and the radius.
6. **Number of attachments.** For example, the biceps brachii has two attachments, or origins (and is located on the arm). The quadriceps femoris has four origins (and is located on the anterior femur).
7. **Action.** For example, the *extensor digitorum* extends the fingers or digits. The *adductor magnus* is a large muscle that adducts the thigh. Other terms used to indicate action are flexor (to flex), masseter (to chew), and levator (to lift).

With every muscle you learn, try to understand its name.

Skeletal Muscle Groups

In our discussion, the muscles of the body (Figs. 7.11 and 7.12) will be grouped according to their location and their action. After you understand the meaning of a muscle's name, try to correlate its name with the muscle's location and the action it performs. Knowing the origin and insertion will also help you remember what the muscle does. Why? Because the insertion is on the bone that moves. You should review the various body movements listed and illustrated in Chapter 6 (see page 106). Only then will you be able to understand the actions of the muscles listed in Tables 7.2–7.5. Scientific terminology is necessary because it allows all persons to know the exact action being described for that muscle. Also review the meaning of the terms *arm* and *leg*.

Figure 7.13 Muscles of the head and neck. Some of these muscles account for our facial expressions and the ability to chew our food; others move the head.



Muscles of the Head

The muscles of the head and neck are the first group of muscles we will study. The muscles of the head and neck are illustrated in Figure 7.13 and listed in Table 7.2. The muscles of the head are responsible for facial expression and mastication (chewing). One muscle of the head and several muscles of the neck allow us to swallow. The muscles of the neck also move the head.

Muscles of Facial Expression

The muscles of facial expression are located on the scalp and face. These muscles are unusual in that they insert into and move the skin. Therefore, we expect them to move the skin and not a bone. The use of these muscles communicates to others whether we are surprised, angry, fearful, happy, and so forth.

Frontalis lies over the frontal bone; it raises the eyebrows and wrinkles the brow. Frequent use results in furrowing of the forehead.

Orbicularis oculi is a ringlike band of muscle that encircles (forms an orbit about) the eye. It causes the eye to close or blink, and is responsible for "crow's feet" at the eye corners.

Orbicularis oris encircles the mouth and is used to pucker the lips, as in forming a kiss. Frequent use results in lines about the mouth.

Buccinator muscles are located in the cheek areas. When a buccinator contracts, the cheek is compressed, as when a person whistles or blows out air. Therefore, this muscle is called the "trumpeter's muscle." Important to everyday life, the buccinator helps hold food in contact with the teeth during chewing. It is also used in swallowing, as discussed next.

Zygomaticus extends from each zygomatic arch (cheekbone) to the corners of the mouth. It raises the corners of the mouth when a person smiles.

Muscles of Mastication

The muscles of mastication are used when we chew food or bite something. Although there are four pairs of muscles for chewing, only two pairs are superficial and shown in Figure 7.13. As you might expect, both of these muscles insert on the mandible.

Each **masseter** has its origin on the zygomatic arch and its insertion on the mandible. The masseter is a muscle of mastication (chewing) because it is a prime mover for elevating the mandible.

Each **temporalis** is a fan-shaped muscle that overlies the temporal bone. It is also a prime mover for elevating the mandible. The masseter and temporalis are synergists.

Table 7.2 Muscles of the Head and Neck

Name	Function	Origin/Insertion
Muscles of Facial Expression		
Frontalis (frun-ta′lis)	Raises eyebrows	Cranial fascia/skin and muscles around eye
Orbicularis oculi (or-bik′yū-lā-ris ok′yū-li)	Closes eye	Maxillary and frontal bones/skin around eye
Orbicularis oris (or-bik′yū-lā-ris o′ris)	Closes and protrudes lips	Muscles near the mouth/skin around mouth
Buccinator (buk′si-na″tor)	Compresses cheeks inward	Outer surfaces of maxilla and mandible/orbicularis oris
Zygomaticus (zi″go-mat′ik-us)	Raises corner of mouth	Zygomatic bone/skin and muscle around mouth
Muscles of Mastication		
Masseter (mas-se′ter)	Closes jaw	Zygomatic arch/mandible
Temporalis (tem-po-ra′lis)	Closes jaw	Temporal bone/mandibular coronoid process
Muscles That Move the Head		
Sternocleidomastoid (ster″no-kli″do-mas′toid)	Flexes head and rotates head	Sternum and clavicle/mastoid process of temporal bone
Trapezius (truh-pe′ze-us)	Extends head and adducts scapula	Occipital bone and all cervical and thoracic vertebrae/spine of scapula and clavicle

Muscles of the Neck

Deep muscles of the neck (not illustrated) are responsible for swallowing. Superficial muscles of the neck move the head (see Table 7.2 and Figure 7.13).

Swallowing

Swallowing is an important activity that begins after we chew our food. First, the tongue (a muscle) and the buccinators squeeze the food back along the roof of the mouth toward the pharynx. An important bone that functions in swallowing is the hyoid (see page 92). The hyoid is the only bone in the body that does not articulate with another bone.

Muscles that lie superior to the hyoid, called the suprahyoid muscles, and muscles that lie inferior to the hyoid, called the infrahyoid muscles, move the hyoid. These muscles lie deep in the neck and are not illustrated in Figure 7.13. The suprahyoid muscles pull the hyoid forward and upward toward the mandible. Because the hyoid is attached to the larynx, this pulls the larynx upward and forward. The epiglottis now lies over the glottis and closes the respiratory passages. Small palatini muscles (not illustrated) pull the soft palate backward, closing off the nasal passages. Pharyngeal constrictor muscles (not illustrated) push the bolus of food into the pharynx, which widens when the suprahyoid muscles move the hyoid. The hyoid bone and larynx are returned to their original positions by the infrahyoid muscles. Notice that the suprahyoid and infrahyoid muscles are antagonists.

Muscles That Move the Head

Two muscles in the neck are of particular interest: The sternocleidomastoid and the trapezius are listed in Table 7.2 and illustrated in Figure 7.13. Recall that *flexion* is a movement that closes the angle at a joint and *extension* is a movement that increases the angle at a joint. Recall that *abduction* is a movement away from the midline of the body, while *adduction* is a movement toward the midline. Also, *rotation* is the movement of a part around its own axis.

Sternocleidomastoid muscles ascend obliquely from their origin on the sternum and clavicle to their insertion on the mastoid process of the temporal bone. Which part of the body do you expect them to move? When both sternocleidomastoid muscles contract, flexion of the head occurs. When only one contracts, the head turns to the opposite side. If you turn your head to the right, you can see how the left sternocleidomastoid shortens, pulling the head to the right.

Each **trapezius** muscle is triangular, but together, they take on a diamond or trapezoid shape. The origin of a trapezius is at the base of the skull. Its insertion is on a clavicle and scapula. You would expect the trapezius muscles to move the scapulae, and they do. They adduct the scapulae when the shoulders are shrugged or pulled back. The trapezius muscles also help extend the head, however. The prime movers for head extension are actually deep to the trapezius and not illustrated in Figure 7.13.

Figure 7.14 Muscles of the anterior shoulder and trunk. The right pectoralis major is removed to show the deep muscles of the chest.

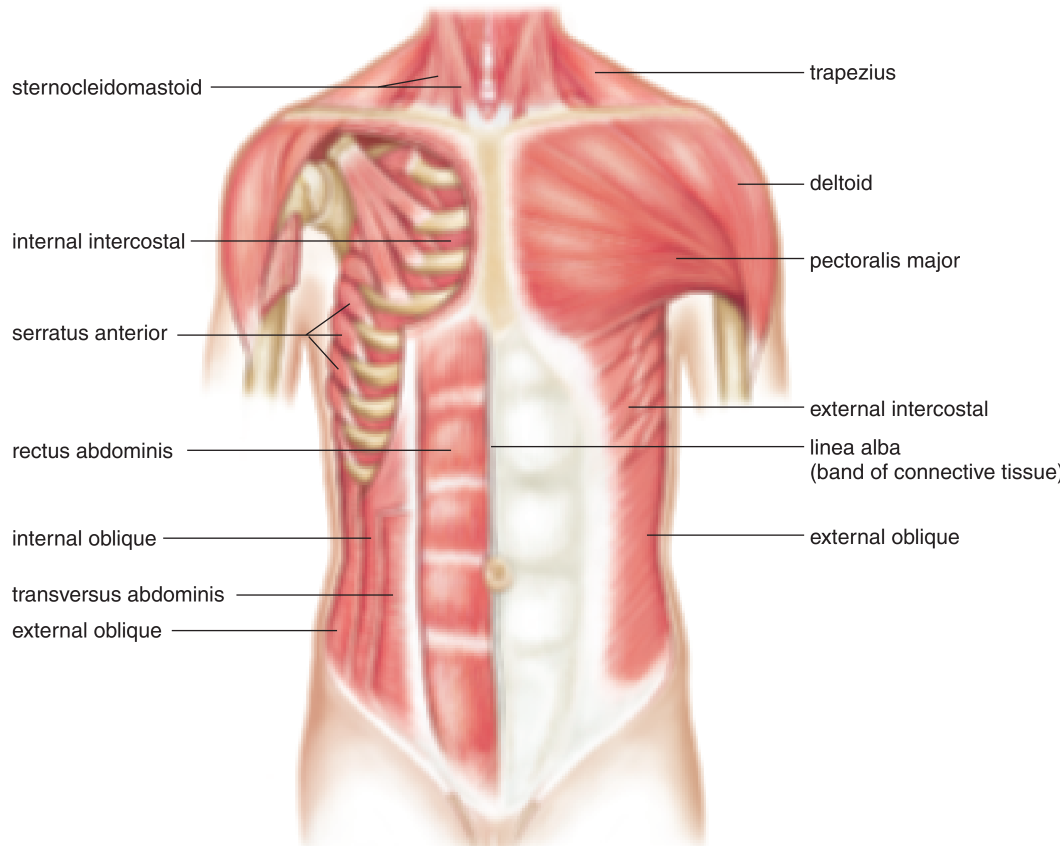


Table 7.3 Muscles of the Trunk

Name	Function	Origin/Insertion
Muscles of the Trunk		
External intercostals	Elevate rib cage for inspiration	Superior rib/inferior rib
Internal intercostals	Depress rib cage for expiration	Inferior rib/superior rib
External oblique	Tenses abdominal wall; lateral rotation of trunk	Lower eight ribs/iliac crest
Internal oblique	Tenses abdominal wall; lateral rotation of trunk	Iliac crest/lower three ribs
Transversus abdominis	Tenses abdominal wall	Lower six ribs/pubis
Rectus abdominis	Flexes and rotates the vertebral column	Pubis, pubic symphysis/xiphoid process of sternum, fifth to seventh costal cartilages

Muscles of the Trunk

The muscles of the trunk are listed in Table 7.3 and illustrated in Figure 7.14. The muscles of the thoracic wall are primarily involved in breathing. The muscles of the abdominal wall protect and support the organs within the abdominal cavity.

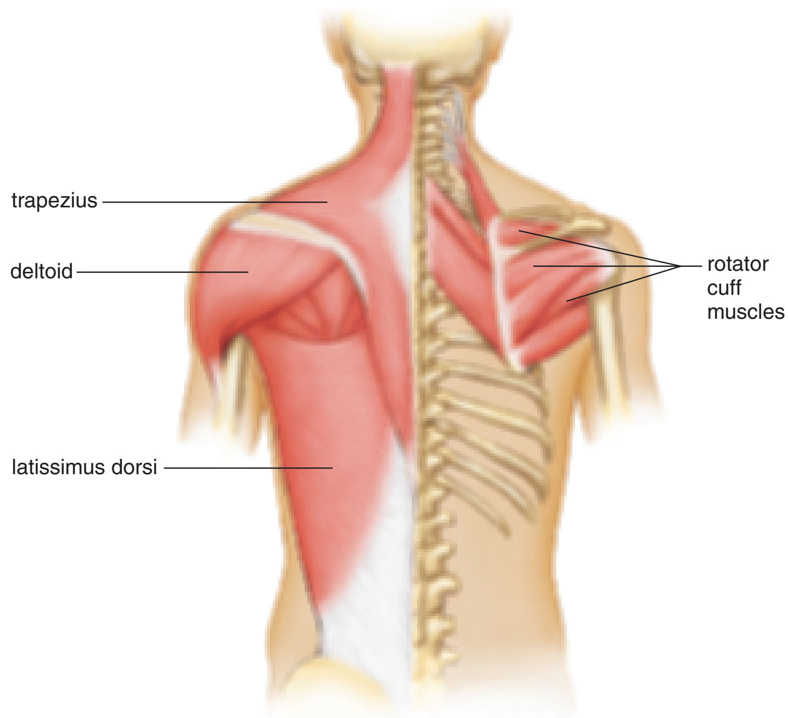
Muscles of the Thoracic Wall

External intercostal muscles occur between the ribs; they originate on a superior rib and insert on an inferior rib. These muscles elevate the rib cage during the inspiration phase of breathing.

The **diaphragm** is a dome-shaped muscle that, as you know, separates the thoracic cavity from the abdominal cavity (see Fig. 1.5). Contraction of the diaphragm also assists inspiration.

Internal intercostal muscles originate on an inferior rib and insert on a superior rib. These muscles depress the rib cage and contract only during a forced expiration. Normal expiration does not require muscular action.

Figure 7.15 **Muscles of the posterior shoulder. The right trapezius is removed to show deep muscles that move the scapula and the rotator cuff muscles.**



Muscles of the Abdominal Wall

The abdominal wall has no bony reinforcement (Fig. 7.14). The wall is strengthened by four pairs of muscles that run at angles to one another. The external and internal obliques and the transversus abdominis occur laterally, but the fasciae of these muscle pairs meet at the midline of the body, forming a tendinous area called the linea alba. The rectus abdominis is a superficial medial pair of muscles.

All of the muscle pairs of the abdominal wall compress the abdominal cavity and support and protect the organs within the abdominal cavity.

External and **internal obliques** occur on a slant and are at right angles to one another between the lower ribs and the pelvic girdle. The external obliques are superior to the internal obliques. These muscles also aid trunk rotation and lateral flexion.

Transversus abdominis, deep to the obliques, extends horizontally across the abdomen. The obliques and the transversus abdominis are synergistic muscles.

Rectus abdominis has a straplike appearance but takes its name from the fact that it runs straight (*rectus* means straight) up from the pubic bones to the ribs and sternum. These muscles also help flex and rotate the lumbar portion of the vertebral column.

Muscles of the Shoulder

Muscles of the shoulder are shown in Figures 7.14 and 7.15. They are also listed in Table 7.4 on page 130. The muscles of the shoulder attach the scapula to the thorax and move the scapula; they also attach the humerus to the scapula and move the arm.

Muscles That Move the Scapula

Of the muscles that move the scapula, we have already discussed the trapezius (see page 127).

Serratus anterior is located below the axilla (armpit) on the lateral chest. It runs between the upper ribs and the scapula. It depresses the scapula and pulls it forward, as when we push something. It also helps to elevate the arm above the horizontal level.

Muscles That Move the Arm

Deltoid is a large, fleshy, triangular muscle (*deltoid* in Greek means triangular) that covers the shoulder and causes a bulge in the arm where it meets the shoulder. It runs from both the clavicle and the scapula of the pectoral girdle to the humerus. This muscle abducts the arm to the horizontal position.

Table 7.4 Muscles of the Shoulder and Upper Limb

Name	Function	Origin/Insertion
Muscles That Move the Scapula and Arm		
Serratus anterior	Depresses scapula and pulls it forward; elevates arm above horizontal	Upper nine ribs/vertebral border of scapula
Deltoid	Abducts arm to horizontal	Acromion process, spine of scapula, and clavicle/deltoid tuberosity of humerus
Pectoralis major	Flexes and adducts arm	Clavicle, sternum, second to sixth costal cartilages/ intertubular groove of humerus
Latissmus dorsi	Extends or adducts arm	Iliac crest/intertubular groove of humerus
Rotator cuff	Angular and rotational movements of arm	Scapula/humerus
Muscles That Move the Forearm		
Biceps brachii	Flexes forearm, and supinates hand	Scapula/radial tuberosity
Triceps brachii	Extends forearm	Scapula, proximal humerus/olecranon process of ulna
Brachialis	Flexes forearm	Anterior humerus/coronoid process of ulna
Muscles That Move the Hand and Fingers		
Flexor carpi and extensor carpi	Move wrist and hand	Humerus/carpals and metacarpals
Flexor digitorum and extensor digitorum	Move fingers	Humerus, radius, ulna/phalanges

Pectoralis major (Fig. 7.14) is a large anterior muscle of the upper chest. It originates from a clavicle, but also from the sternum and ribs. It inserts on the humerus. The pectoralis major flexes the arm (raises it anteriorly) and adducts the arm, pulling it toward the chest.

Latissimus dorsi (Fig. 7.15) is a large, wide, triangular muscle of the back. This muscle originates from the lower spine and sweeps upward to insert on the humerus. The latissimus dorsi extends and adducts the arm (brings it down from a raised position). This muscle is very important for swimming, rowing, and climbing a rope.

Rotator cuff (Fig. 7.15). This group of muscles is so named because their tendons help form a cuff over the proximal humerus. These muscles lie deep to those already mentioned, and they are synergists to them.

Muscles of the Arm

The muscles of the arm move the forearm. They are illustrated in Figure 7.16 and listed in Table 7.4.

Biceps brachii is a muscle of the proximal anterior arm (Fig. 7.16*a*) that is familiar because it bulges when the forearm is flexed. It also supinates the hand when a doorknob is turned or the cap of a jar is unscrewed. The name of the muscle refers to its two heads that attach to the scapula, where it originates. The biceps brachii inserts on the radius.

Brachialis originates on the humerus and inserts on the ulna. It is a muscle of the distal anterior humerus and lies deep to the biceps brachii. It is synergistic to the biceps brachii in flexing the forearm.

Triceps brachii is the only muscle of the posterior arm (Fig. 7.16*b*). It has three heads that attach to the scapula and humerus, and it inserts on the ulna. The triceps extends the forearm. It is sometimes called the "boxer's muscle" because it extends the elbow when a punch is thrown. The triceps is also used in tennis to do a backhand volley.

Muscles of the Forearm

The muscles of the forearm move the hand and fingers. They are illustrated in Figure 7.16*c*,*d* and listed in Table 7.4. Note that extensors of the wrists and fingers are on the lateral fore-arm and flexors are on the medial forearm.

Flexor carpi and **extensor carpi** muscles originate on the bones of the forearm and insert on the bones of the hand. The flexor carpi flex the wrists and hands, and the extensor carpi extend the wrists and hands.

Flexor digitorum and **extensor digitorum** muscles also originate on the bones of the forearm and insert on the bones of the hand. The flexor digitorum flexes the wrist and fingers, and the extensor digitorum extends the wrist and fingers (i.e., the digits).

Figure 7.16 **a.** Muscles of the anterior arm and shoulder. **b.** Muscles of the posterior arm and shoulder. **c.** Muscles of the anterior forearm. **d.** Muscles of the posterior forearm.

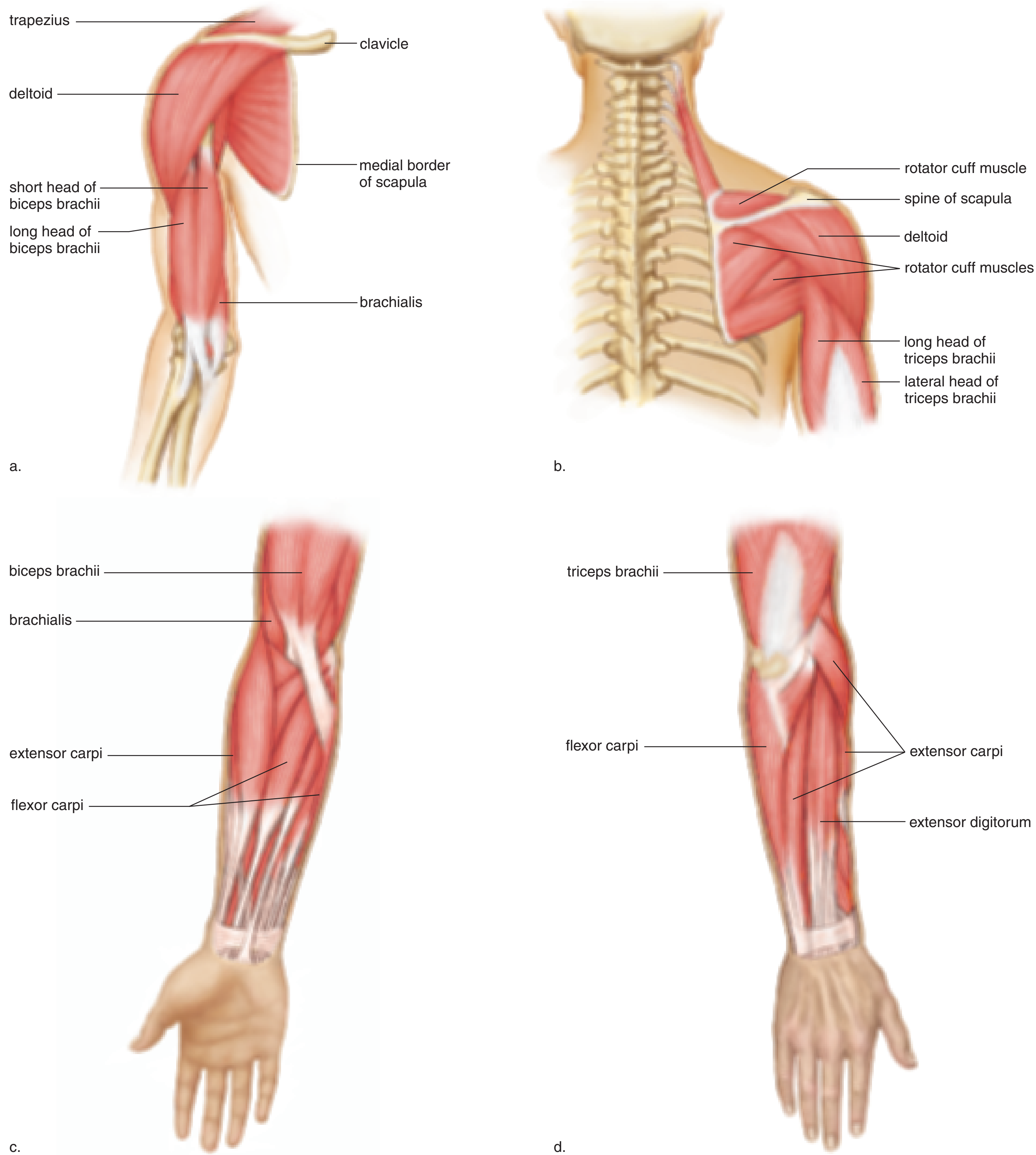


Table 7.5 **Muscles of the Hip and Lower Limb**

Name	Function	Origin/Insertion
Muscles That Move the Thigh		
Iliopsoas (il′e-o-so′us)	Flexes thigh	Lumbar vertebrae, ilium/lesser trochanter of femur
Gluteus maximus	Extends thigh	Posterior ilium, sacrum/proximal femur
Gluteus medius	Abducts thigh	Ilium/greater trochanter of femur
Adductor group	Adducts thigh	Pubis, ischium/femur and tibia
Muscles That Move the Leg		
Quadriceps femoris group	Extends leg	Ilium, femur/patellar tendon that continues as a ligament to tibial tuberosity
Sartorius	Flexes, abducts, and rotates leg laterally	Ilium/medial tibia
Hamstring group	Flexes and rotates leg medially, and extends thigh	Ischial tuberosity/lateral and medial tibia
Muscles That Move the Ankle and Foot		
Gastrocnemius (gas″trok-ne′me-us)	Plantar flexion and eversion of foot	Condyles of femur/calcaneus by way of Achilles tendon
Tibialis anterior (tib″e-a′lis an-te′re-or)	Dorsiflexion and inversion of foot	Condyles of tibia/tarsal and metatarsal bones
Peroneus group (per″o-ne-us)	Plantar flexion and eversion of foot	Fibula/tarsal and metatarsal bones
Flexor and extensor digitorum longus	Moves toes	Tibia, fibula/phalanges

Muscles of the Hip and Lower Limb

The muscles of the hip and lower limb are listed in Table 7.5 and shown in Figures 7.17 to 7.20. These muscles, particularly those of the hips and thigh, tend to be large and heavy because they are used to move the entire weight of the body and to resist the force of gravity. Therefore, they are important for movement and balance.

Muscles That Move the Thigh

The muscles that move the thigh have at least one origin on the pelvic girdle and insert on the femur. Notice that the iliopsoas is an anterior muscle that moves the thigh, while the gluteal muscles ("gluts") are posterior muscles that move the thigh. The adductor muscles are medial muscles (Fig. 7.17 and Fig. 7.18). Before studying the action of these muscles, review the movement of the hip joint when the thigh flexes, extends, abducts, and adducts.

Iliopsoas (includes psoas major and iliacus) originates at the ilium and the bodies of the lumbar vertebrae, and inserts on the femur anteriorly (Fig. 7.17). This muscle is the prime mover for flexing the thigh and also the trunk, as when we bow. As the major flexor of the thigh, the iliopsoas is important to the process of walking. It also helps prevent the trunk from falling backward when a person is standing erect.

The gluteal muscles form the buttocks. We will consider only the gluteus maximus and the gluteus medius, both of which are illustrated in Figure 7.18.

Gluteus maximus is the largest muscle in the body and covers a large part of the buttock (*gluteus* means buttocks in Greek). It originates at the ilium and sacrum, and inserts on the femur. The gluteus maximus is a prime mover of thigh extension, as when a person is walking, climbing stairs, or jumping from a crouched position. Notice that the iliopsoas and the gluteus maximus are antagonistic muscles.

Gluteus medius lies partly behind the gluteus maximus (Fig. 7.18). It runs between the ilium and the femur, and functions to abduct the thigh. The gluteus maximus assists the gluteus medius in this function. Therefore, they are synergistic muscles.

Adductor group muscles (pectineus, adductor longus, adductor magnus, gracilis) are located on the medial thigh (Fig. 7.17). All of these muscles originate from the pubis and ischium, and insert on the femur; the deep adductor magnus is shown in Figure 7.17. Adductor muscles adduct the thigh—that is, they lower the thigh sideways from a horizontal position. Because they press the thighs inward, these are the muscles that keep a rider on a horse. Notice that the gluts and the adductor group are antagonistic muscles.

Figure 7.17 Muscles of the anterior right hip and thigh.

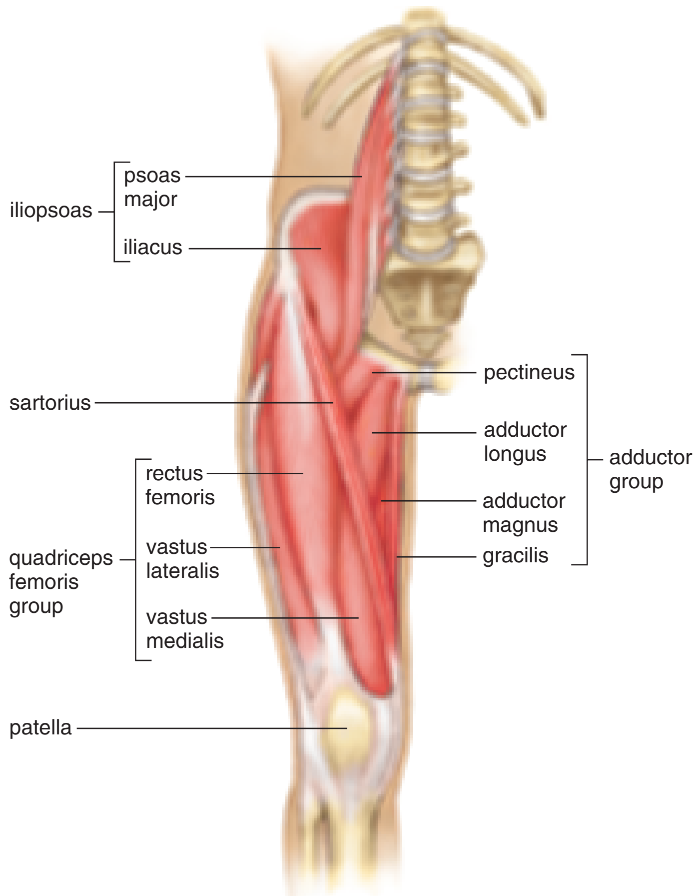
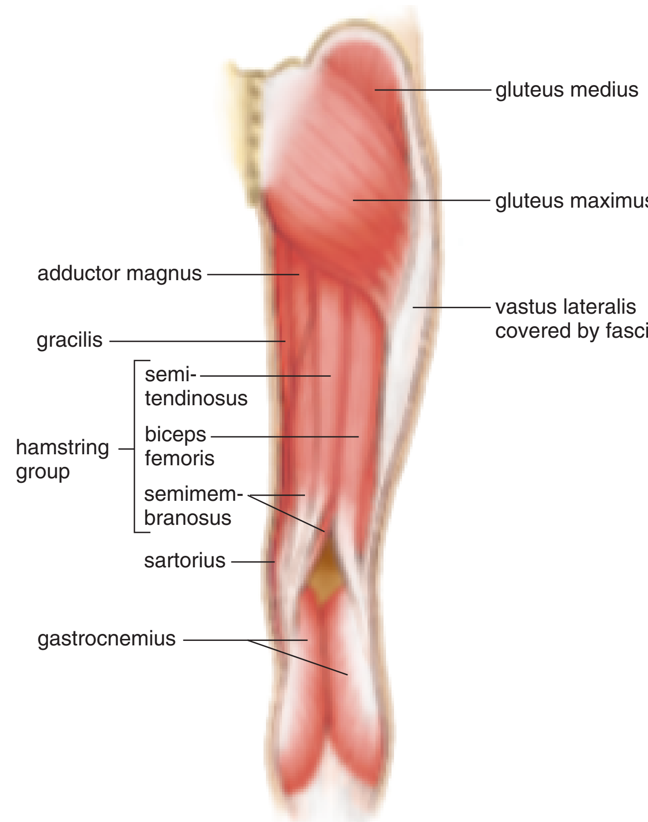


Figure 7.18 Muscles of the posterior right hip and thigh.



Muscles That Move the Leg

The muscles that move the leg originate from the pelvic girdle or femur and insert on the tibia. They are listed in Table 7.5 and illustrated in Figures 7.17 and 7.18. Before studying these muscles, review the movement of the knee when the leg extends and when it flexes.

Quadriceps femoris group (rectus femoris, vastus lateralis, vastus medialis, vastus intermedius), also known as the "quads," is found on the anterior and medial thigh. The rectus femoris, which originates from the ilium, is external to the vastus intermedius, and therefore the vastus intermedius is not shown in Figure 7.17. These muscles are the primary extensors of the leg, as when you kick a ball by straightening your knee.

Sartorius is a long, straplike muscle that has its origin on the iliac spine and then goes across the anterior thigh to insert on the medial side of the knee (Fig. 7.17). Because this muscle crosses both the hip and knee joint, it acts on the thigh in addition to the leg. The insertion of the sartorius is such that it flexes both the leg and the thigh. It also rotates the thigh laterally, enabling us to sit cross-legged, as tailors were accustomed to do in another era. Therefore, it is sometimes called the "tailor's muscle," and in fact, *sartor* means tailor in Latin.

Hamstring group (biceps femoris, semimembranosus, semitendinosus) is located on the posterior thigh (Fig. 7.18). Notice that these muscles also cross the hip and knee joint because they have origins on the ischium and insert on the tibia. They flex and rotate the leg medially, but they also extend the thigh. Their strong tendons can be felt behind the knee. These same tendons are present in hogs and were used by butchers as strings to hang up hams for smoking—hence, the name. Notice that the quadriceps femoris group and the hamstring group are antagonistic muscles in that the quads extend the leg and the hamstrings flex the leg.

Figure 7.19 Muscles of the anterior right leg.

Muscles That Move the Ankle and Foot

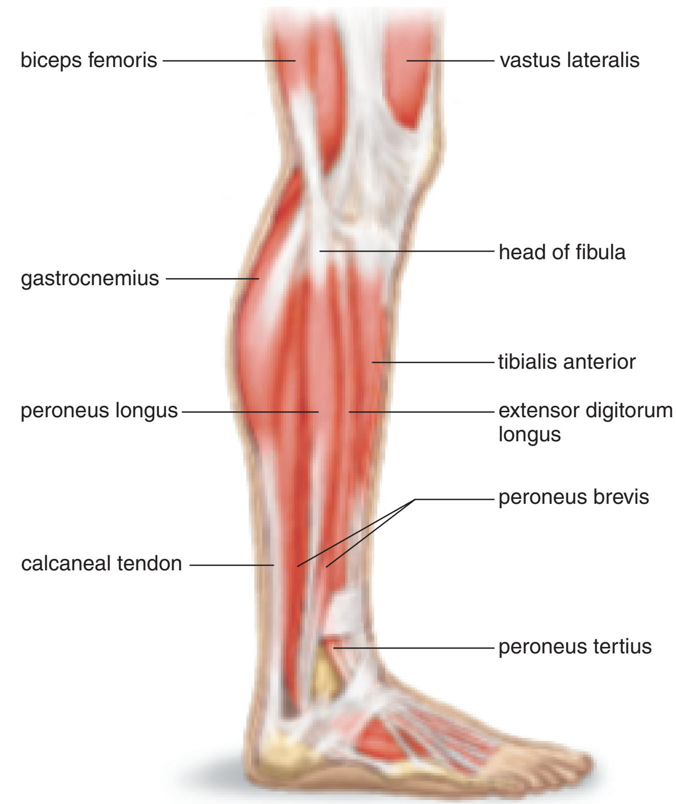
Muscles that move the ankle and foot are shown in Figures 7.19 and 7.20.

Gastrocnemius is a muscle of the posterior leg, where it forms a large part of the calf. It arises from the femur; distally, the muscle joins the strong calcaneal tendon, which attaches to the calcaneus bone (heel). The gastrocnemius is a powerful plantar flexor of the foot that aids in pushing the body forward during walking or running. It is sometimes called the "toe dancer's muscle" because it allows a person to stand on tiptoe.

Tibialis anterior is a long, spindle-shaped muscle of the anterior leg. It arises from the surface of the tibia and attaches to the bones of the ankle and foot. Contraction of this muscle causes dorsiflexion and inversion of the foot.

Peroneus muscles (peroneus longus, peroneus brevis) are found on the lateral side of the leg, connecting the fibula to the metatarsal bones of the foot. These muscles evert the foot and also help bring about plantar flexion.

Figure 7.20 Muscles of the lateral right leg.



Flexor (not shown) and **extensor digitorum longus** muscles are found on the lateral and posterior portion of the leg. They arise mostly from the tibia and insert on the toes. They flex and extend the toes, respectively, and assist in other movements of the feet.

7.5 Effects of Aging

Muscle mass and strength tend to decrease as people age. How much of this is due to lack of exercise and a poor diet has yet to be determined. Deteriorated muscle elements are replaced initially by connective tissue and, eventually, by fat. With age, degenerative changes take place in the mitochondria, and endurance decreases. Also, changes in the nervous and cardiovascular systems adversely affect the structure and function of muscles.

Muscle mass and strength can improve remarkably if elderly people undergo a training program. Exercise at any age appears to stimulate muscle buildup. As discussed in the Medical Focus on page 135, exercise has many other benefits as well. For example, exercise improves the cardiovascular system and reduces the risk of diabetes and glycation. During glycation, excess glucose molecules stick to body proteins so that the proteins no longer have their normal structure and cannot function properly. Exercise burns glucose and, in this way, helps prevent muscle deterioration.

Benefits of Exercise

Exercise programs improve muscular strength, muscular endurance, and flexibility. Muscular strength is the force a muscle group (or muscle) can exert against a resistance in one maximal effort. Muscular endurance is judged by the ability of a muscle to contract repeatedly or to sustain a contraction for an extended period. Flexibility is tested by observing the range of motion about a joint.

As muscular strength improves, the overall size of the muscle, as well as the number of muscle fibers and myofibrils in the muscle, increases. The total amount of protein, the number of capillaries, and the amounts of connective tissue, including tissue found in tendons and ligaments, also increase. Physical training with weights can improve muscular strength and endurance in all adults, regardless of their age. Over time, increased muscle strength promotes strong bones.

A surprising finding, however, is that health benefits also accompany less strenuous programs, such as those described in Table 7A. A study of 12,000 men by Dr. Arthur Leon at the University of Minnesota showed that even moderate exercise lowered the risk of a heart attack by one-third. People with arthritis reported much less pain, swelling, fatigue, and depression after only four months of attending a twice-weekly, low-impact aerobics class. Increasing daily activity by walking to the corner store instead of driving and by taking the stairs instead of the elevator can improve a person's health.

The benefits of exercise are most apparent with regard to cardiovascular health. Brisk walking for 2.5–4 hours a week can raise the blood levels of high-density lipoprotein (HDL), a chemical that promotes healthy blood vessels (see Chapter 12). Exercise also helps prevent osteoporosis, a condition in which the bones are weak and tend to break. The stronger the bones are when a person is young, the less chance of osteoporosis as a person ages. Exercise promotes the activity of osteoblasts (as opposed to osteocytes) in young people, as well as older people. An increased activity level can also keep off unwanted pounds, which is a worthwhile goal because added body weight contributes to numerous conditions, such as type II diabetes (see page 197). Increased muscle activity is also helpful by causing glucose to be transported into muscle cells and making the body less dependent on the presence of insulin.

People in chronic pain are often diagnosed as having **fibromyalgia**, characterized by achy pain, tenderness, and stiffness of muscles. Substance P has been found in the bloodstream of these patients. Exercise (more frequent and longer periods of exercise, not increased intensity) decreases the concentration of substance P. Stretching exercises, such as yoga, and massages (two to three a week) also decrease the amount of substance P. More information on this subject is currently being sought.

Cancer prevention and early detection involve eating properly, not smoking, avoiding cancer-causing chemicals and radiation, undergoing appropriate medical screening tests, and knowing the early warning signs of cancer. However, evidence indicates that exercise also helps prevent certain kinds of cancer. Studies show that people who exercise are less likely to develop colon, breast, cervical, uterine, and ovarian cancer.

Table 7A **A Checklist for Staying Fit**

Children, 7–12	Teenagers, 13–18	Adults, 19–55	Seniors, 56 and Up
Vigorous activity 1–2 hours daily	Vigorous activity 1 hour 3–5 days a week; otherwise, ½ hour daily moderate activity	Vigorous activity 1 hour 3 days a week; otherwise, ½ hour daily moderate activity	Moderate exercise 1 hour daily 3 days a week; otherwise, ½ hour daily moderate activity
Free play	Build muscle with calisthenics	Exercise to prevent lower back pain: aerobics, stretching, yoga	Take a daily walk
Build motor skills through team sports, dance, swimming	Do aerobic exercise to control buildup of fat cells	Take active vacations: hike, bicycle, cross-country ski	Do daily stretching exercises
Encourage more exercise outside of physical education classes	Pursue tennis, swimming, horseback riding—sports that can be enjoyed for a lifetime	Find exercise partners: join a running club, bicycle club, outing group	Learn a new sport or activity: golf, fishing, ballroom dancing
Initiate family outings: bowling, boating, camping, hiking	Continue team sports, dancing, hiking, swimming		Try low-impact aerobics. Before undertaking new exercises, consult your doctor

7.6 Homeostasis

The illustration in Human Systems Work Together on page 137 tells how the muscular system works with other systems of the body to maintain homeostasis.

Cardiac muscle contraction accounts for the heartbeat, which creates blood pressure, the force that propels blood in the arteries and arterioles. The walls of the arteries and arterioles contain smooth muscle. Constriction of arteriole walls is regulated to help maintain blood pressure. Arterioles branch into the capillaries where exchange takes place that creates and cleanses tissue fluid. Blood and tissue fluid are the internal environment of the body, and without cardiac and smooth muscle contraction, blood would never reach the capillaries for exchange to take place. Blood is returned to the heart in cardiovascular veins, and excess tissue fluid is returned to the cardiovascular system within lymphatic vessels. Skeletal muscle contraction presses on the cardiovascular veins and lymphatic vessels, and this creates the pressure that moves fluids in both types of vessels. Without the return of blood to the heart, circulation would stop, and without the return of lymph to the blood vessels, normal blood pressure could not be maintained.

The contraction of sphincters composed of smooth muscle fibers temporarily prevents the flow of blood into a capillary. This is an important homeostatic mechanism because in times of emergency it is more important, for example, for blood to be directed to the skeletal muscles than to the tissues of the digestive tract. Smooth muscle contraction also accounts for peristalsis, the process that moves food along the digestive tract. Without this action, food would never reach all the organs of the digestive tract where digestion releases nutrients that enter the bloodstream. Smooth muscle contraction assists the voiding of urine, which is necessary for ridding the body of metabolic wastes and for regulating the blood volume, salt concentration, and pH of internal fluids.

Skeletal muscles protect internal organs, and their strength protects joints by stabilizing their movements. Skeletal muscle contraction raises the rib cage and lowers the diaphragm during the active phase of breathing. As we breathe, oxygen enters the blood and is delivered to the tissues, including the muscles, where ATP is produced in mitochondria with heat as a by-product. The heat produced by skeletal muscle contraction allows the body temperature to remain within the normal range for human beings.

Finally, skeletal muscle contraction moves bones and allows us to perform those daily activities necessary to our health and benefit. Although it may seem as if movement of our limbs does not affect homeostasis, it does so by allowing us to relocate our bodies to keep the external environment within favorable limits for our existence.

Muscular Disorders

When spasms or injuries occur, homeostasis is challenged, and when disease is present, homeostasis may be overcome to the point of death.

Spasms and Injuries

Spasms are sudden and involuntary muscular contractions, most often accompanied by pain. Spasms can occur in both smooth and skeletal muscles. A spasm of the intestinal tract is a type of colic sometimes called a "bellyache." Multiple spasms of skeletal muscles are called a seizure or convulsion. Cramps are strong painful spasms, especially of the leg and foot, usually due to strenuous activity. Cramps can even occur when sleeping after a strenuous workout. Facial tics, such as periodic eye blinking, head turning, or grimacing, are spasms that can be controlled voluntarily but only with great effort.

A **strain** is the overstretching of a muscle near a joint. A **sprain** is the twisting of a joint, leading to swelling and to injury not only of muscles but also of ligaments, tendons, blood vessels, and nerves. The ankle is often subject to sprains.

Myalgia refers to inflammation of muscle tissue. **Tendinitis** is inflammation of a tendon due to the strain of repeated athletic activity. The tendons most commonly affected are those associated with the shoulder, elbow, hip, and knee.

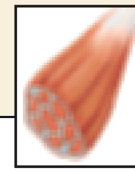
Diseases

In persons who have not been properly immunized, the toxin of the tetanus bacterium can cause muscles to lock in a tetanic contraction. A rigidly locked jaw is one of the first signs of an infection known as **tetanus.** Like other bacterial infections, tetanus is curable with the administration of an antibiotic.

Muscular dystrophy is a broad term applied to a group of disorders characterized by progressive degeneration and weakening of muscles. As muscle fibers die, fat and connective tissue take their place. Duchenne muscular dystrophy, the most common type, is inherited through a flawed gene carried by the mother. It is now known that the lack of a protein called dystrophin causes the condition. When dystrophin is absent, calcium leaks into the cell and activates an enzyme that dissolves muscle fibers. In an attempt to treat the condition, muscles have been injected with immature muscle cells that do produce dystrophin.

Myasthenia gravis is an autoimmune disease characterized by weakness that especially affects the muscles of the eyelids, face, neck, and extremities. Muscle contraction is impaired because the immune system mistakenly produces antibodies that destroy acetylcholine receptors. In many cases, the first signs of the disease are drooping eyelids and double vision. Treatment includes drugs that are antagonistic to the enzyme acetylcholinesterase.

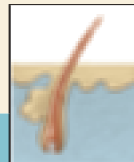
How the Muscular System works with other body systems



Integumentary System

Muscle contraction provides heat to warm skin. Muscle moves skin of face.

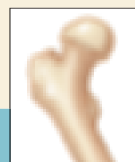
Skin protects muscles; rids the body of heat produced by muscle contraction.



Skeletal System

Muscle contraction causes bones to move joints; muscles help protect bones.

Bones provide attachment sites for muscles; store Ca^{2+} for muscle function.



Nervous System

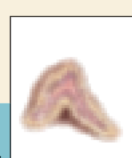
Muscle contraction moves eyes, permits speech, creates facial expressions.

Brain controls nerves that innervate muscles; receptors send sensory input from muscles to brain.

Endocrine System

Muscles help protect glands.

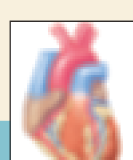
Androgens promote growth of skeletal muscle; epinephrine stimulates heart and constricts blood vessels.



Cardiovascular System

Muscle contraction keeps blood moving in heart and blood vessels.

Blood vessels deliver nutrients and oxygen to muscles, carry away wastes.



Lymphatic System/Immunity

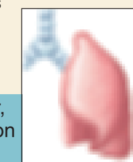
Skeletal muscle contraction moves lymph; physical exercise enhances immunity.

Lymphatic vessels pick up excess tissue fluid; immune system protects against infections.

Respiratory System

Muscle contraction assists breathing; physical exercise increases respiratory capacity.

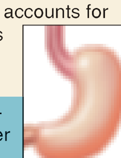
Lungs provide oxygen for, and rid the body of, carbon dioxide from contracting muscles.



Digestive System

Smooth muscle contraction accounts for peristalsis; skeletal muscles support and help protect abdominal organs.

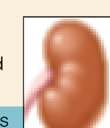
Digestive tract provides glucose for muscle activity; liver metabolizes lactic acid following anaerobic muscle activity.



Urinary System

Smooth muscle contraction assists voiding of urine; skeletal muscles support and help protect urinary organs.

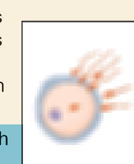
Kidneys maintain blood levels of Na^{+}, K^{+}, and Ca^{2+}, which are needed for muscle innervation, and eliminate creatinine, a muscle waste.



Reproductive System

Muscle contraction occurs during orgasm and moves gametes; abdominal and uterine muscle contraction occurs during childbirth.

Androgens promote growth of skeletal muscle.



Selected New Terms

Basic Key Terms

actin (ak′tin), p. 116
all-or-none law, p. 122
antagonist (an-tag′o-nist), p. 124
cardiac muscle (kar′de-ak mus′el), p. 114
creatine phosphate (kre′uh-tin fos′fāt), p. 120
insertion (in-ser′shun), p. 124
motor unit (mo′tor yū′nit), p. 122
muscle fiber (mus′el fi′ber), p. 114
muscle twitch (mus′el twich), p. 122
myofibril (mi″o-fi′bril), p. 116
myoglobin (mi″o-glo′bin), p. 116
myosin (mi′o-sin), p. 116
neuromuscular junction (nu″ro-mus′kyū-ler junk′shun), p. 118
origin (or′ĭ-jin), p. 124
oxygen deficit (ok′sĭ-jen def′ĭ-sit), p. 120
prime mover (prīm mu′ver), p. 124
recruitment (re-krūt′ment), p. 123
sarcomere (sar′ko-mēr), p. 116
skeletal muscle (skel′ĕ-tal mus′el), p. 114
sliding filament theory (sli′ding fil′uh-ment the′o-re), p. 116
smooth muscle (smūth mus′el), p. 114
synergist (sin′er-jist), p. 124
T (transverse) tubules (tranz-vers′ tu′byūl), p. 116
tendon (ten′don), p. 115
tone (tōn), p. 123

Clinical Key Terms

atrophy (at′ro-fe), p. 123
hypertrophy (hi-per′tro-fe), p. 123
lockjaw (lok′jaw), p. 136
muscular dystrophy (mus′kyū-ler dis′trĕ-fe), p. 136
myalgia (mi-al′juh), p. 136
myasthenia gravis (mi″as-the′ne-uh grah′vis), p. 136
spasm (spazm), p. 136
sprain (sprān), p. 136
strain (strān), p. 136
tendinitis (ten″dĕ-ni′tis), p. 136
tetanus (tet′uh-nus), p. 136

Summary

7.1 Functions and Types of Muscles

A. Muscular tissue is either smooth, cardiac, or skeletal. Skeletal muscles have tubular, multinucleated, and striated fibers that contract voluntarily.

B. Skeletal muscles support the body, make bones move, help maintain a constant body temperature, assist movement in cardiovascular and lymphatic vessels, and help protect internal organs and stabilize joints.

7.2 Microscopic Anatomy and Contraction of Skeletal Muscle

A. The sarcolemma, which extends into a muscle fiber, forms T tubules; the sarcoplasmic reticulum has calcium storage sites. The placement of actin and myosin in the contractile myofibrils accounts for the striations of skeletal muscle fibers.

B. Skeletal muscle innervation occurs at neuromuscular junctions. Impulses travel down the tubules of the T system and cause the release of calcium from calcium storage sites. The presence of calcium and ATP in muscle cells prompts actin myofilaments to slide past myosin myofilaments, shortening the length of the sarcomere.

C. ATP, required for muscle contraction, can be generated by way of creatine phosphate breakdown and fermentation. Lactic acid from fermentation represents an oxygen deficit, because oxygen is required to metabolize this product. Cellular respiration, an aerobic process, is the best source of ATP.

7.3 Muscle Responses

A. In the laboratory, muscle fibers obey the all-or-none law, but whole muscles do not. The occurrence of a muscle twitch, summation, or tetanic contraction depends on the frequency with which a muscle is stimulated.

B. In the body, muscle fibers belong to motor units that obey the all-or-none law. The strength of muscle contraction depends on the recruitment of motor units. A muscle has tone because some fibers are always contracting.

7.4 Skeletal Muscles of the Body

A. When muscles cooperate to achieve movement, some act as prime movers, others as synergists, and still others as antagonists.

B. The skeletal muscles of the body are divided into those that move: the head and neck (see Table 7.2); the trunk (see Table 7.3); the shoulder and arm (see Table 7.4); the forearm (see Table7.4); the hand and fingers (see Table 7.4); the thigh (see Table 7.5); the leg (see Table 7.5); and the ankle and foot (see Table 7.5).

7.5 Effects of Aging

As we age, muscles become weaker, but exercise can help retain vigor.

7.6 Homeostasis

Smooth muscle contraction helps move the blood; cardiac muscle contraction pumps the blood. Skeletal muscle contraction produces heat and is needed for breathing.

Study Questions

1. Name and describe the three types of muscles, and give a general location for each type. (p. 114)
2. List and discuss five functions of muscles. (p. 115)
3. Describe the anatomy of a muscle, from the whole muscle to the myofilaments within a sarcomere. Name the layers of fascia that cover a skeletal muscle and divide the muscle interior. (pp. 116–17)
4. List the sequential events that occur after a nerve impulse reaches a muscle. (pp. 118–19)
5. How is ATP supplied to muscles? What is oxygen deficit? (pp. 120–21)
6. What is the all-or-none law? What is the difference between a single muscle twitch, summation, and a tetanic contraction? (p. 122)
7. What is muscle tone? How does muscle contraction affect muscle size? (p. 123)
8. Describe how muscles are attached to bones. Define the terms prime mover, synergist, and antagonist. (p. 124)
9. How do muscles get their names? Give an example for each characteristic used in naming muscles. (pp. 124–25)
10. Which of the muscles of the head are used for facial expression? Which are used for chewing? (p. 126)
11. Which muscles of the neck flex and extend the head? (p. 127)
12. What are the muscles of the thoracic wall? What are the muscles of the abdominal wall? (pp. 128–29)
13. Which of the muscles of the shoulder and upper limb move the arm and forearm, and what are their actions? Name the muscles that move the hand and fingers. (p. 130)
14. Which of the muscles of the hip move the thigh, and what are their actions? Which of the muscles of the thigh move the leg, and what are their actions? Which of the muscles of the leg move the feet? (pp. 132–34)

Objective Questions

I. Fill in the blanks.

1. ____________ muscle is uninucleated, nonstriated, and located in the walls of internal organs.
2. The fascia called ____________ separates muscle fibers from one another within a fascicle.
3. When a muscle fiber contracts, an ____________ myofilament slides past a myosin myofilament.
4. The energy molecule ____________ is needed for muscle fiber contraction.
5. Whole muscles have ____________, a condition in which some fibers are always contracted.
6. When muscles contract, the ____________ does most of the work, but the ____________ help.
7. The ____________ is a muscle in the arm that has two origins.
8. The ____________ acts as the origin of the latissimus dorsi, and the ____________ acts as the insertion during most activities.

II. For questions 9–12, name the muscle indicated by the combination of origin and insertion shown.

	Origin	*Insertion*
9.	temporal bone	mandibular coronoid process
10.	scapula, clavicle	humerus
11.	scapula, proximal humerus	olecranon process of ulna
12.	posterior ilium, sacrum	proximal femur

III. Match the muscles in the key to the actions listed in questions 13–20.
Key:

a. orbicularis oculi
b. zygomaticus
c. deltoid
d. serratus anterior
e. rectus abdominis
f. iliopsoas
g. gluteus maximus
h. gastrocnemius

13. Allows a person to stand on tiptoe
14. Tenses abdominal wall
15. Abducts arm
16. Flexes thigh
17. Raises corner of mouth
18. Closes eyes

Medical Terminology Reinforcement Exercise

Consult Appendix B for help in pronouncing and analyzing the meaning of the terms that follow.

1. hyperkinesis (hi″per-ki-ne′sis)
2. dystrophy (dis′tro-fe)
3. electromyogram (e-lek″tro-mi′-o-gram)
4. menisectomy (men″i-sek′to-me)
5. tenorrhaphy (te-nor′uh-fe)
6. myatrophy (mi-at′ro-fe)
7. leiomyoma (li″o-mi-o′muh)
8. kinesiotherapy (ki-ne″se-o-thĕr′uh-pe)
9. myocardiopathy (mi″o-kar″de-op′ uh-the)
10. myasthenia (mi″as-the′ne-uh)

Website Link

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