Muscular System

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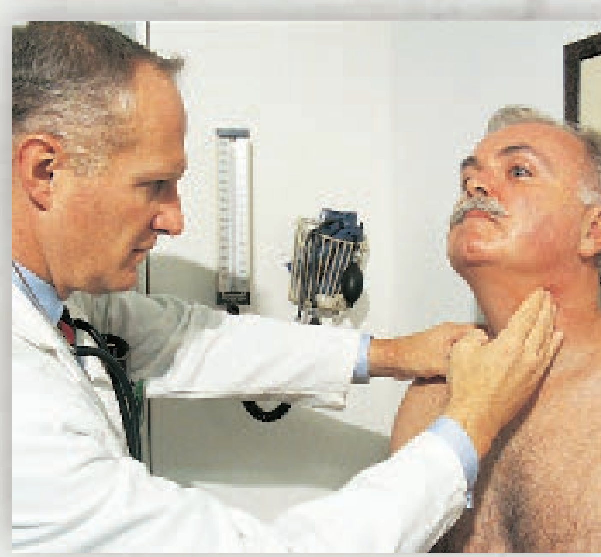


Clinical Case Study

A 66-year-old man went to a doctor for a routine physical exam. The man's medical history revealed that he had been treated surgically for cancer of the oropharynx 6 years earlier. The patient stated that the cancer had spread to the lymph nodes in the left side of his neck. He pointed to the involved area, explaining that lymph nodes, a vein, and a muscle, among other things, had been removed. On the right side, only lymph nodes had been removed, and they were found to be benign. The patient then stated that he had difficulty turning his head to the right. Obviously perplexed, he commented, "It seems to me Doc, that if they took the muscle out of the left side of my neck, I would be able to turn my head only to the right."

Does the patient have a valid point? If not, how would you explain the reason for his disability in terms of neck musculature?

Hints: The action of a muscle can always be explained on the basis of its points of attachment and the joint or joints it spans. Carefully examine the muscles shown in figure 9.20 and described in table 9.7.

FIGURE: Understanding the actions of muscles is possible only through knowing their precise points of attachment.

INTRODUCTION TO THE MUSCULAR SYSTEM

Skeletal muscles are adapted to contract in order to carry out the functions of generating body movement, producing heat, and supporting the body and maintaining posture.

Objective 1 Define the term *myology* and describe the three principal functions of muscles.

Objective 2 Explain how muscles are described according to their anatomical location and cooperative function.

Myology is the study of muscles. More than 600 skeletal muscles make up the muscular system, and technically each one is an organ—it is composed of skeletal muscle tissue, connective tissue, and nervous tissue. Each muscle also has a particular function, such as moving a finger or blinking an eyelid. Collectively, the skeletal muscles account for approximately 40% of the body weight.

Muscle cells (fibers) contract when stimulated by nerve impulses. The stimulation of just a few fibers is not enough to cause a noticeable effect, but isolated fiber contractions are important and occur continuously within a muscle. When a sufficient number of skeletal muscle fibers are activated, the muscle contracts and causes body movement.

Muscles perform three principal functions: (1) movement, (2) heat production, and (3) body support and maintenance of posture.

1. **Movement.** The most obvious function performed by skeletal muscles is to move the body or parts of the body, as in walking, running, writing, chewing, and swallowing. Even the eyeball and the auditory ossicles have associated skeletal muscles that are responsible for various movements. The contraction of skeletal muscle is equally important in breathing and in moving internal body fluids. The stimulation of individual skeletal muscle fibers maintains a state of muscle contraction called *tonus*, which is important in the movement of blood and lymph. Tonus is also important in continuously exercising skeletal muscle fibers.

   The involuntary contraction of smooth muscle tissue is also essential for movement of materials through the body. Likewise, the involuntary contraction of cardiac muscle tissue continuously pumps blood throughout the body.
2. **Heat production.** Body temperature is held remarkably constant. Metabolism within the cells releases heat as an end product. Because muscles constitute approximately 40% of body weight and are in a continuous state of fiber activity, they are the primary source of body heat. The rate of heat production increases greatly during strenuous exercise.
3. **Posture and body support.** The skeletal system provides a framework for the body, but skeletal muscles maintain posture, stabilize the flexible joints, and support the viscera. Certain muscles are active postural muscles whose primary function is to work in opposition to gravity. Some postural muscles are working even when you think you are relaxed. As you are sitting, for example, the weight of your head is balanced at the atlanto-occipital joint through the efforts of the muscles located at the back of the neck. If you start to get sleepy, your head will suddenly nod forward as the postural muscles relax and the weight (resistance) overcomes the effort.

Muscle tissue in the body is of three types: *smooth*, *cardiac*, and *skeletal* (see fig. 4.26). Although these three types differ in structure and function, and the muscular system refers only to the skeletal muscles composed of skeletal tissue, the following basic properties characterize all muscle tissue:

1. **Irritability.** Muscle tissue is sensitive to stimuli from nerve impulses.
2. **Contractility.** Muscle tissue responds to stimuli by contracting lengthwise, or shortening.
3. **Extensibility.** Once a stimulus has subsided and the fibers within muscle tissue are relaxed, they may be stretched even beyond their resting length by the contraction of an opposing muscle. The fibers are then prepared for another contraction.
4. **Elasticity.** Muscle fibers, after being stretched, have a tendency to recoil to their original resting length.

A histological description of each of the three muscle types was presented in chapter 4 and should be reviewed at this time. Cardiac muscle is involuntary and is discussed further in chapter 13 in the autonomic nervous system and in chapter 16, in connection with the heart. Smooth muscle is widespread throughout the body and is also involuntary. It is discussed in chapter 13 and, when appropriate, in connection with the organs in which it occurs. The remaining information presented in this chapter pertains only to skeletal muscle and the skeletal muscular system of the body.

Muscles are usually described in groups according to anatomical location and cooperative function. The *muscles of the axial skeleton* include the facial muscles, neck muscles, and anterior and posterior trunk muscles. The *muscles of the appendicular skeleton* include those that act on the pectoral and pelvic girdles and those that move limb joints. The principal superficial muscles are shown in figure 9.1.

Knowledge Check

1. How do the functions of muscles help maintain body homeostasis?
2. What is meant by a postural muscle?
3. Distinguish between the axial and the appendicular muscles.

myology: Gk. *myos*, muscle; *logos*, study of
muscle: L. *mus*, mouse (from the appearance of certain muscles)

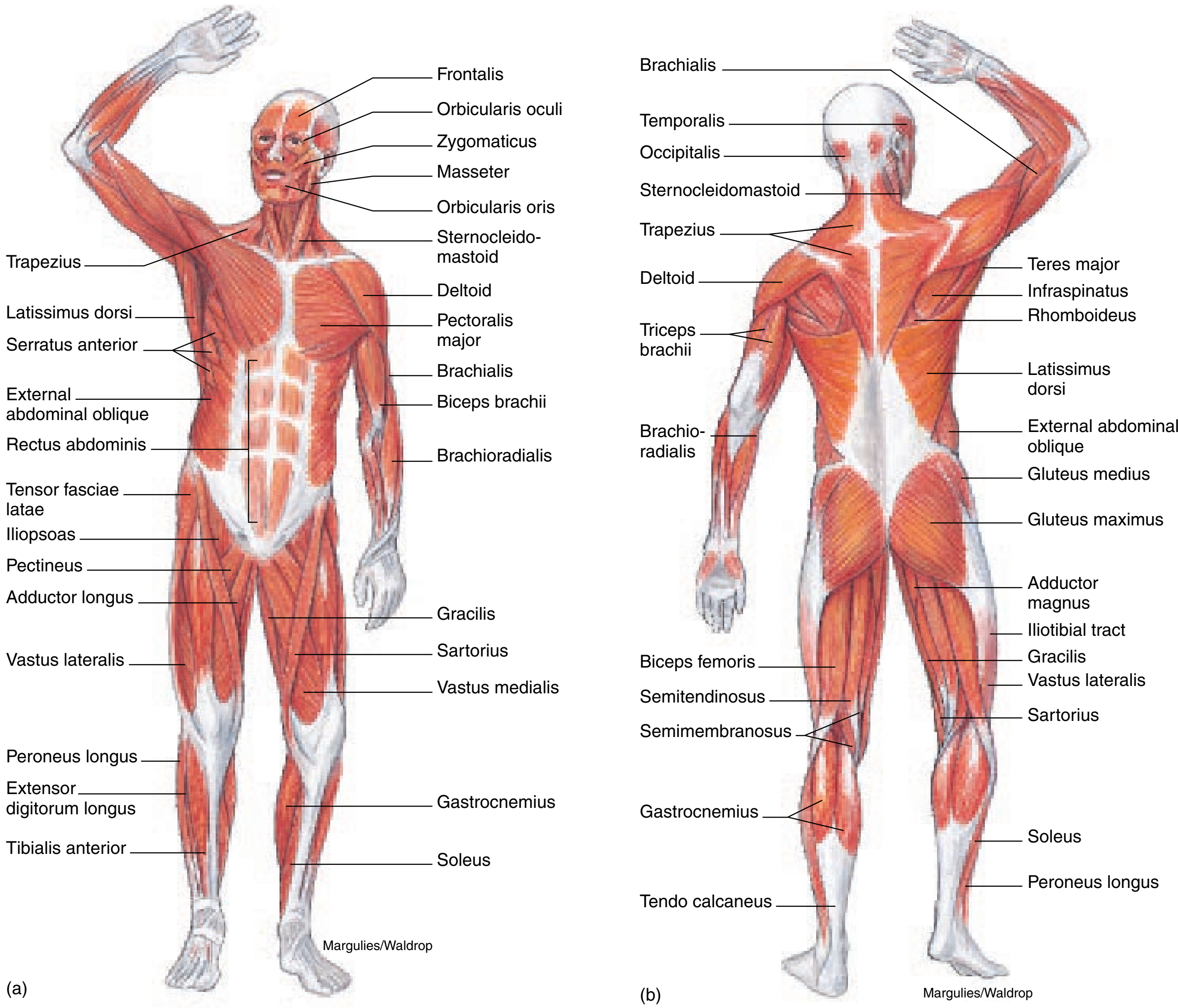


FIGURE 9.1 The principal superficial skeletal muscles. (*a*) An anterior view and (*b*) a posterior view.

STRUCTURE OF SKELETAL MUSCLES

Skeletal muscle tissue and its binding connective tissue are arranged in a highly organized pattern that unites the forces of the contracting muscle fibers and directs them onto the structure being moved.

Objective 3 Compare and contrast the various binding connective tissues associated with skeletal muscles.

Objective 4 Distinguish between synergistic and antagonistic muscles. Explain why a muscle must have an antagonistic force.

Objective 5 Describe the various types of muscle fiber architecture and discuss the biomechanical advantage of each type.

Muscle Attachments

Skeletal muscles are attached to a bone on each end by **tendons** (fig. 9.2). A tendon is composed of dense regular connective tissue and binds a muscle to the periosteum of a bone. When a muscle contracts, it shortens, and this places tension on its tendons and attached bones. The muscle tension causes movement of the bones at a synovial joint (see figs. 8.7 and 8.8), where one

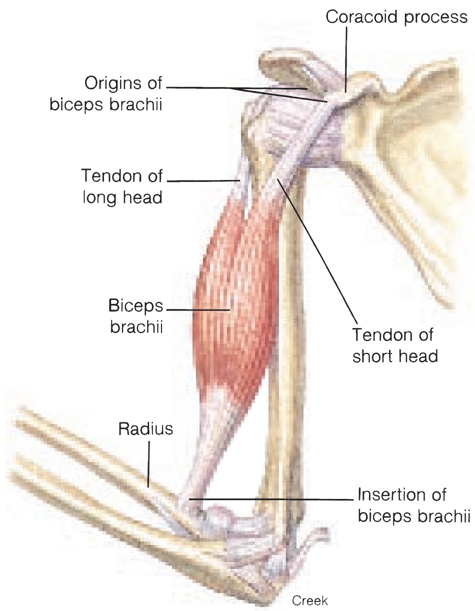


FIGURE 9.2 The skeletomuscular relationship. The more proximal, fixed point of muscle attachment is the origin; the distal, maneuverable point of attachment is the insertion. The contraction of muscle fibers causes one bone to move relative to another around a joint.

of the attached bones generally moves more than the other. The more movable bony attachment of the muscle, known as the **insertion,** is pulled toward its less movable attachment, the **origin.** In muscles associated with the girdles and appendages, the origin is the proximal attachment and the insertion is the distal attachment. The fleshy, thickened portion of a muscle is referred to as its **belly (gaster).**

Flattened, sheetlike tendons are called **aponeuroses** (*ap''ŏ-noo-ro'sēz*). An example is the galea aponeurotica, which is found on the top and sides of the skull (see fig. 9.14). In certain places, especially in the wrist and ankle, the tendons are not only enclosed by protective **tendon sheaths** (see fig. 8.8), but also the entire group of tendons is covered by a thin but strong band of connective tissue called a **retinaculum** (*ret''ĭ-nak'yoo-lum*) (see, for example, the extensor retinaculum in fig. 9.43). Attached to articulating bones, retinacula anchor groups of tendons and keep them from bowing during muscle contraction.

Associated Connective Tissue

Contracting muscle fibers would not be effective if they worked as isolated units. Each fiber is bound to adjacent fibers to form bundles, and the bundles in turn are bound to other bundles. With this arrangement, the contraction in one area of a muscle works in conjunction with contracting fibers elsewhere in the muscle. The binding substance within muscles is the associated loose connective tissue.

Connective tissue is structurally arranged within muscle to protect, strengthen, and bind muscle fibers into bundles and bind the bundles together (fig. 9.3). The individual fibers of skeletal muscles are surrounded by a fine sheath of connective tissue called **endomysium** (*en''do-mis'e-um*). The endomysium binds adjacent fibers together and supports capillaries and nerve endings serving the muscle. Another connective tissue, the **perimysium,** binds groups of muscle fibers together into bundles called **fasciculi** (*fă-sik'yū-li*—singular, *fasciculus* or *fascicle*). The perimysium supports blood vessels and nerve fibers serving the various fasciculi. The entire muscle is covered by the **epimysium,** which in turn is continuous with a tendon.

Fascia (*fash'e-ă*) is a fibrous connective tissue of varying thickness that covers muscle and attaches to the skin (table 9.1). *Superficial fascia* secures the skin to the underlying structures. The superficial fascia over the buttocks and abdominal wall is thick and laced with adipose tissue. By contrast, the superficial fascia under the skin of the back of the hand, elbow, and facial region is thin. *Deep fascia* is an inward extension of the superficial fascia. It lacks adipose tissue and blends with the epimysium of muscle. Deep fascia surrounds adjacent muscles, compartmentalizing and binding them into functional groups. *Subserous fascia* extends between the deep fascia and serous membranes. Nerves and vessels traverse subserous fascia to serve serous membranes.

The tenderness of meat is due in part to the amount of connective tissue present in a particular cut. A slice of meat from the ends of a muscle contains much more connective tissue than a cut through the belly of the muscle. Fibrous meat is difficult to chew and may present a social problem in trying to extract it discreetly from between the teeth.

Muscle Groups

Just as individual muscle fibers seldom contract independently, muscles generally do not contract separately but work as functional groups. Muscles that contract together in accomplishing a

aponeurosis: Gk. *aponeurosis*, change into a tendon
retinaculum: L. *retinere*, to hold back (retain)

endomysium: Gk. *endon*, within; *myos*, muscle
perimysium: Gk. *peri*, around; *myos*, muscle
fasciculus: L. *fascis*, bundle
epimysium: Gk. *epi*, upon; *myos*, muscle
fascia: L. *fascia*, a band or girdle

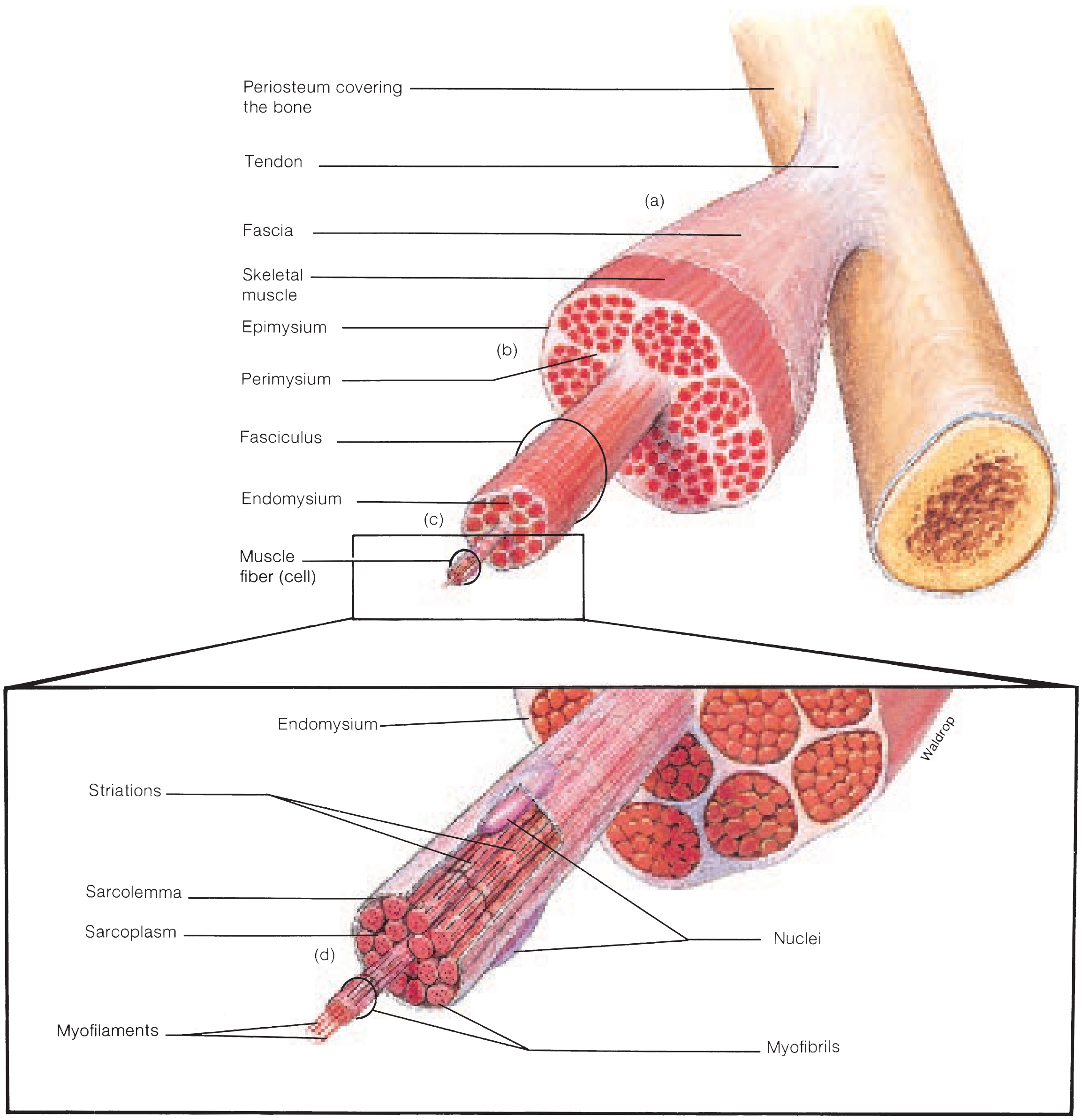
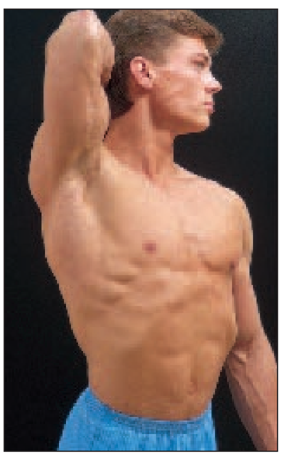
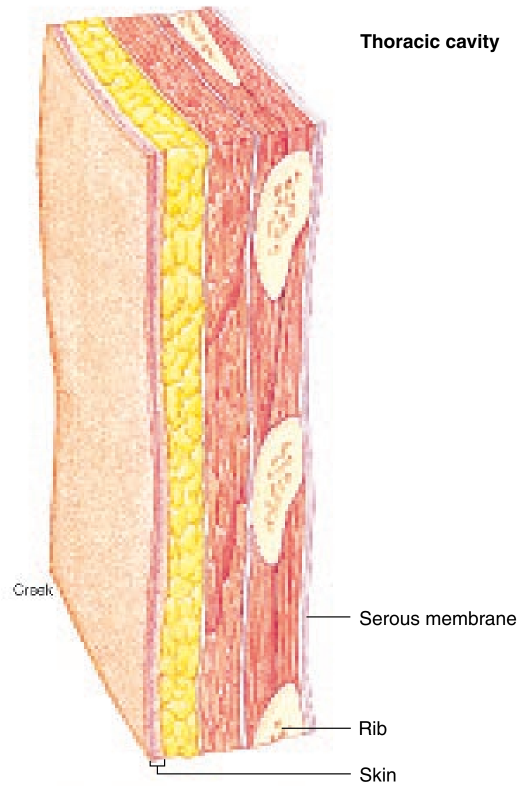


FIGURE 9.3 The relationship between skeletal muscle tissue and its associated connective tissue. (*a*) The fascia and tendon attaches a muscle to the periosteum of a bone. (*b*) The epimysium surrounds the entire muscle, and the perimysium separates and binds the fasciculi (muscle bundles). (*c*) The endomysium surrounds and binds individual muscle fibers. (*d*) An individual muscle fiber contains myofibrils (specialized contractile organelles) composed of thin (actin) and thick (myosin) myofilaments.

TABLE 9.1 Types of Fascia

Superficial Fascia	Deep Fascia	Subserous Fascia
Supports skin and binds it to underlying structures; provides elasticity to hypodermis (subcutaneous layer); provides support for nerves and vessels serving the skin	Supports and binds muscles to other associated structures; forms basis of tendons, ligaments, and joint capsules; provides support for nerves and vessels serving muscles, joints, and associated structures	Supports and binds serous membranes to deep fascia; provides support for nerves and vessels serving serous membranes
Consists of a mesh of loose connective tissue interspersed with adipose tissue	Consists of dense connective tissue	Consists of loose connective tissue





particular movement are said to be *synergistic* (*sin″er-jis′tik*) (fig. 9.4). *Antagonistic* muscles perform opposite functions and are generally located on the opposite sides of the joint. For example, the two heads of the biceps brachii muscle, together with the brachialis muscle, contract to *flex* the elbow joint. The triceps brachii muscle, the antagonist to the biceps brachii and brachialis muscles, *extends* the elbow as it is contracted.

Antagonistic muscles are necessary because the fibers in a contracted muscle are shortened and must be elongated before they can once again cause movement through another contraction. Gravity may also act as the antagonist for certain muscles. When an elevated upper appendage is relaxed, for example, gravity brings it down to the side of the body, and the fibers within the muscles responsible for the elevated appendage are shortened.

Seldom does the action of a single muscle cause a movement at a joint. Utilization of several synergistic muscles rather than one massive muscle allows for a division of labor. One muscle may be an important postural muscle, for example, whereas another may be adapted for rapid, powerful contraction.

Muscle Architecture

Skeletal muscles may be classified on the basis of fiber arrangement as *parallel*, *convergent*, *sphincteral* (circular), or *pennate* (table 9.2). Each type of fiber arrangement provides the muscle with distinct capabilities.

Muscle fiber architecture can be observed on a cadaver or other dissection specimen. If you have the opportunity to learn the muscles of the body from a cadaver, observe the fiber architecture of specific muscles and try to determine the advantages afforded to each muscle by its location and action.

synergistic: Gk. *synergein*, cooperate

antagonistic: Gk. *antagonistes*, struggle against

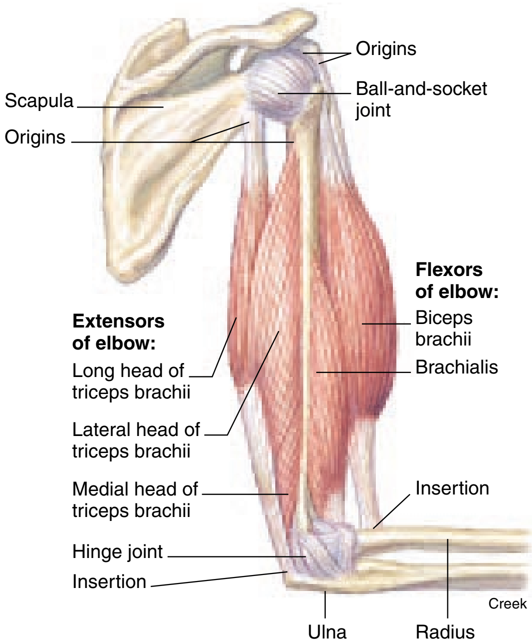
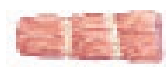
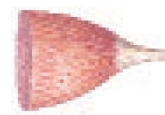
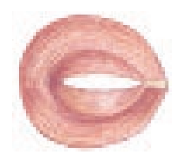
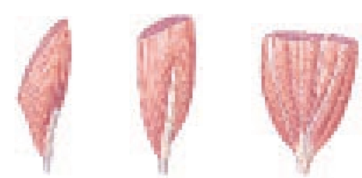


FIGURE 9.4 Examples of synergistic and antagonistic muscles. The two heads of the biceps brachii and the brachialis muscle are synergistic to each other, as are the three heads of the triceps brachii. The biceps brachii and the brachialis are antagonistic to the triceps brachii, and the triceps brachii is antagonistic to the biceps brachii and the brachialis muscle. When one antagonistic group contracts, the other one must relax; otherwise, movement does not occur.

TABLE 9.2 **Muscle Architecture**

Type and Description	Appearance
Parallel—straplike; long excursion (contract over a great distance); good endurance; not especially strong; e.g., sartorius and rectus abdominis muscles	
Convergent—fan-shaped; force of contraction focused onto a single point of attachment; stronger than parallel type; e.g., deltoid and pectoralis major	
Sphincteral—fibers concentrically arranged around a body opening (orifice); act as a sphincter when contracted; e.g., orbicularis oculi and orbicularis oris	
Pennate—many fibers per unit area; strong muscles; short excursions; highly dexterous; tire quickly; three types: (*a*) unipennate, (*b*) bipennate, and (c) multipennate	 (a) (b) (c)

orifice: L. *orificium*, mouth; *facere*, to make
pennate: L. *pennatus*, feather

Blood and Nerve Supply to Skeletal Muscle

Muscle cells have a high rate of metabolic activity and therefore require extensive vascularity to receive nutrients and oxygen and to eliminate waste products. Smaller muscles generally have a single artery supplying blood and perhaps two veins returning blood (fig. 9.5). Large muscles may have several arteries and veins. The microscopic capillary exchange between arteries and veins occurs throughout the endomysium that surrounds individual fibers.

A skeletal muscle fiber cannot contract unless it is stimulated by a nerve impulse. This means that there must be extensive *innervation* (served with neurons) to a muscle to ensure the connection of each muscle fiber to a nerve cell. Actually there are two nerve pathways for each muscle. A **motor (efferent) neuron** is a nerve cell that conducts nerve impulses *to the muscle fiber*, stimulating it to contract. A **sensory (afferent) neuron** conducts nerve impulses *away from the muscle fiber* to the central nervous system, which responds to the activity of the muscle fiber. Muscle fibers will atrophy if they are not periodically stimulated to contract.

For years it was believed that muscle soreness was simply caused by a buildup of lactic acid within the muscle fibers during exercise. Although lactic acid accumulation probably is a factor related to soreness, recent research has shown that there is also damage to the contractile proteins within the muscle. If a muscle is used to exert an excessive force (for example, to lift a heavy object or to run a distance farther than it is conditioned to), some of the actin and myosin filaments become torn apart. This microscopic damage causes an inflammatory response that results in swelling and pain. If enough proteins are torn, use of the entire muscle may be compromised. Staying in good physical condition guards against muscle soreness following exercise. Conditioning the body not only improves vascularity but enlarges muscle fibers and allows them to work more efficiently over a longer duration.

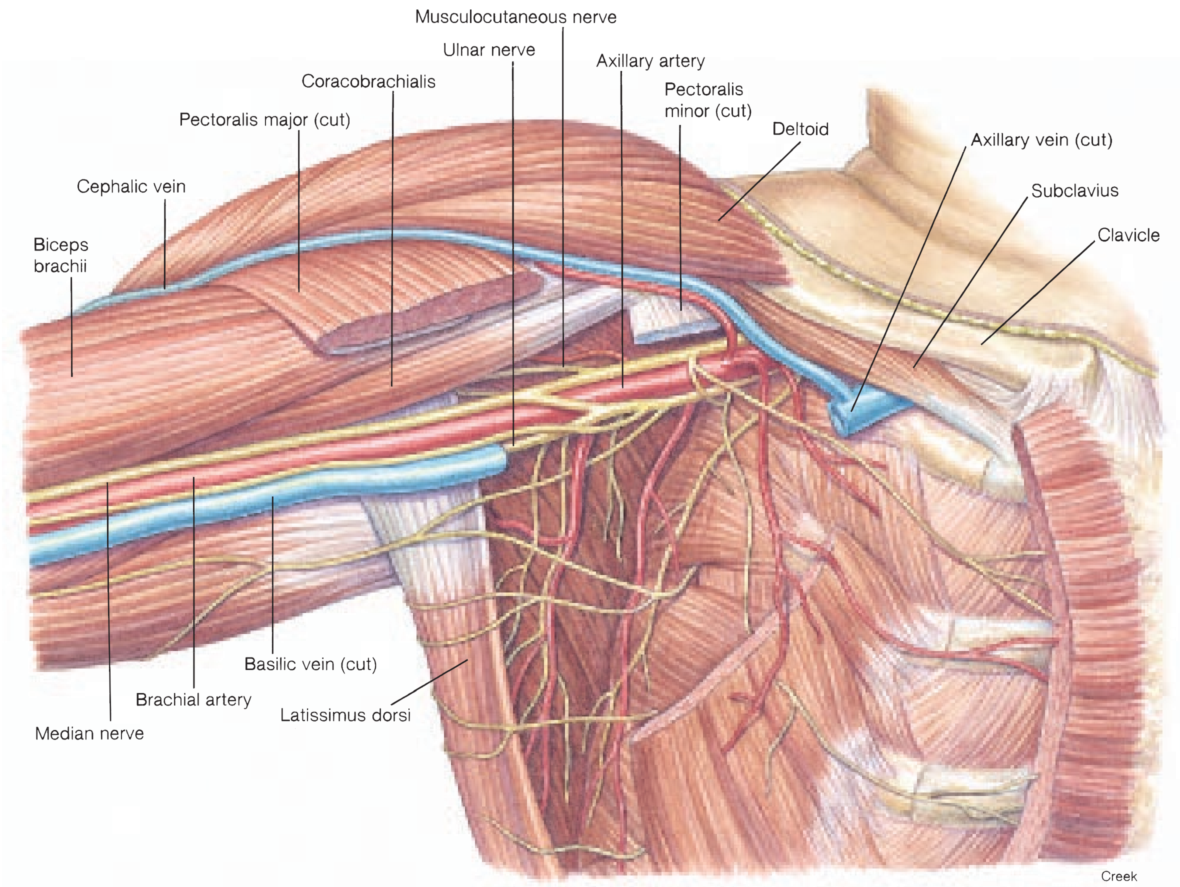


FIGURE 9.5 The relationship of blood vessels and nerves to skeletal muscles of the axillary region. (Note the close proximity of the nerves and vessels as they pass between muscle masses.)

Knowledge Check

4. Contrast the following terms: *endomysium* and *epimysium; fascia* and *tendon; aponeurosis* and *retinaculum*.
5. Discuss the biomechanical advantage of having synergistic muscles. Give some examples of synergistic muscles and state which muscles are antagonistic.
6. Which type of muscle architecture provides dexterity and strength?

SKELETAL MUSCLE FIBERS AND TYPES OF MUSCLE CONTRACTION

Muscle fiber contraction in response to a motor impulse results from a sliding movement within the myofibrils in which the length of the sarcomeres is reduced.

Objective 6 Identify the major components of a muscle fiber and discuss the function of each part.

Objective 7 Distinguish between isotonic and isometric contractions.

Objective 8 Define *motor unit* and discuss the role of motor units in muscular contraction.

Skeletal Muscle Fibers

Despite their unusual elongated shape, muscle cells have the same organelles as other cells: mitochondria, intracellular membranes, glycogen granules, and so forth. Unlike most other cells in the body, however, skeletal muscle fibers are multinucleated and striated (fig. 9.6). In addition, some skeletal muscle fibers may reach lengths of 30 cm (12 in.) and have diameters of 10 to 100 µm.

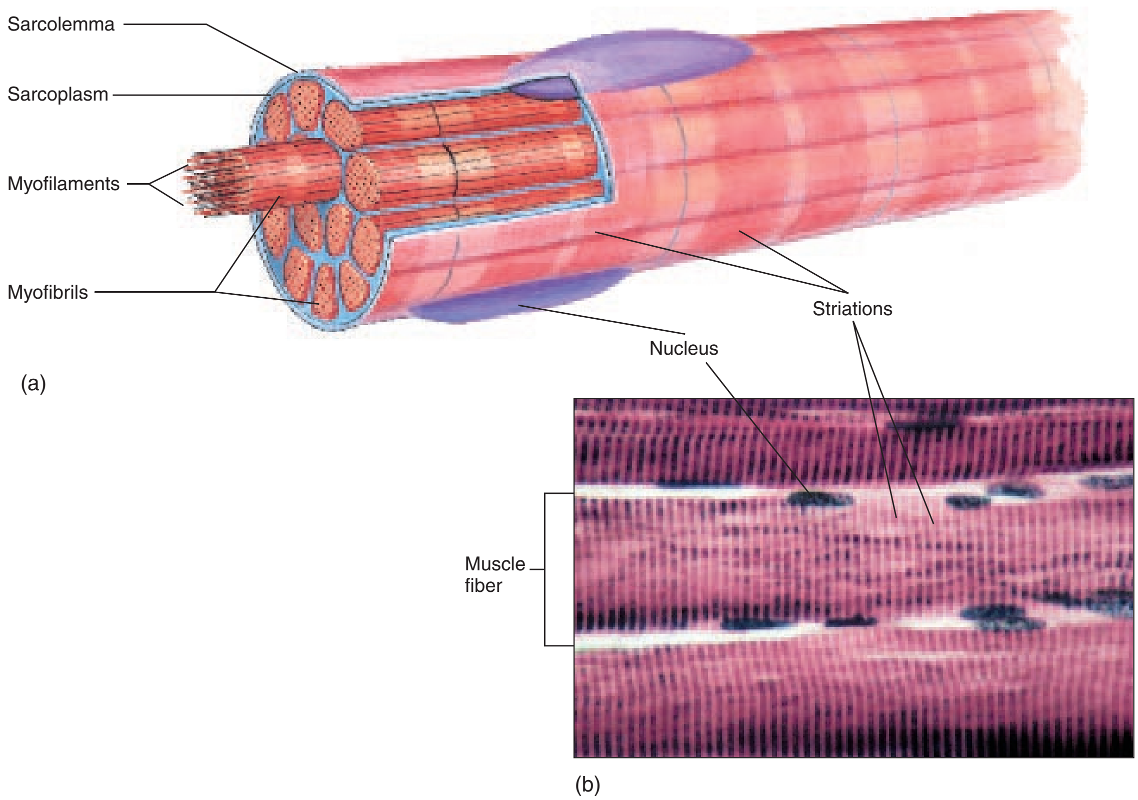


FIGURE 9.6 (*a*) A skeletal muscle fiber contains numerous organelles called myofibrils composed of the thick and thin myofilaments of actin and myosin. A skeletal muscle fiber is striated and multinucleated. (*b*) A light micrograph of skeletal muscle fibers showing the striations and the peripheral location of the nuclei.

Each muscle fiber is surrounded by a cell membrane called the **sarcolemma** (*sar''kŏ-lem'ă*). A network of membranous channels, the **sarcoplasmic reticulum,** extends throughout the cytoplasm of the fiber, which is called **sarcoplasm** (fig. 9.7). A system of **transverse tubules** (T tubules) runs perpendicular to the sarcoplasmic reticulum and opens to the outside through the sarcolemma. Also embedded in the muscle fiber are many threadlike structures called **myofibrils** (fig. 9.8). These myofibrils are approximately one micrometer (1µm) in diameter and extend in parallel from one end of the muscle fiber to the other. They are so densely packed that other organelles—such as mitochondria and intracellular membranes—are restricted to the narrow spaces in the sarcoplasm that remain between adjacent myofibrils. Each myofibril is composed of even smaller protein filaments, or **myofilaments.** *Thin filaments* are about 6 nm in diameter and are composed of the protein **actin.** *Thick filaments* are about 16 nm in diameter and are composed of the protein **myosin.**

actin: L. *actus*, motion, doing
myosin: L. *myosin*, within muscle

The characteristic dark and light striations of skeletal muscle myofibrils are due to the arrangement of these myofilaments. The dark bands are called *A bands*, and the light bands are called *I bands*. At high magnification, thin dark lines can be seen in the middle of the I bands. These are called *Z lines*. The arrangement of thick and thin filaments between a pair of Z lines forms a repeating structural pattern that serves as the basic subunit of skeletal muscle contraction. These subunits, from Z line to Z line, are known as **sarcomeres** (fig. 9.8). A longitudinal section of a myofibril thus presents a side view of successive sarcomeres (fig. 9.9 *a*,*b*).

The I bands within a myofibril are the lighter areas that extend from the edge of one stack of thick myosin filaments to the edge of the next stack of thick filaments. They are light in appearance because they contain only thin filaments. The thin filaments, however, do not end at the edges of the I bands. Instead, each thin filament extends part way into the A bands on each side. Because thick and thin filaments overlap at the edges of each A band, the edges of the A band are darker in appearance than the central region. The central lighter regions of the A bands are called *H zones* (for *helle*, a German word meaning

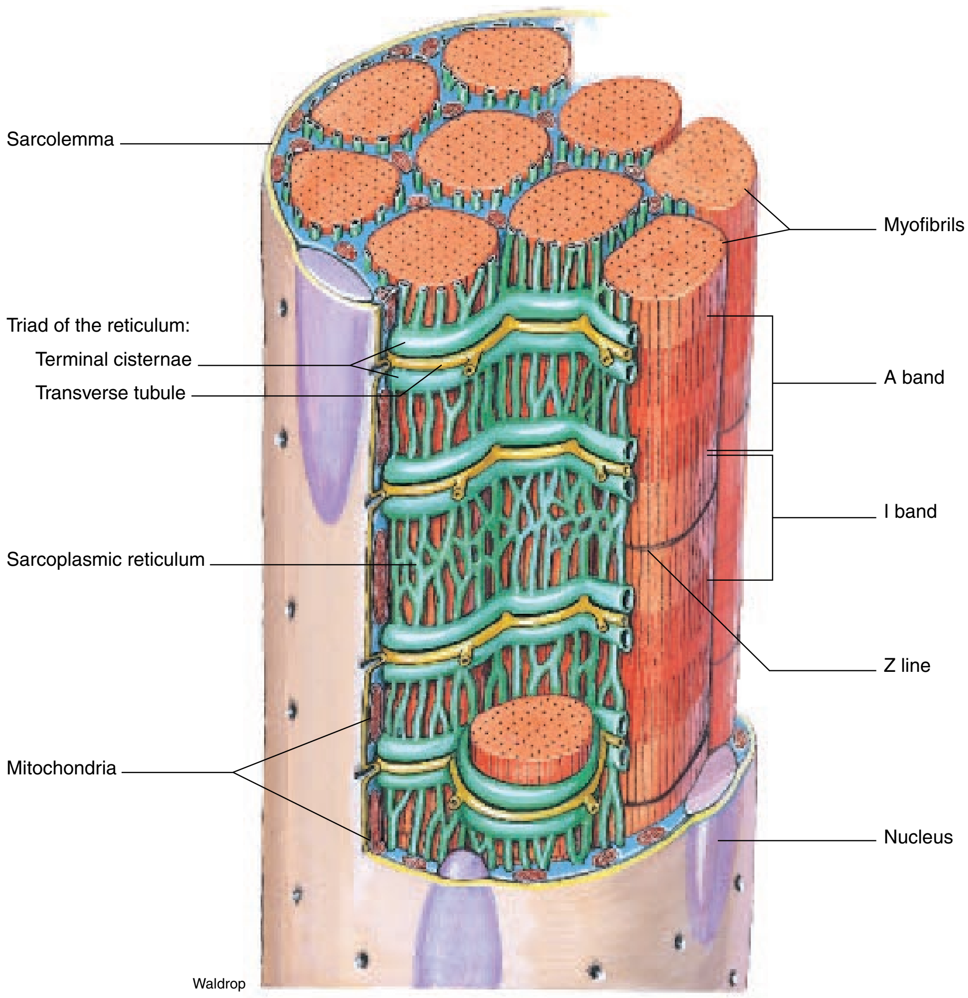


FIGURE 9.7 The structural relationship of the myofibrils of a muscle fiber to the sarcolemma, transverse tubules, and sarcoplasmic reticulum. (Note the position of the mitochondria.)

"bright"). The central H zones thus contain only thick filaments that are not overlapped by thin filaments.

The side view of successive sarcomeres in figure 9.9*b* is, in a sense, misleading. There are numerous sarcomeres within each myofibril that are out of the plane of the section (and out of the picture). A better appreciation of the three-dimensional structure of a myofibril can be obtained by viewing the myofibril in transverse section. In this view, shown in figure 9.9*c*, it can be seen that the Z lines are actually disc-shaped (Z stands for *Zwischenscheibe*, a German word meaning "between disc"), and that the thin filaments that penetrate these Z discs surround the thick filaments in a hexagonal arrangement. If one concentrates on a single row of dark thick myofilaments in this transverse section, the alternating pattern of thick and thin filaments seen in longitudinal section becomes apparent.

When a muscle is stimulated to contract, it decreases in length as a result of the shortening of its individual fibers. Shortening of the muscle fibers, in turn, is produced by shortening of their myofibrils, which occurs as a result of the shortening of the distance from Z line to Z line (fig. 9.10). As the sarcomeres shorten in length, however, the A bands do *not* shorten but instead appear closer together. The I bands—which represent the distance between A bands of successive myomeres—decrease in length.

CHAPTER 9

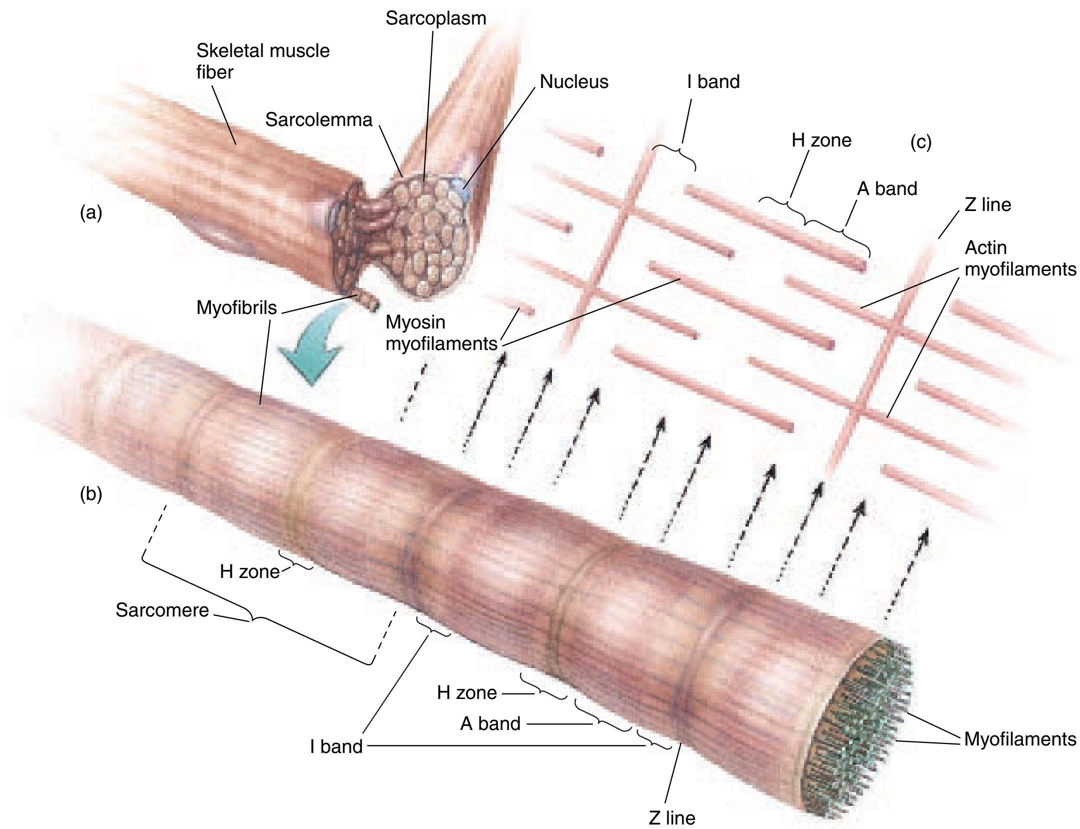


FIGURE 9.8 The structure of a myofibril. (*a*) The many myofibrils of a skeletal muscle fiber are arranged into compartments (*b*) called sarcomeres. (*c*) The characteristic striations of a sarcomere are due to the arrangement of thin and thick myofilaments, composed of actin and myosin, respectively.

The thin actin filaments composing the I band do not shorten, however. Close examination reveals that the length of the thick and thin myofilaments remains constant during muscle contraction. Shortening of the sarcomeres is produced not by shortening of the myofilaments, but rather by the *sliding* of thin filaments over and between thick ones. In the process of contraction, the thin filaments on either side of each A band extend deeper and deeper toward the center, thereby increasing the amount of overlap with the thick filaments. The central H bands thus get shorter and shorter during contraction.

Isotonic and Isometric Contractions

In order for muscle fibers to shorten when they contract, they must generate a force that is greater than the opposing forces that act to prevent movement of the muscle's insertion. Flexion of the elbow, for example, occurs against the force of gravity and the weight of the objects being lifted. The tension produced by the contraction of each muscle fiber separately is insufficient to overcome these opposing forces, but the combined contractions of large numbers of muscle fibers may be sufficient to overcome them and flex the elbow as the muscle fibers shorten.

Contraction that results in visible muscle shortening is called *isotonic contraction* because the force of contraction remains relatively constant throughout the shortening process (fig. 9.11). If the opposing forces are too great or if the number of muscle fibers activated is too few to shorten the muscle, however, an *isometric contraction* is produced, and movement does not occur.

isotonic: Gk. *isos*, equal; *tonos*, tension
isometric: Gk. *isos*, equal; *metron*, measure

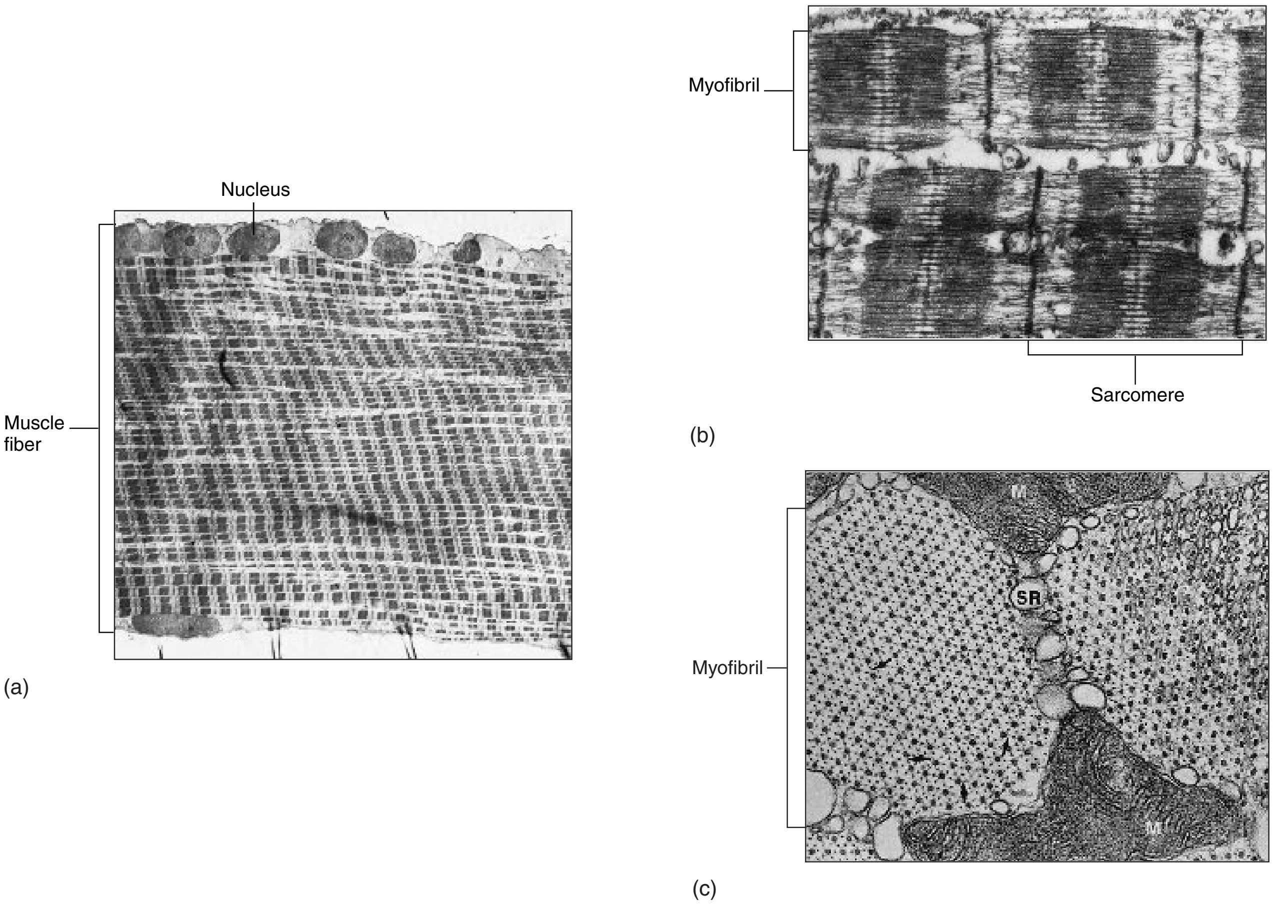


FIGURE 9.9 Electron micrographs of myofibrils of a muscle fiber. (*a*) At a low power (1,600×), a single muscle fiber containing numerous myofibrils. (*b*) At high power (53,000×), myofibrils in longitudinal section. (Note the sarcomeres and overlapping thick and thin myofilaments.) (*c*) The hexagonal arrangement of thick and thin filaments as seen in transverse section (arrows point to cross bridges; SR = sarcoplasmic reticulum).
(From R.G. Kessel and R.H. Kardon. Tissues and Organs: A Text-Atlas of Scanning Electron Microscopy © *1979 W.H. Freeman and Company.*)

Neuromuscular Junction

A nerve serving a muscle is composed of both motor and sensory neurons. Each motor neuron has a threadlike **axon** that extends from the CNS to a group of skeletal muscle fibers. Close to these skeletal muscle fibers, the axon divides into numerous branches called **axon terminals.** The axon terminals contact the sarcolemma of the muscle fibers by means of **motor end plates** (fig. 9.12). The area consisting of the motor end plate and the cell membrane of a muscle fiber is known as the **neuromuscular** (myoneural) **junction.**

axon: Gk. *axon,* axis

Acetylcholine (*ă-sēt''l-ko'lēn*) is a neurotransmitter chemical stored in **synaptic vesicles** at the axon terminals. A nerve impulse reaching the axon terminal causes the release of acetylcholine into the **neuromuscular cleft** of the neuromuscular junction. As this chemical mediator contacts the receptor sites of the sarcolemma, it initiates physiological activity within the muscle fiber, resulting in contraction.

Motor Unit

A **motor unit** consists of a single motor neuron and the aggregation of muscle fibers innervated by the motor neuron (fig. 9.12*b*). When a nerve impulse travels through a motor unit, all of the fibers served by it contract simultaneously to their maximum.

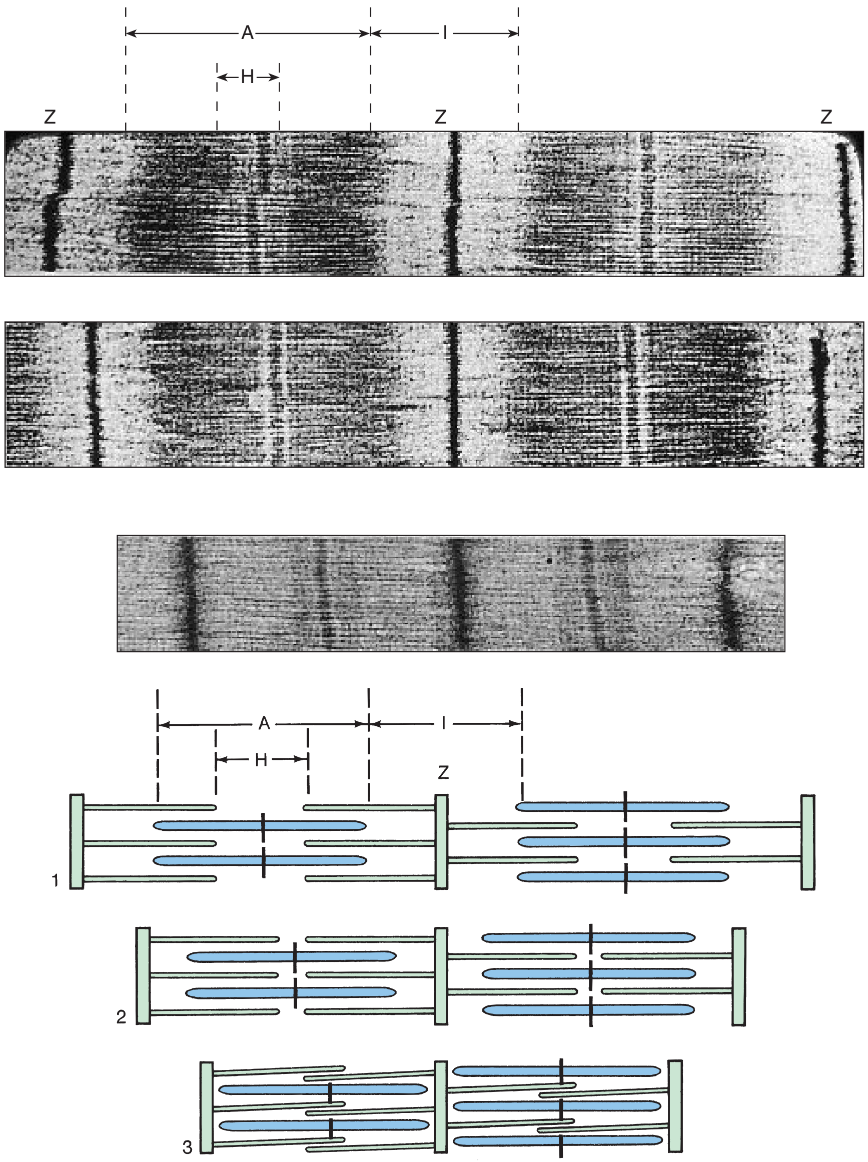
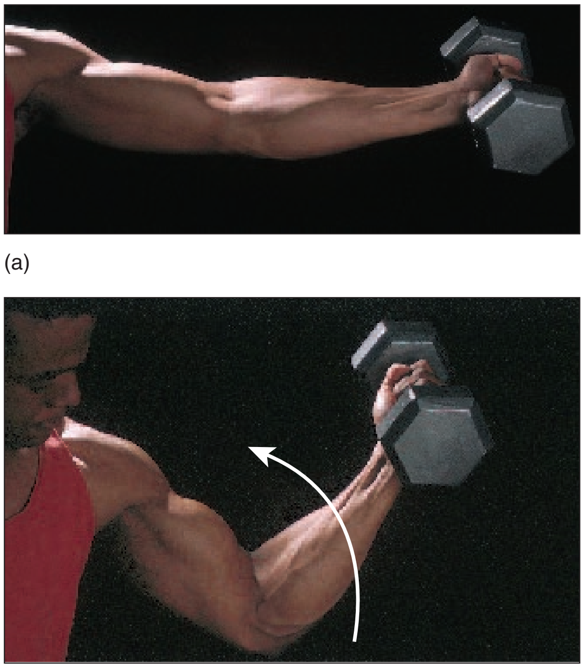


FIGURE 9.10 The sliding filament model of contraction. As the myofilaments slide, the Z lines are brought closer together. The A bands remain the same length during contraction, but the I and H bands narrow progressively and eventually may be obliterated. (1) Relaxed muscle, (2) partially contracted muscle, and (3) fully contracted muscle.

Most muscles have an innervation ratio of 1 motor neuron for each 100 to 150 muscle fibers. Muscles capable of precise, dexterous movements, such as an eye muscle, may have an innervation ratio of 1:10. Massive muscles that are responsible for gross body movements, such as those of the thigh, may have innervation ratios exceeding 1:500.

All of the motor units controlling a particular muscle, however, are not the same size. Innervation ratios in a large thigh muscle may vary from 1:100 to 1:2,000. Neurons that innervate smaller numbers of muscle fibers have smaller cell bodies and axon diameters than neurons that have larger innervation ratios. The smaller neurons also are stimulated by lower levels of excitatory input. The small motor units, as a result, are the ones that are used most often. The larger motor units are activated only when very forceful contractions are required.



(a)

(b)

FIGURE 9.11 Photograph of isometric and isotonic contractions. (*a*) An isometric contraction, in which the muscle stays the same length and (*b*) an isotonic contraction, in which the muscle shortens.

Skeletal muscles are voluntary in that they can be consciously contracted. The magnitude of the task determines the number of motor units that are activated. Performing a light task, such as lifting a book, requires few motor units, whereas lifting a table requires many. Muscles with pennate architecture have many motor units and are strong and dexterous; however, they generally fatigue more readily than muscles with fewer motor units. Being mentally "psyched up" to accomplish an athletic feat involves voluntary activation of more motor units within the muscles. Although a person seldom utilizes all of the motor units within a muscle, the secretion of *epinephrine* (*ep″ĭ-nef′rin*) from the adrenal gland does promote an increase in the force that can be produced when a given number of motor units are activated.

Steroids are hormones produced by the adrenal glands, testes, and ovaries. Because they are soluble in lipids, they readily pass through cell membranes and enter the cytoplasm, where they combine with proteins to form steroid-protein complexes that are necessary for the syntheses of specific kinds of messenger RNA molecules. Synthetic steroids were originally developed to promote weight gain in cancer and anorexic patients. It soon became apparent, however, that steroids taken by bodybuilders and athletes could provide them with increased muscle mass, strength, and aggressiveness. The use of steroids is now considered illegal by most athletic associations. Not only do they confer unfair advantages in physical competition, they also can have serious side effects. These include gonadal atrophy, hypertension, induction of malignant tumors of the liver, and overly aggressive behavior, to name just a few.

Knowledge Check

7. Draw three successive sarcomeres in a myofibril of a resting muscle fiber. Label the myofibril, sarcomeres, A bands, I bands, H bands, and Z lines.
8. Why do the A bands appear darker than the I bands?
9. Draw three successive sarcomeres in a myofibril of a contracted fiber. Indicate which bands get shorter during contraction and explain how this occurs.
10. Describe how the antagonistic muscles in the brachium can be exercised through both isotonic and isometric contractions.
11. Explain why sarcomeres are considered the basic structural components of skeletal muscles, and motor units are considered the basic functional units of muscle contraction.

NAMING OF MUSCLES

Skeletal muscles are named on the basis of shape, location, attachment, orientation of fibers, relative position, or function.

Objective 9 Use examples to describe the various ways in which muscles are named.

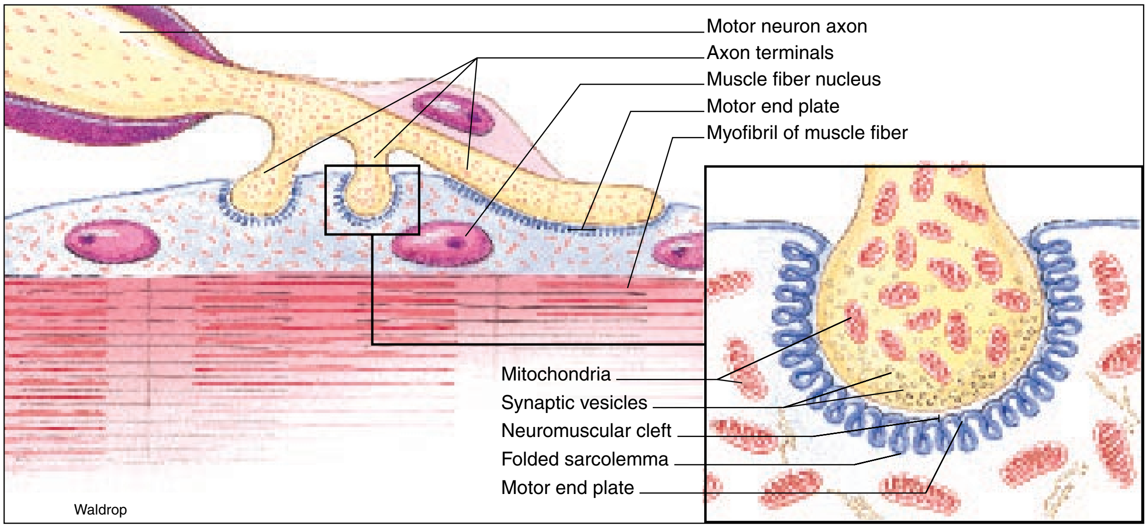
One of your tasks as a student of anatomy is to learn the names of the principal muscles of the body. Although this may seem overwhelming, keep in mind that most of the muscles are paired; that is, the right side is the mirror image of the left. To help you further, most muscles have names that are descriptive.

As you study the muscles of the body, consider how each was named. Identify the muscle on the figure referenced in the text narrative and locate it on your own body as well. Use your body to act out its movement. Feel it contracting beneath your skin and note the movement that occurs at the joint. Learning the muscles in this way will simplify the task and make it more meaningful.

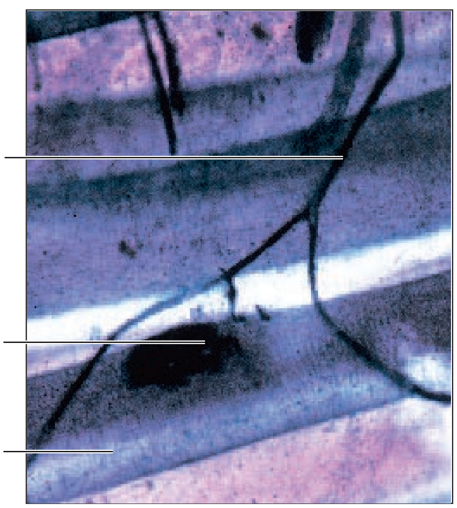
The following are some criteria by which the names of muscles have been logically derived:

1. **Shape:** rhomboideus (like a rhomboid); trapezius (like a trapezoid); or denoting the number of heads of origin: triceps (three heads), biceps (two heads)
2. **Location:** pectoralis (in the chest, or pectus); intercostal (between ribs); brachia (arm)
3. **Attachment:** many facial muscles (zygomaticus, temporalis, nasalis); sternocleidomastoid (sternum, clavicle, and mastoid process of the temporal bone)

CHAPTER 9



(a)



(b)

FIGURE 9.12 A motor end plate at the neuromuscular junction. (*a*) A neuromuscular junction is the site where the nerve fiber and muscle fiber meet. The motor end plate is the specialized portion of the sarcolemma of a muscle fiber surrounding the terminal end of the axon. (Note the slight gap between the membrane of the axon and that of the muscle fiber.) (*b*) A photomicrograph of muscle fibers and motor end plates. A motor neuron and the skeletal muscle fibers it innervates constitute a motor unit.

4. **Size:** maximus (larger, largest); minimus (smaller, smallest); longus (long); brevis (short)
5. **Orientation of fibers:** rectus (straight); transverse (across); oblique (in a slanting or sloping direction)
6. **Relative position:** lateral, medial, internal, and external
7. **Function:** adductor, flexor, extensor, pronator, and levator (lifter)

Knowledge Check

12. Refer to chapter 2 (fig. 2.14) and review the location of the following body regions: cervical, pectoral, abdominal, gluteal, perineal, brachial, antebrachial, inguinal, thigh, and popliteal.
13. Refer to chapter 8 and review the movements permitted at synovial joints.

Developmental Exposition

The Muscular System

EXPLANATION

The formation of skeletal muscle tissue begins during the fourth week of embryonic development as specialized mesodermal cells called *myoblasts* begin rapid mitotic division (exhibit I). The proliferation of new cells continues while the myoblasts migrate and fuse together into *syncytial myotubes*. (A *syncytium* [*sin-sishé-um*] is a multinucleated protoplasmic mass formed by the union of originally separate cells.) At 9 weeks, primitive myofilaments course through the myotubes, and the nuclei of the contributing myoblasts are centrally located. Growth in length continues through the addition of myoblasts.

The process of muscle fiber development occurs within specialized mesodermal masses called *myotomes* in the embryonic trunk area and from loosely organized masses of mesoderm in the head and appendage areas. At 6 weeks, the trunk of an embryo is segmented into distinct myotomes (exhibit II) that are associated dorsally with specific *sclerotomes*—paired masses of mesenchymal tissue that give rise to vertebrae and ribs. As will be explained in chapter 12, spinal nerves arise from the spinal cord and exit between vertebrae to innervate developing muscles in the adjacent myotomes. As myotomes develop, additional myoblasts migrate ventrally, toward the midline of the body, or distally, into the developing limbs. The muscles of the entire muscular system have been differentiated and correctly positioned by the eighth week. The orientation of the developing muscles is preceded and influenced by cartilaginous models of bones.

It is not certain when skeletal muscle is sufficiently developed to sustain contractions, but by week 17 the fetal movements known as *quickening* are strong enough to be recognized by the mother. The individual muscle fibers have now thickened, the nuclei have moved peripherally, and the filaments (myofilaments) can be recognized as alternating dark and light bands. Growth in length still continues through addition of myoblasts. Shortly before a baby is born, the formation of myoblast cells ceases, and all of the muscle cells have been determined. Differences in strength, endurance, and coordination are somewhat genetically determined but are primarily the result of individual body conditioning. Muscle coordination is an ongoing process of achieving a fine neural control of muscle fibers. Mastery of muscle movement is comparatively slow in humans. Although innervation and muscle contraction occur early during fetal development, it is several months before a human infant has the coordination to crawl, and about a year before it can stand or walk. By contrast, most mammals can walk and run within a few hours after they are born.

myoblast: Gk. *myos*, muscle; *blastos*, germ

syncytial: Gk. *syn*, with; *cyto*, cell

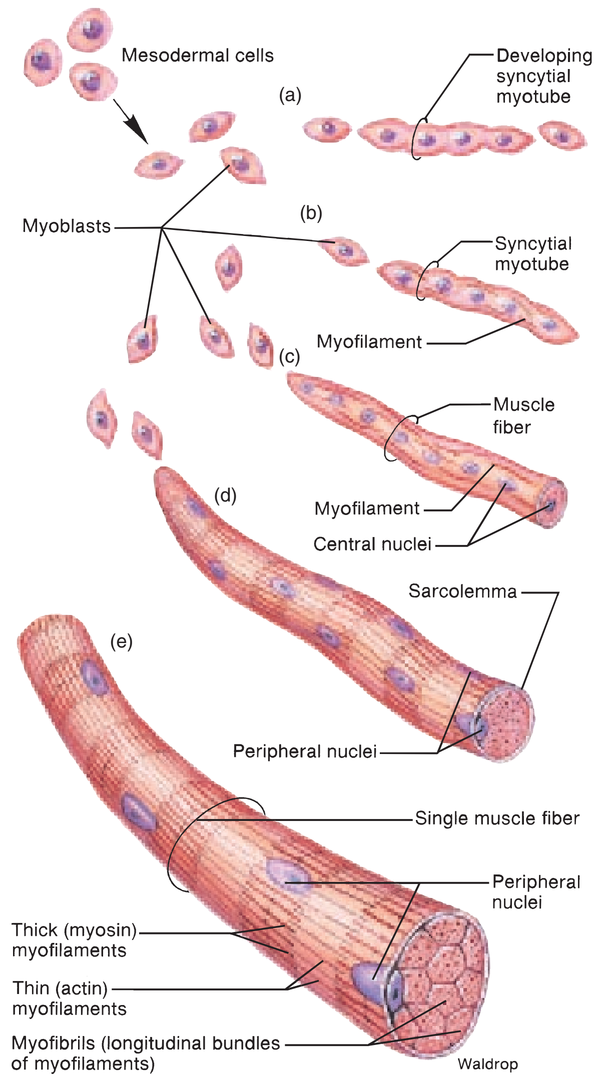


EXHIBIT I The development of skeletal muscle fibers. (*a*) At 5 weeks, the myotube is formed as individual cell membranes are broken down. Myotubes grow in length by incorporating additional myoblasts; each adds an additional nucleus. (*b*) Muscle fibers are distinct at 9 weeks, but the nuclei are still centrally located, and growth in length continues through the addition of myoblasts. (*c*) At 5 months, thin (actin) and thick (myosin) myofilaments are present and moderate growth in length still continues. (*d*) By birth, the striated myofilaments have aggregrated into bundles, the fiber has thickened, and the nuclei have shifted to the periphery. Myoblast activity ceases and all the muscle fibers a person will have are formed. (*e*) The appearance of a mature muscle fiber.

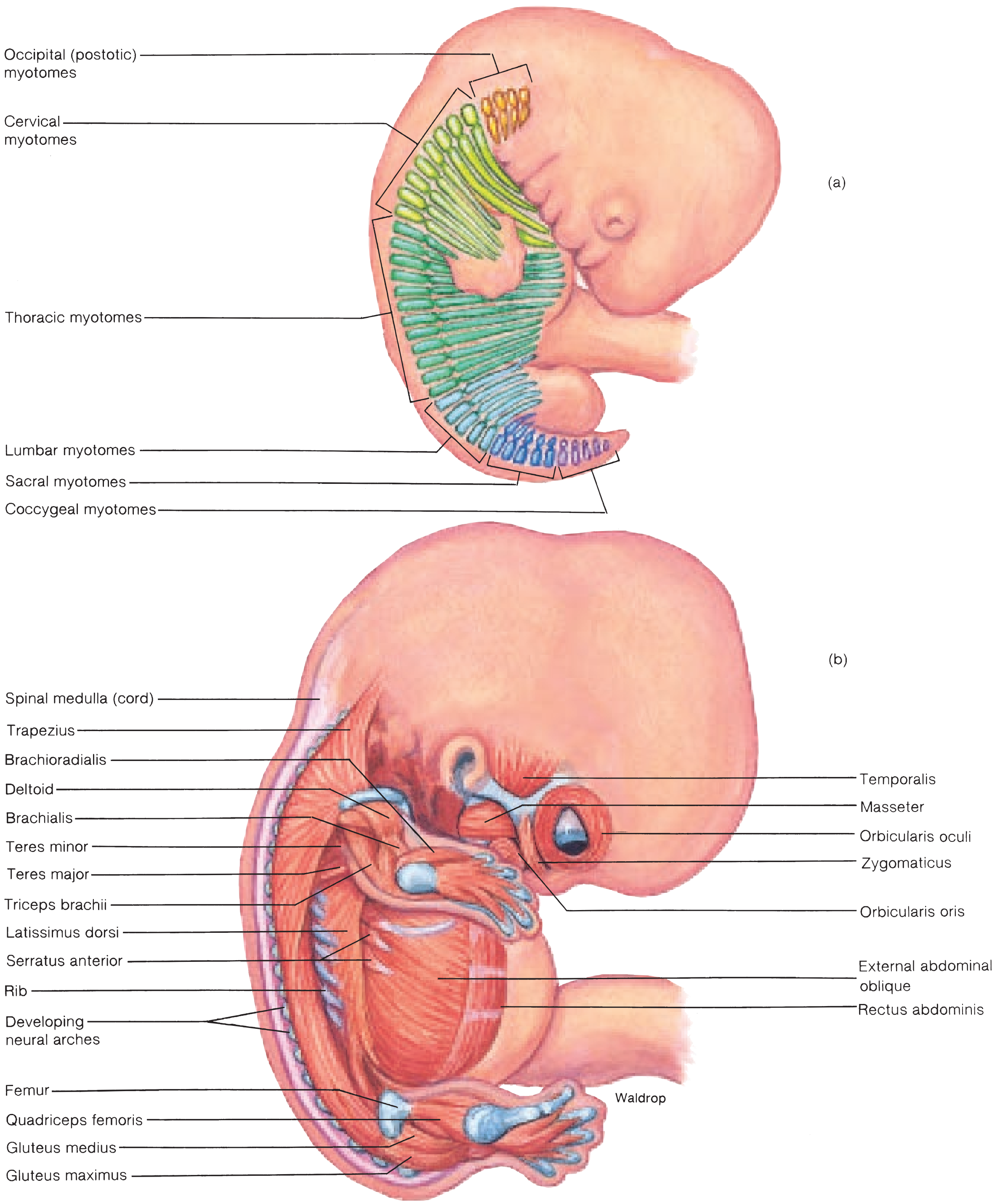


EXHIBIT II The development of skeletal muscles. (*a*) The distribution of embryonic myotomes at 6 weeks. Segmental myotomes give rise to the muscles of the trunk area and girdles. Loosely organized masses of mesoderm form the muscles of the head and extremities. (*b*) The arrangement of skeletal muscles at 8 weeks. The development of muscles is influenced by the preceding cartilaginous models of bones. The innervation of muscles corresponds to the development of spinal nerves and dermatome arrangement.

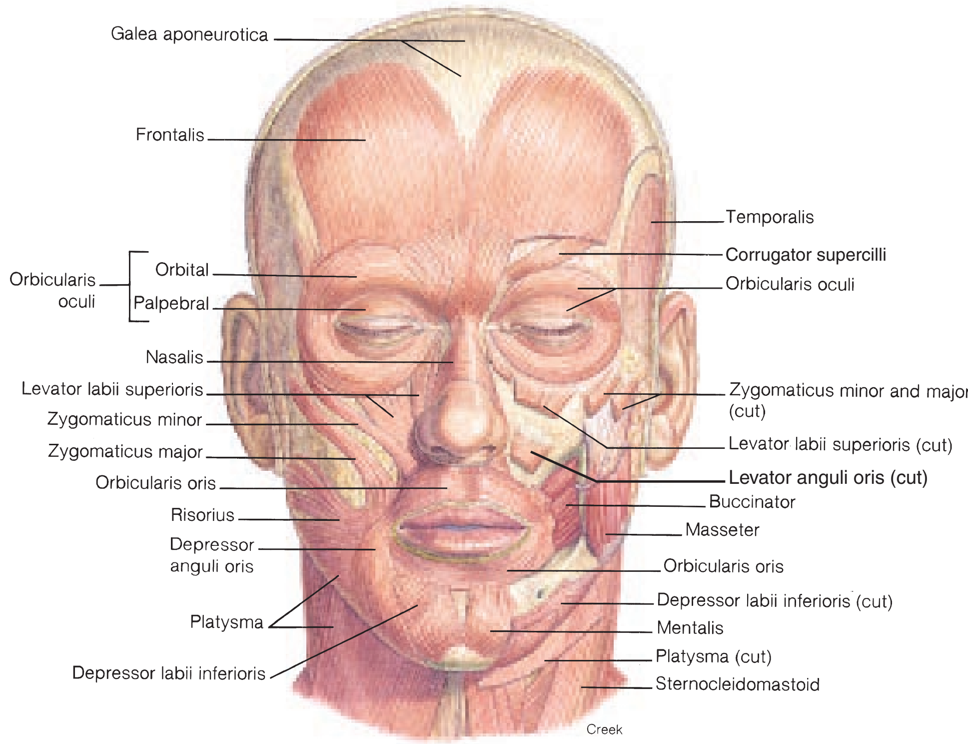


FIGURE 9.13 An anterior view of the superficial facial muscles involved in facial expression.

MUSCLES OF THE AXIAL SKELETON

Muscles of the axial skeleton include those responsible for facial expression, mastication, eye movement, tongue movement, neck movement, and respiration, and those of the abdominal wall, the pelvic outlet, and the vertebral column.

Objective 10 Locate the major muscles of the axial skeleton. Identify synergistic and antagonistic muscles and describe the action of each one.

Muscles of Facial Expression

Humans have a well-developed facial musculature (figs. 9.13 and 9.14) that allows for complex facial expression as a means of social communication. Very often we let our feelings be known without a word spoken.

The muscles of facial expression are located in a superficial position on the scalp, face, and neck. Although highly variable in size and strength, these muscles all originate on the bones of the skull or in the fascia and insert into the skin (table 9.3). They are all innervated by the facial nerves (see fig. 12.8). The locations and points of attachments of most of the facial muscles are such that, when contracted, they cause movements around the eyes, nostrils, or mouth (fig. 9.15).

The muscles of facial expression are of clinical concern for several reasons, all of which involve the facial nerve. Located right under the skin, the many branches of the facial nerve are vulnerable to trauma. Facial lacerations and fractures of the skull frequently damage branches of this nerve. The extensive pattern of motor innervation becomes apparent in stroke victims and persons suffering from *Bell's palsy.* The facial muscles on one side of the face are affected in these people, and that side of the face appears to sag.

Muscles of Mastication

The large **temporalis** and **masseter** (*mă-se'ter*) muscles (fig. 9.16) are powerful elevators of the mandible in conjunction with the **medial pterygoid** (*ter'ĭ-goid*) muscle. The primary function of the medial and lateral pterygoid muscles is to provide grinding movements of the teeth. The **lateral pterygoid** also protracts the mandible (table 9.4).

Tetanus is a bacterial disease caused by the introduction of anaerobic *Clostridium tetani* into the body, usually from a puncture wound. The bacteria produce a neurotoxin that is carried to the spinal cord by sensory nerves. The motor impulses relayed back cause certain muscles to contract continuously (tetany). The muscles that move the mandible are affected first, which is why the disease is commonly known as *lockjaw.*

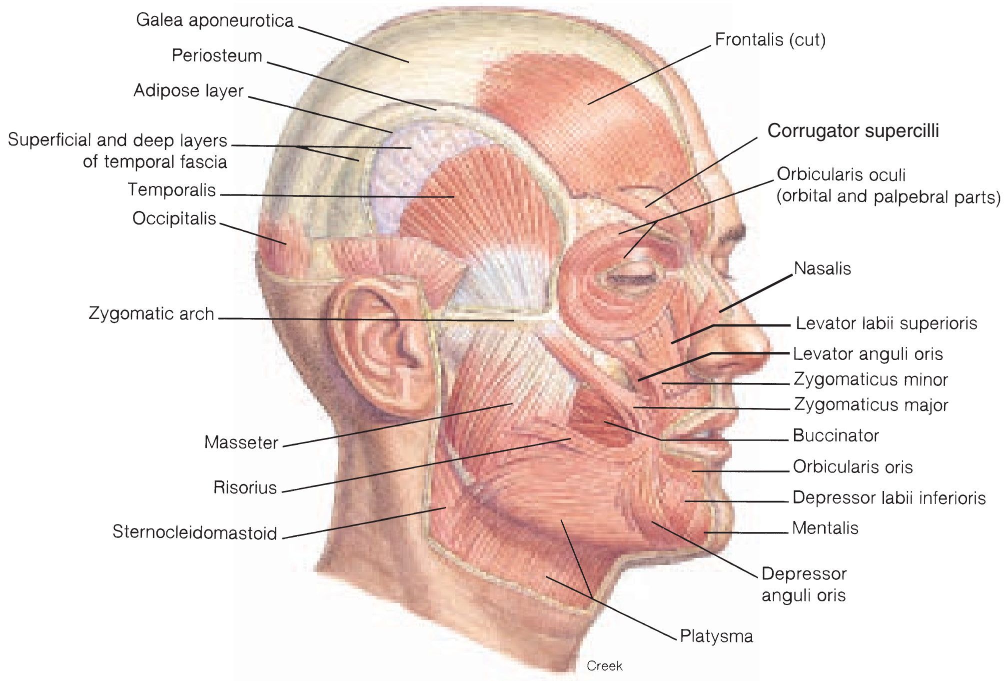


FIGURE 9.14 A lateral view of the superficial facial muscles involved in facial expression.

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TABLE 9.3 Muscles of Facial Expression*

Muscle	Origin	Insertion	Action
Epicranius	Galea aponeurotica and occipital bone	Skin of eyebrow and galea aponeurotica	Wrinkles forehead and moves scalp
Frontalis	Galea aponeurotica	Skin of eyebrow	Wrinkles forehead and elevates eyebrow
Occipitalis	Occipital bone and mastoid process	Galea aponeurotica	Moves scalp backward
Corrugator supercilli	Fascia above eyebrow	Root of nose	Draws eyebrow toward midline
Orbicularis oculi	Bones of medial orbit	Tissue of eyelid	Closes eye
Nasalis	Maxilla and nasal cartilage	Aponeurosis of nose	One part widens nostrils; another part depresses nasal cartilages and compresses nostrils
Orbicularis oris	Fascia surrounding lips	Mucosa of lips	Closes and purses lips
Levator labii superioris	Upper maxilla and zygomatic bone	Orbicularis oris and skin above lips	Elevates upper lip
Levator anguli oris	Maxilla	Orbicularis oris	Elevates upper lip
Zygomaticus	Zygomatic bone	Superior corner of orbicularis oris	Elevates corner of mouth
Risorius	Fascia of cheek	Orbicularis oris at corner of mouth	Draws angle of mouth laterally
Depressor anguli oris	Mandible	Inferior corner of orbicularis oris	Depresses corner of mouth
Depressor labii inferioris	Mandible	Orbicularis oris and skin of lower lip	Depresses lower lip
Mentalis	Mandible (chin)	Orbicularis oris	Protrudes lower lip
Platysma	Fascia of neck and chest	Inferior border of mandible	Depresses mandible and lower lip
Buccinator	Maxilla and mandible	Orbicularis oris	Compresses cheek

*Each of the muscles of facial expression is innervated by the facial nerve.
corrugator: L. *corrugo*, a wrinkle
risorius: L. *risor*, a laughter
mentalis: L. *mentum*, chin
platysma: Gk. *platys*, broad
buccinator: L. *bucca*, cheek

FIGURE 9.15 Expressions produced by contractions of facial muscles. In each of these photographs, identify the muscles that are being contracted.

Ocular Muscles

The movements of the eyeball are controlled by six extrinsic ocular (eye) muscles (fig. 9.17 and table 9.5). Five of these muscles arise from the margin of the optic foramen at the back of the orbital cavity and insert on the outer layer (sclera) of the eyeball. Four **rectus muscles** maneuver the eyeball in the direction indicated by their names **(superior, inferior, lateral,** and **medial),** and two **oblique muscles (superior** and **inferior)** rotate the eyeball on its axis. The medial rectus on one side contracts with the medial rectus of the opposite eye when focusing on close objects. When looking to the side, the lateral rectus of one eyeball works with the medial rectus of the opposite eyeball to keep both eyes functioning together. The superior oblique muscle passes through a pulleylike cartilaginous loop, the *trochlea,* before attaching to the eyeball.

Another muscle, the **levator palpebrae** (*le-va'tor pal'pe-bre*) **superioris** (fig. 9.17*b*), is located in the ocular region but is not attached to the eyeball. It extends into the upper eyelid and raises the eyelid when contracted.

Muscles That Move the Tongue

The tongue is a highly specialized muscular organ that functions in speaking, manipulating food, cleansing the teeth, and swallowing. The *intrinsic tongue muscles* are located within the tongue and are responsible for its mobility and changes of shape. The *extrinsic tongue muscles* are those that originate on structures other than the tongue and insert onto it to cause gross tongue movement (fig. 9.18 and table 9.6). The four paired extrinsic muscles are the **genioglossus** (*je-ne''o-glos'us*) **styloglossus, hyoglossus,** and **palatoglossus.** When the anterior portion of the genioglossus muscle is contracted, the tongue is depressed and thrust forward. If both genioglossus muscles are contracted together along their entire lengths, the superior surface of the tongue becomes transversely concave. This muscle is extremely important to nursing infants; the tongue is positioned around the nipple with a concave groove channeled toward the pharynx.

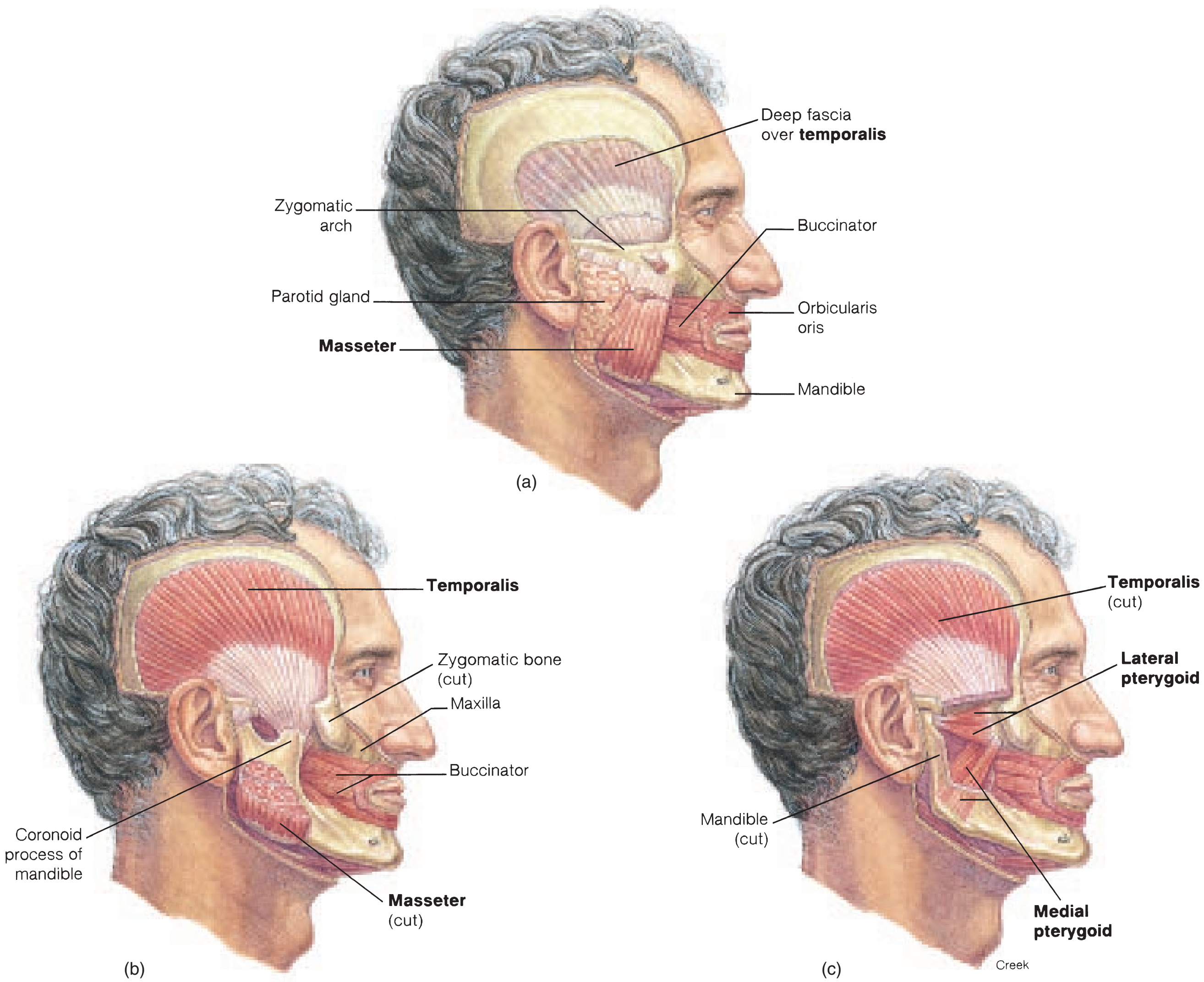


FIGURE 9.16 Muscles of mastication. (*a*) A superficial view, (*b*) a deep view, and (*c*) the deepest view, showing the pterygoid muscles. (The muscles of mastication are labeled in boldface type.)

TABLE 9.4 Muscles of Mastication*

Muscle	Origin	Insertion	Action
Temporalis	Temporal fossa	Coronoid process of mandible	Elevates and retracts mandible
Masseter	Zygomatic arch	Lateral part of ramus of mandible	Elevates mandible
Medial pterygoid	Sphenoid bone	Medial aspect of mandible	Elevates mandible and moves mandible laterally
Lateral pterygoid	Sphenoid bone	Anterior side of mandibular condyle	Protracts mandible

*Each of the muscles of mastication is innervated by the mandibular nerve, a branch of the trigeminal nerve.
masseter: Gk. *maseter*, chew
pterygoid: Gk. *pteron*, wing

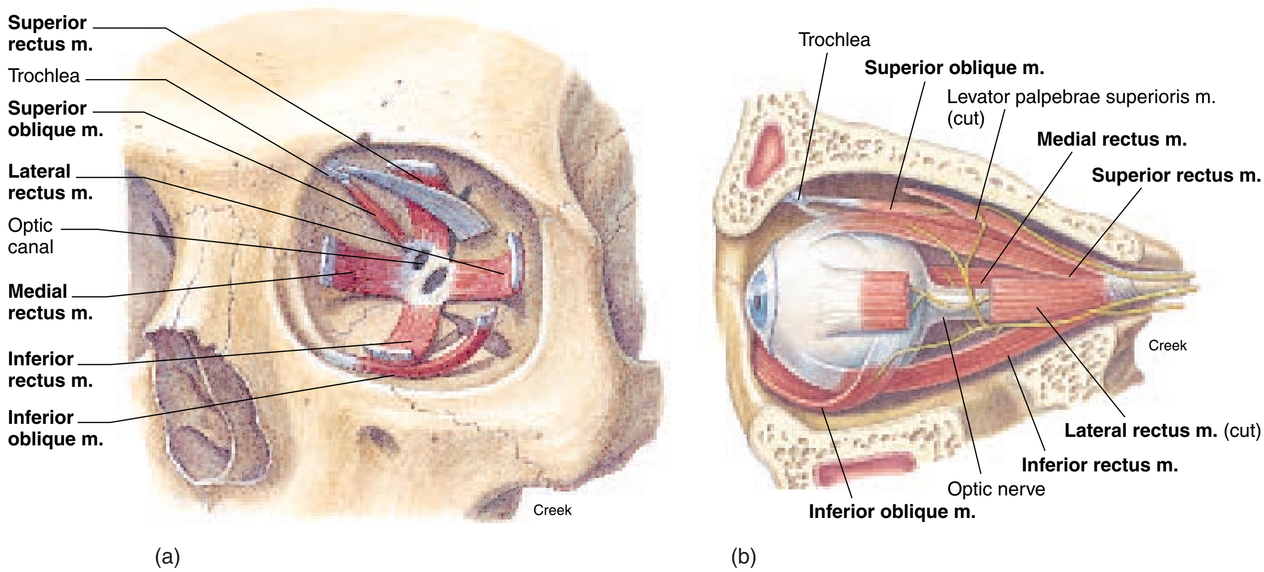


FIGURE 9.17 Extrinsic ocular muscles of the left eyeball. (*a*) An anterior view and (*b*) a lateral view. (The extrinsic ocular muscles are labeled in boldface type.)

TABLE 9.5 Ocular Muscles

Muscle	Cranial Nerve Innervation	Movement of Eyeball
Lateral rectus	Abducens	Lateral
Medial rectus	Oculomotor	Medial
Superior rectus	Oculomotor	Superior and medial
Inferior rectus	Oculomotor	Inferior and medial
Inferior oblique	Oculomotor	Superior and lateral
Superior oblique	Trochlear	Inferior and lateral

Muscles of the Neck

Muscles of the neck either support and move the head or are attached to structures within the neck region, such as the hyoid bone and larynx. Only the more obvious neck muscles will be considered in this chapter.

You can observe many of the muscles in this section and those that follow on your own body. Refer to chapter 10 to determine which muscles form important surface landmarks. The muscles of the neck are illustrated in figures 9.19 and 9.20 and are summarized in table 9.7.

Posterior Muscles

The posterior muscles include the *sternocleidomastoid* (originates anteriorly), *trapezius*, *splenius capitis*, *semispinalis capitis*, and *longissimus capitis*.

As the name implies, the **sternocleidomastoid** (*ster''no-kli''do-mas'toid*) muscle originates on the sternum and clavicle and inserts on the mastoid process of the temporal bone (fig. 9.20 and table 9.7). When contracted on one side, it turns the head sideways in the direction opposite the side on which the muscle is located. If both sternocleidomastoid muscles are contracted, the head is pulled forward and down. The sternocleidomastoid muscle is covered by the platysma muscle (see figs. 9.13 and 9.14).

Although a portion of the **trapezius** muscle extends over the posterior neck region, it is primarily a superficial muscle of the back and will be described later.

The **splenius capitis** (*sple'ne-us kap'ĭ-tis*) is a broad muscle, positioned deep to the trapezius (fig. 9.19). It originates on the ligamentum nuchae and the spinous processes of the seventh cervical and first three thoracic vertebrae. It inserts on the back of the skull below the superior nuchal line and on the mastoid process of the temporal bone. When the splenius capitis contracts on one side, the head rotates and extends to one side. Contracted together, the splenius capitis muscles extend the head at the neck. Further contraction causes hyperextension of the neck and head.

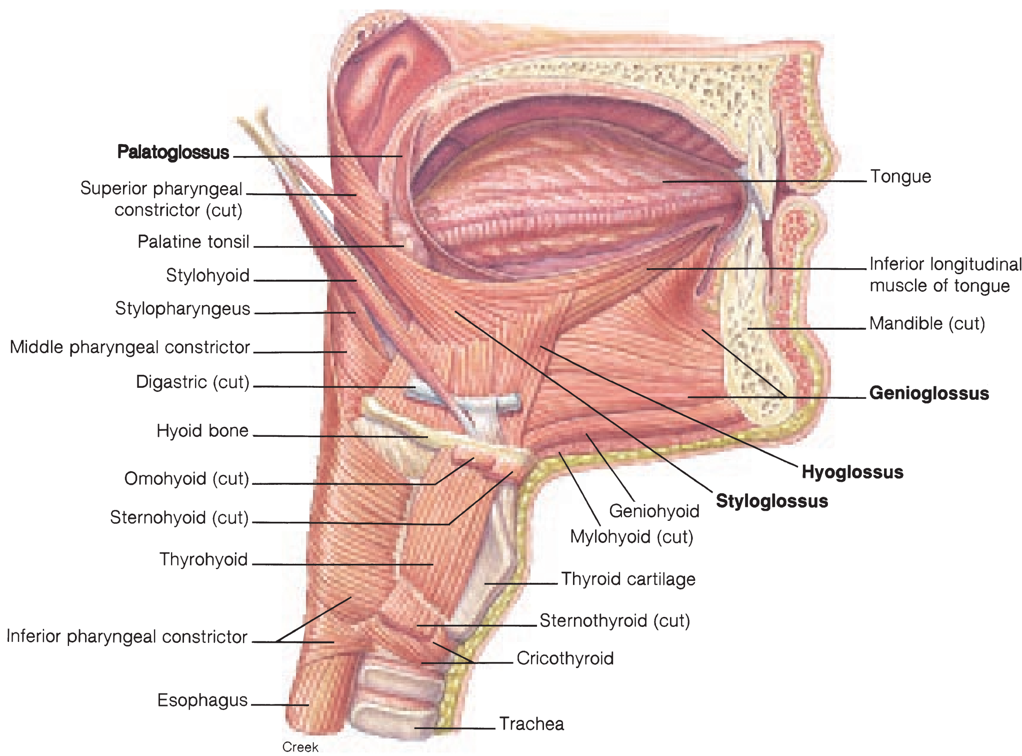


FIGURE 9.18 Extrinsic muscles of the tongue and deep structures of the neck. (The extrinsic muscles of the tongue are labeled in boldface type.)

CHAPTER 9

TABLE 9.6 Extrinsic Tongue Muscles*

Muscle	Origin	Insertion	Action
Genioglossus	Mental spine of mandible	Undersurface of tongue	Depresses and protracts tongue
Styloglossus	Styloid process of temporal bone	Lateral side and undersurface of tongue	Elevates and retracts tongue
Hyoglossus	Body of hyoid bone	Side of tongue	Depresses sides of tongue
Palatoglossus	Soft palate	Side of tongue	Elevates posterior tongue; constricts fauces (opening from oral cavity to pharynx)

*Each of the extrinsic tongue muscles is innervated by the hypoglossal nerve.
genioglossus: L. *geneion*, chin; *glossus*, tongue

The broad, sheetlike **semispinalis capitis** muscle extends upward from the seventh cervical and first six thoracic vertebrae to insert on the occipital bone (fig. 9.19). When the two semispinalis capitis muscles contract together, they extend the head at the neck, along with the splenius capitis muscle. If one of the muscles acts alone, the head is rotated to the side.

The narrow, straplike **longissimus** (*lon-jis'ĭ-mus*) **capitis** muscle ascends from processes of the lower four cervical and upper five thoracic vertebrae and inserts on the mastoid process of the temporal bone (fig. 9.19). This muscle extends the head at the neck, bends it to one side, or rotates it slightly.

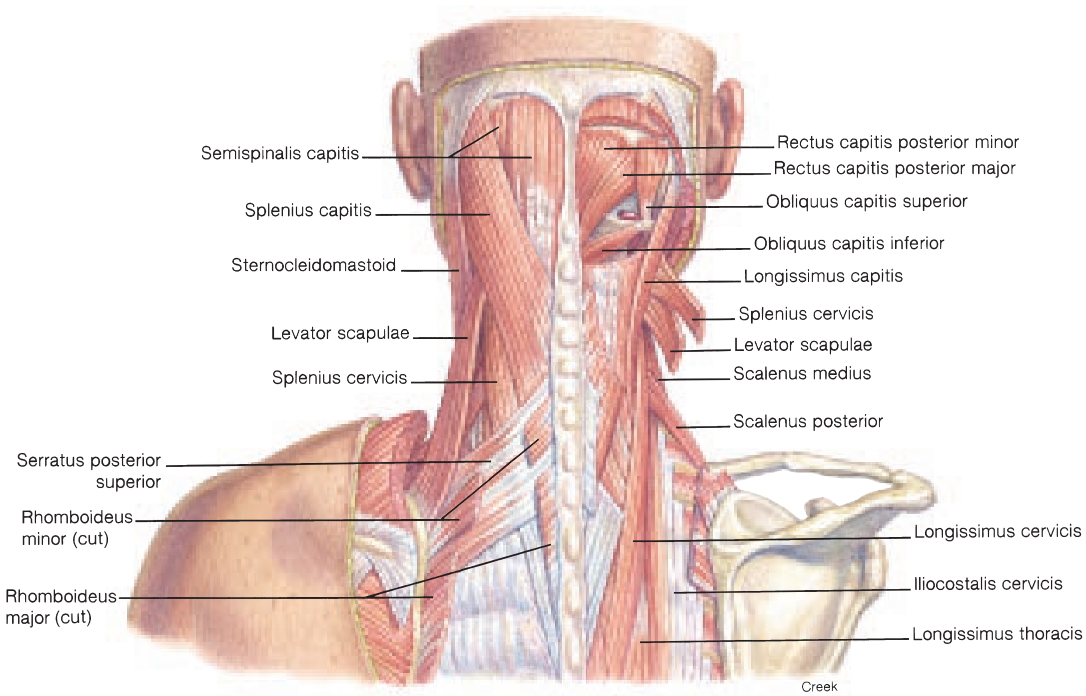


FIGURE 9.19 Deep muscles of the posterior neck and upper back regions.

Suprahyoid Muscles

The group of suprahyoid muscles located above the hyoid bone includes the *digastric, mylohyoid,* and *stylohyoid* muscles (fig. 9.20).

The **digastric** is a two-bellied muscle of double origin that inserts on the hyoid bone. The anterior origin is on the mandible at the point of the chin, and the posterior origin is near the mastoid process of the temporal bone. The digastric muscle can open the mouth or elevate the hyoid bone.

The **mylohyoid** muscle forms the floor of the mouth. It originates on the inferior border of the mandible and inserts on the median raphe and body of the hyoid bone. As this muscle contracts, the floor of the mouth is elevated. It aids swallowing by forcing food toward the back of the mouth.

The slender **stylohyoid** muscle extends from the styloid process of the skull to the hyoid bone, which it elevates as it contracts. Thus an indirect action of this muscle is to elevate the base of the tongue.

Infrahyoid Muscles

The thin, straplike infrahyoid muscles are located below the hyoid bone. They are individually named on the basis of their origin and insertion and include the *sternohyoid, sternothyroid, thyrohyoid,* and *omohyoid* muscles (fig. 9.20).

The **sternohyoid** muscle originates on the manubrium of the sternum and inserts on the hyoid bone. It depresses the hyoid bone as it contracts.

The **sternothyroid** muscle also originates on the manubrium but inserts on the thyroid cartilage of the larynx. When this muscle contracts, the larynx is pulled downward.

The short **thyrohyoid** muscle extends from the thyroid cartilage to the hyoid bone. It elevates the larynx and lowers the hyoid bone.

The long, thin **omohyoid** muscle originates on the superior border of the scapula and inserts on the hyoid bone. It acts to depress the hyoid bone.

The coordinated movements of the hyoid bone and the larynx are impressive. The hyoid bone does not articulate with any other bone, yet it has eight paired muscles attached to it. Two involve tongue movement, one lowers the jaw, one elevates the floor of the mouth, and four depress the hyoid bone or elevate the thyroid cartilage of the larynx.

Muscles of Respiration

The muscles of respiration are skeletal muscles that continually contract rhythmically, usually involuntarily. Breathing, or *pulmonary ventilation*, is divided into two phases: *inspiration (inhalation)* and *expiration (exhalation)*.

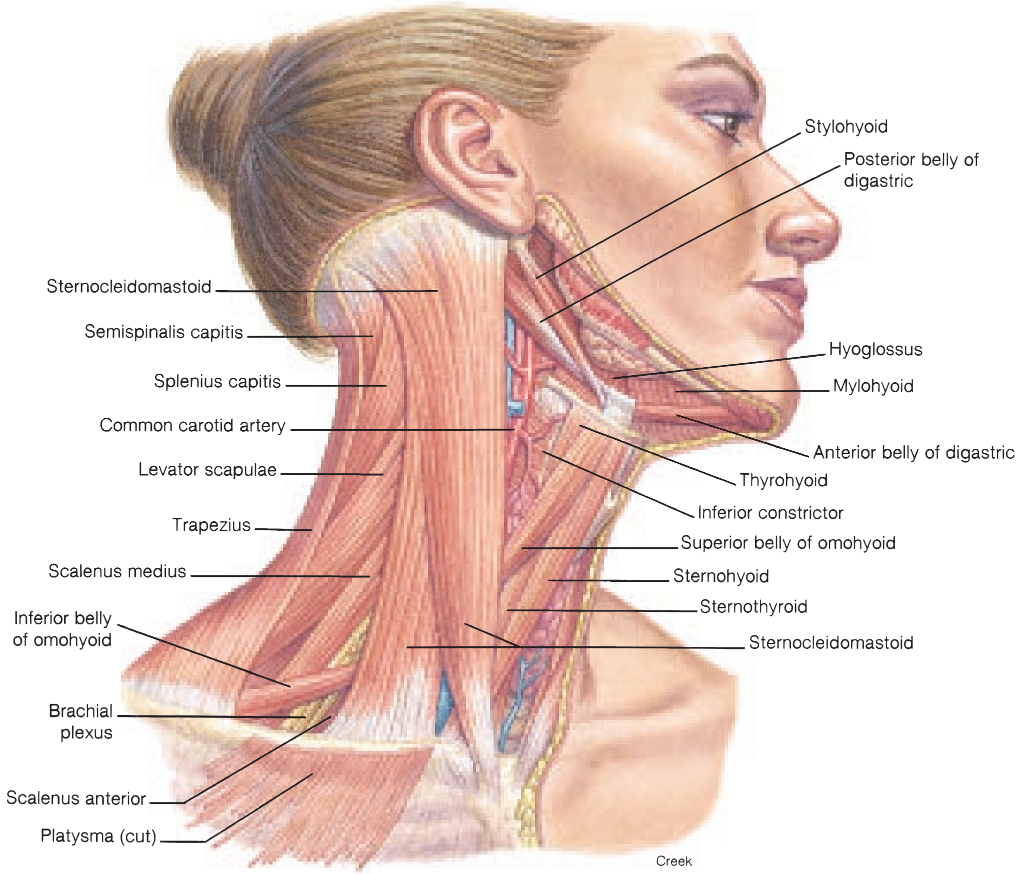


FIGURE 9.20 Muscles of the anterior and lateral neck regions.

TABLE 9.7 Muscles of the Neck

Muscle	Origin	Insertion	Action	Innervation
Sternocleidomastoid	Sternum and clavicle	Mastoid process of temporal bone	Rotation of head; flexes neck	Accessory n.
Digastric	Inferior border of mandible and mastoid process of temporal bone	Hyoid bone	Opens mouth; elevates hyoid bone	Trigeminal n. (ant. belly); facial n. (post. belly)
Mylohyoid	Inferior border of mandible	Body of hyoid bone and median raphe	Elevates hyoid bone and floor of mouth	Trigeminal n.
Geniohyoid	Medial surface of mandible at chin	Body of hyoid bone	Elevates hyoid bone	Spinal n. (C1)
Stylohyoid	Styloid process of temporal bone	Body of hyoid bone	Elevates and retracts tongue	Facial n.
Sternohyoid	Manubrium	Body of hyoid bone	Depresses hyoid bone	Spinal nn. (C1–C3)
Sternothyroid	Manubrium	Thyroid cartilage	Depresses thyroid cartilage	Spinal nn. (C1–C3)
Thyrohyoid	Thyroid cartilage	Great cornu of hyoid bone	Depresses hyoid bone; elevates larynx	Spinal nn. (C1–C3)
Omohyoid	Superior border of scapula	Body of hyoid bone	Depresses hyoid bone	Spinal nn. (C1–C3)

digastric: L. *di*, two; Gk. *gaster*, belly
mylohyoid: Gk. *mylos*, akin to; *hyoeides*, pertaining to hyoid bone
omohyoid: Gk. *omos*, shoulder

CHAPTER 9

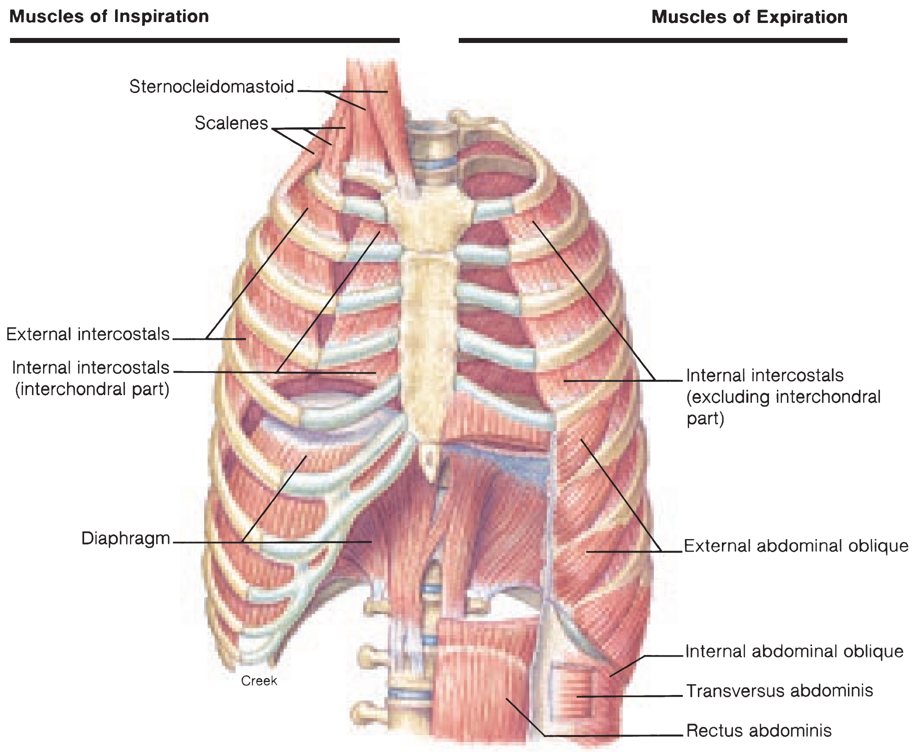


FIGURE 9.21 Muscles of respiration.

During normal, relaxed inspiration, the contracting muscles are the **diaphragm,** the **external intercostal** muscles, and the interchondral portion of the **internal intercostal** muscles (fig. 9.21). A downward contraction of the dome-shaped diaphragm causes a vertical increase in thoracic dimension. A simultaneous contraction of the external intercostals and the interchondral portion of the internal intercostals produces an increase in the lateral dimension of the thorax. In addition, the **sternocleidomastoid** and **scalene** (*ska'lēn*) muscles may assist in inspiration through elevation of the first and second ribs, respectively. The intercostal muscles are innervated by the intercostal nerves, and the diaphragm receives its stimuli through the phrenic nerves.

Expiration is primarily a passive process, occurring as the muscles of inspiration are relaxed and the rib cage recoils to its original position. During forced expiration, the interosseous portion of the **internal intercostals** contracts, causing the rib cage to be depressed. This portion of the internal intercostals lies under the external intercostals, and its fibers are directed downward and backward. The *abdominal muscles* may also contract during forced expiration, which increases pressure within the abdominal cavity and forces the diaphragm superiorly, squeezing additional air out of the lungs.

Muscles of the Abdominal Wall

The anterolateral abdominal wall is composed of four pairs of flat, sheetlike muscles: the *external abdominal oblique, internal abdominal oblique, transversus abdominis,* and *rectus abdominis* muscles (fig. 9.22). These muscles support and protect the organs of the abdominal cavity and aid in breathing. When they contract, the pressure in the abdominal cavity increases, which can aid in defecation and in stabilizing the spine during heavy lifting.

The **external abdominal oblique** is the strongest and most superficial of the three layered muscles of the lateral abdominal wall (figs. 9.22 and 9.23). Its fibers are directed inferiorly and medially. The **internal abdominal oblique** lies deep to the external abdominal oblique, and its fibers are directed at right angles to those of the external abdominal oblique. The **transversus abdominis** is the deepest of the abdominal muscles; its fibers run horizontally across the abdomen. The long, straplike **rectus abdominis** muscle is entirely enclosed in a fibrous sheath formed from the aponeuroses of the other three abdominal muscles. The *linea alba* is a band of connective tissue on the midline of the abdomen that separates the two rectus abdominis muscles. *Tendinous inscriptions* transect the rectus abdominis muscles at several points, causing the abdominal region of a well-muscled person with low body fat to appear segmented.

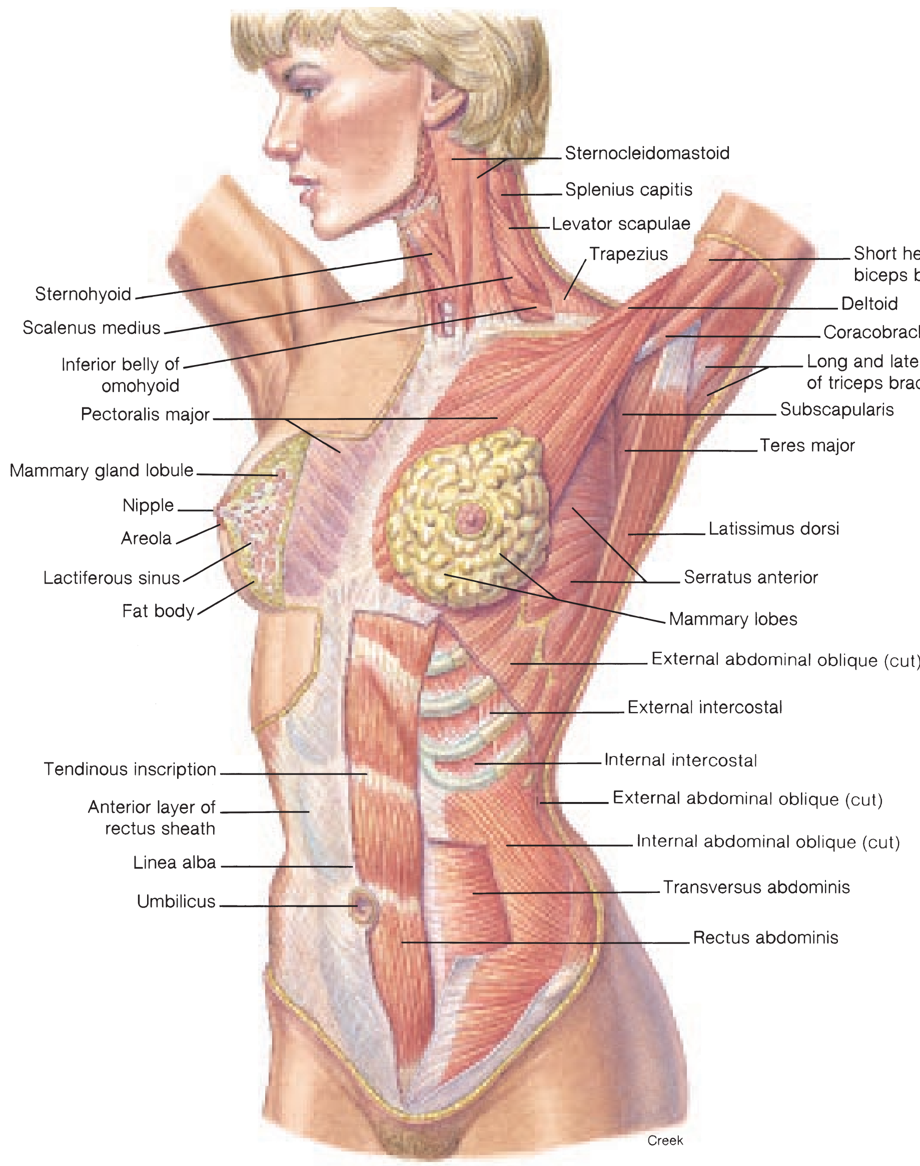


FIGURE 9.22 Muscles of the anterolateral neck, shoulder, and trunk regions. The mammary gland is an integumentary structure positioned over the pectoralis major muscle.

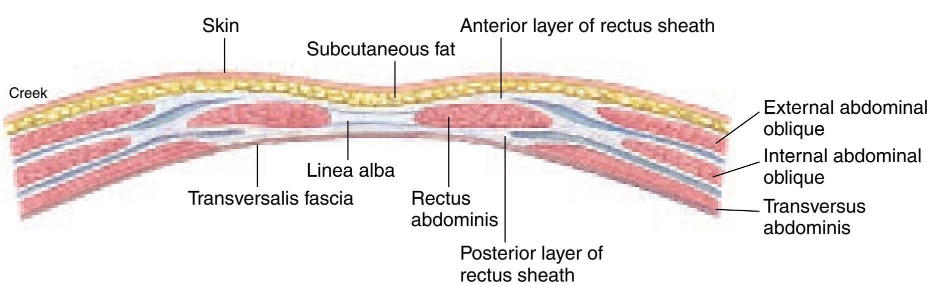


FIGURE 9.23 Muscles of the anterior abdominal wall shown in a transverse view.

TABLE 9.8 Muscles of the Abdominal Wall

Muscle	Origin	Insertion	Action
External abdominal oblique	Lower eight ribs	Iliac crest and linea alba	Compresses abdomen; rotation of lumbar region; draws thorax downward
Internal abdominal oblique	Iliac crest, inguinal ligament, and lumbodorsal fascia	Linea alba and costal cartilage of lower three or four ribs	Compresses abdomen; lateral rotation; draws thorax inferiorly
Transversus abdominis	Iliac crest, inguinal ligament, lumbar fascia, and costal cartilage of lower six ribs	Xiphoid process, linea alba, and pubis	Compresses abdomen
Rectus abdominis	Pubic crest and symphysis pubis	Costal cartilage of fifth to seventh ribs and xiphoid process of sternum	Flexes vertebral column

rectus abdominis: L. *rectus*, straplike; *abdomino*, belly

TABLE 9.9 Muscles of the Pelvic Outlet

Muscle	Origin	Insertion	Action
Levator ani	Spine of ischium and pubic bone	Coccyx	Supports pelvic viscera; aids in defecation
Coccygeus	Ischial spine	Sacrum and coccyx	Supports pelvic viscera; aids in defecation
Transversus perinei	Ischial tuberosity	Central tendon	Supports pelvic viscera
Bulbospongiosus	Central tendon	Males: base of penis; females: root of clitoris	Constricts urethral canal; constricts vagina
Ischiocavernosus	Ischial tuberosity	Males: pubic arch and crus of the penis; females: pubic arch and crus of the clitoris	Aids erection of penis and clitoris

CHAPTER 9

Refer to table 9.8 for a summary of the muscles of the abdominal wall.

Muscles of the Pelvic Outlet

Any sheet that separates cavities may be termed a diaphragm. The **pelvic outlet**—the entire muscular wall at the bottom of the pelvic cavity—contains two: the pelvic diaphragm and the urogenital diaphragm. The **urogenital diaphragm** lies immediately deep to the external genitalia; the **pelvic diaphragm** is situated closer to the internal viscera. Together, these sheets of muscle provide support for pelvic viscera and help regulate the passage of urine and feces.

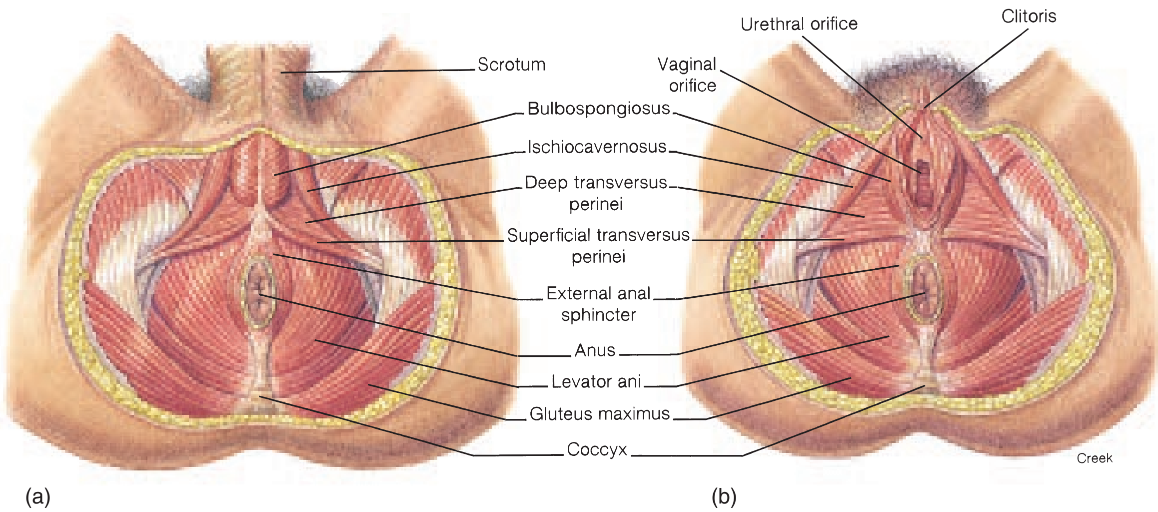
The pelvic diaphragm consists of the levator ani and the coccygeus muscles (table 9.9). The **levator ani** (*le-va'tor a'ni*) (fig. 9.24) is a thin sheet of muscle that helps to support the pelvic viscera and constrict the lower part of the rectum, pulling it forward and aiding defecation. The deeper, fan-shaped **coccygeus** *(kok-sij'e-us)* aids the levator ani in its functions.

An *episiotomy* is a surgical incision, for obstetrical purposes, of the vaginal orifice and a portion of the levator ani muscle of the perineum. Following a pudendal nerve block, an episiotomy may be done during childbirth to accommodate the head of an emerging fetus with minimal tearing of the tissues. After delivery, the cut is sutured.

The urogenital diaphragm consists of the deep, sheetlike **transversus perinei** (*per-ĭ-ne'i*) muscle, and the associated **external anal sphincter** muscle. The external anal sphincter is a funnel-shaped constrictor muscle that surrounds the anal canal.

Inferior to the pelvic diaphragm are the *perineal muscles*, which provide the skeletal muscular support to the genitalia. They include the *bulbocavernosus*, *ischiocavernosus*, and the *superficial transversus perinei* muscles (fig. 9.24). The muscles of the pelvic diaphragm and the urogenital diaphragm are similar in the male and female, but the perineal muscles exhibit marked sex-based differences.

In males, the **bulbospongiosus** *(bul''bo-spon''je-o-sus)* of one side unites with that of the opposite side to form a muscular constriction surrounding the base of the penis. When contracted, the two muscles constrict the urethral canal and assist in emptying the urethra. In females, these muscles are separated by the vaginal orifice, which they constrict as they contract. The **ischiocavernosus** (*is''ke-o-kă''ver-no-sus*) muscle inserts onto the pubic arch and crus of the penis in the male and the pubic arch and crus of the clitoris of the female. This muscle assists the erection of the penis and clitoris during sexual arousal.



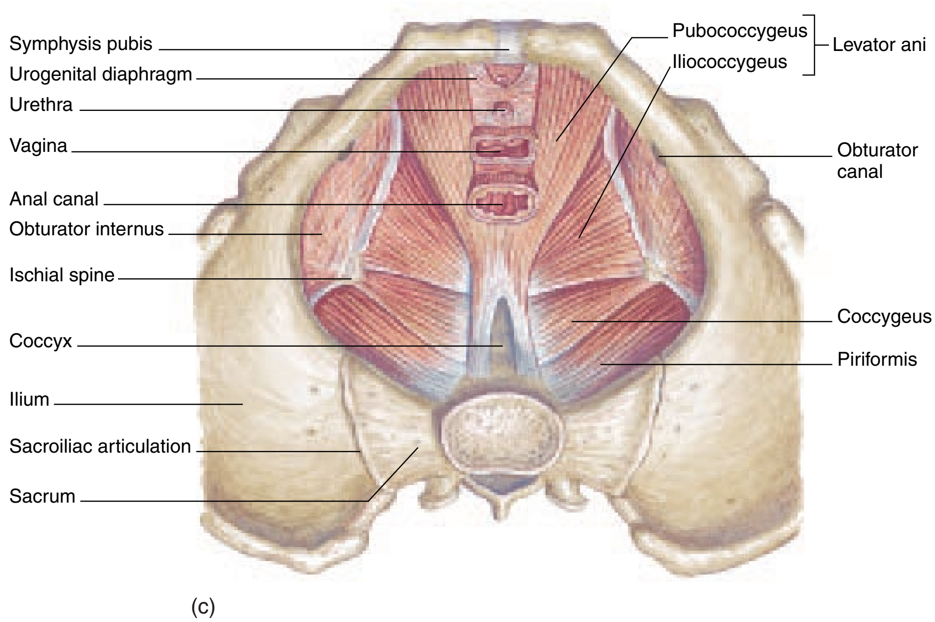


FIGURE 9.24 Muscles of the pelvic outlet: (*a*) male and (*b*) female. (*c*) A superior view of the internal muscles of the female pelvic outlet.

Muscles of the Vertebral Column

The strong, complex muscles of the vertebral column are adapted to provide support and movement in resistance to the effect of gravity.

The vertebral column can be flexed, extended, hyperextended, rotated, and laterally flexed (right or left). The muscle that flexes the vertebral column, the rectus abdominis, has already been described as a long, straplike muscle of the anterior abdominal wall. The extensor muscles located on the posterior side of the vertebral column have to be stronger than the flexors because extension (such as lifting an object) is in opposition to gravity. The extensor muscles consist of a superficial group and a deep group. Only some of the muscles of the vertebral column will be described here.

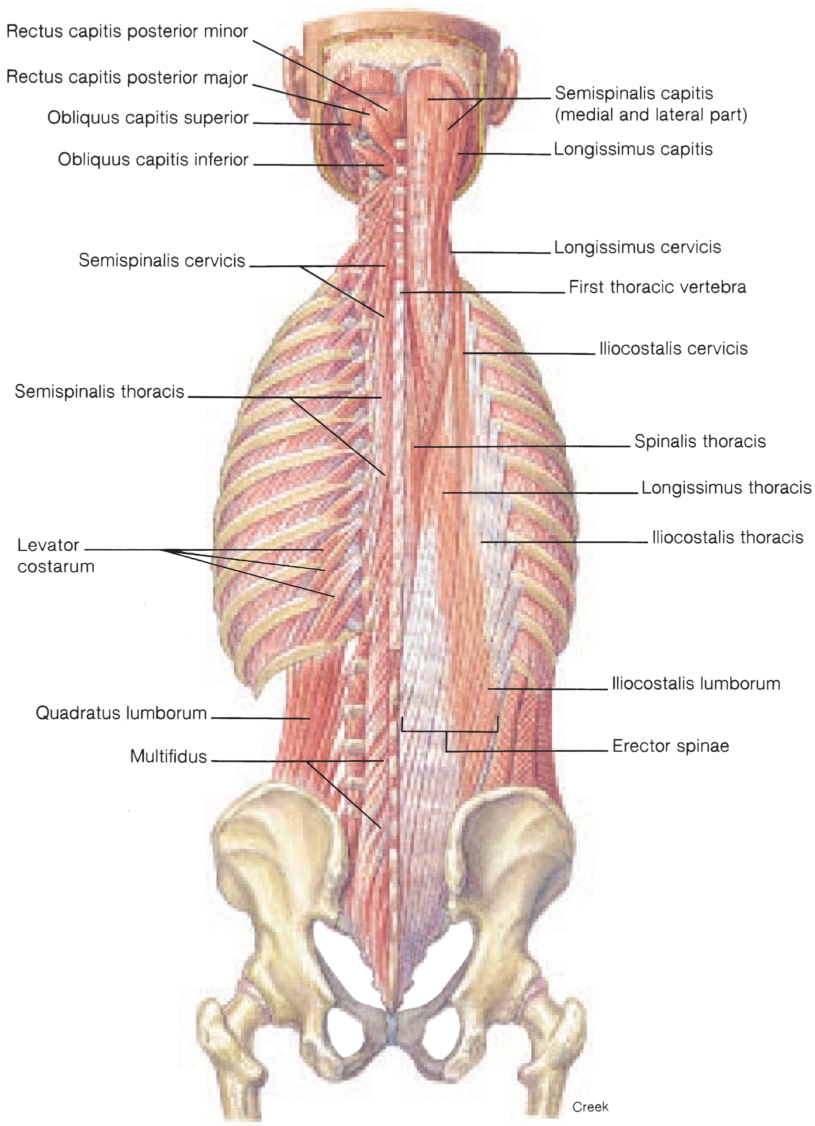


FIGURE 9.25 Muscles of the vertebral column. The superficial neck muscles and erector spinae group of muscles are illustrated on the right, and the deep neck and back muscles are illustrated on the left.

The **erector spinae** *(spi'ne)* muscles constitute a massive superficial muscle group that extends from the sacrum to the skull. It actually consists of three groups of muscles: the **iliocostalis, longissimus,** and **spinalis** muscles (fig. 9.25 and table 9.10). Each of these groups, in turn, consists of overlapping slips of muscle. The iliocostalis is the most lateral group, the longissimus is intermediate in position, and the spinalis, in the medial position, comes in contact with the spinous processes of the vertebrae.

The erector spinae muscles are frequently strained through improper lifting. A heavy object should not be lifted with the vertebral column flexed; instead, the hip and knee joints should be flexed so that the pelvic and leg muscles can aid in the task.

Pregnancy may also put a strain on the erector spinae muscles. Pregnant women will try to counterbalance the effect of a protruding abdomen by hyperextending the vertebral column. This results in an exaggerated lumbar curvature, strained muscles, and a peculiar gait.

TABLE 9.10 Muscles of the Vertebral Column

Muscle	Origin	Insertion	Action	Innervation
Quadratus lumborum	Iliac crest and lower three lumbar vertebrae	Twelfth rib and upper four lumbar vertebrae	Extends lumbar region; laterally flexes vertebral column	Intercostal nerve T12 and lumbar nerves L2–L4
Erector spinae	Consists of three groups of muscles: iliocostalis, longissimus, and spinalis. The iliocostalis and longissimus are further subdivided into three groups each on the basis of location along the vertebral column.			
Iliocostalis lumborum	Crest of ilium	Lower six ribs	Extends lumbar region	Posterior rami of lumbar nerves
Iliocostalis thoracis	Lower six ribs	Upper six ribs	Extends thoracic region	Posterior rami thoracic nerves
Iliocostalis cervicis	Angles of third to sixth rib	Transverse processes of fourth to sixth cervical vertebrae	Extends cervical region	Posterior rami of cervical nerves
Longissimus thoracis	Transverse processes of lumbar vertebrae	Transverse processes of all the thoracic vertebrae and lower nine ribs	Extends thoracic region	Posterior rami of spinal nerves
Longissimus cervicis	Transverse processes of upper four or five thoracic vertebrae	Transverse processes of second to sixth cervical vertebrae	Extends and laterally flexes cervical region	Posterior rami of spinal nerves
Longissimus capitis	Transverse processes of upper five thoracic vertebrae and articular processes of lower three cervical vertebrae	Posterior margin of cranium and mastoid process of temporal bone	Extends head; acting separately, turn face toward that side	Posterior rami of middle and lower cervical nerves
Spinalis thoracis	Spinous processes of upper lumbar and lower thoracic vertebrae	Spinous processes of upper thoracic vertebrae	Extends vertebral column	Posterior rami of spinal nerves
Semispinalis thoracis	Transverse processes of T6–T10	Spinous processes of C6–T4	Extends vertebral column	Posterior rami of spinal nerves
Semispinalis cervicis	Transverse processes of T1–T6	Spinous processes of C2–C5	Extends vertebral column	Posterior rami of spinal nerves
Semispinalis capitis	Transverse processes of C7–T7	Nuchal line of occipital bone	Extends head	Posterior rami of spinal nerves

The deep **quadratus lumborum** *(kwod-ra'tus lum-bor'um)* muscle originates on the iliac crest and the lower three lumbar vertebrae. It inserts on the transverse processes of the first four lumbar vertebrae and the inferior margin of the twelfth rib. When the right and left quadratus lumborum contract together, the vertebral column in the lumbar region extends. Separate contraction causes lateral flexion of the spine.

Knowledge Check

14. Identify the facial muscles responsible for (a) wrinkling the forehead, (b) pursing the lips, (c) protruding the lower lip, (d) smiling, (e) frowning, (f) winking, and (g) elevating the upper lip to show the teeth.
15. Describe the actions of the extrinsic muscles that move the tongue.
16. Which muscles of the neck either originate from or insert on the hyoid bone?
17. Describe the actions of the muscles of inspiration. Which muscles participate in forced expiration?
18. Which muscles of the pelvic outlet support the floor of the pelvic cavity? Which are associated with the genitalia?
19. List the subgroups of the erector spinae group of muscles and describe their locations?

MUSCLES OF THE APPENDICULAR SKELETON

The muscles of the appendicular skeleton include those of the pectoral girdle, arm, forearm, wrist, hand, and fingers, and those of the pelvic girdle, thigh, leg, ankle, foot, and toes.

Objective 11 Locate the major muscles of the appendicular skeleton. Identify synergistic and antagonistic muscles and describe the action of each one.

Muscles Act on the Pectoral Girdle

The shoulder is attached to the axial skeleton only at the sternoclavicular joint; therefore, strong, straplike muscles are

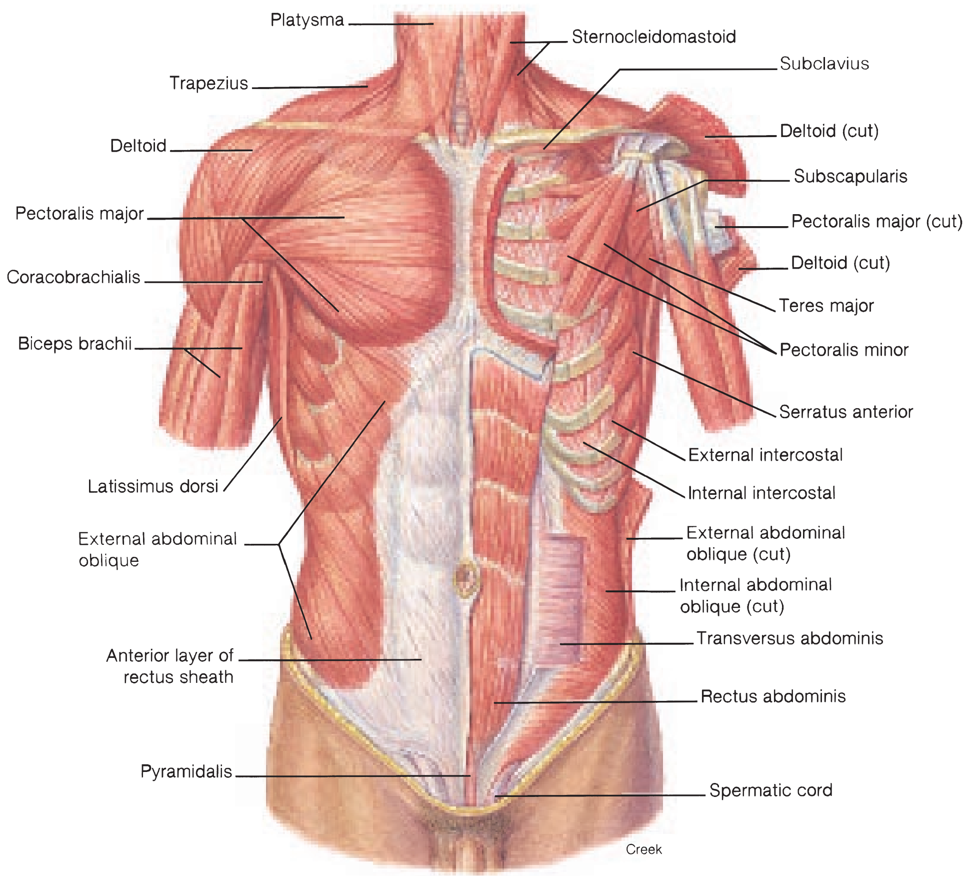


FIGURE 9.26 Muscles of the anterior trunk and shoulder regions. The superficial muscles are illustrated on the right, and the deep muscles are illustrated on the left.

necessary in this region. Furthermore, muscles that move the brachium originate on the scapula, and during brachial movement the scapula has to be held stationary. The muscles that act on the pectoral girdle originate on the axial skeleton and can be divided into anterior and posterior groups.

The anterior group of muscles that act on the pectoral girdle includes the **serratus** (*ser-a'tus*)**anterior, pectoralis** (*pek''to-ra'lis*) **minor,** and **subclavius** (*sub-kla've-us*) muscles (fig. 9.26). The posterior group includes the **trapezius, levator scapulae** (*skap-yŭ'le*) and **rhomboideus** (*rom-boid'e-us*) muscles (fig. 9.27). These muscles are positioned so that one of them does not cause an action on its own. Rather, several muscles contract synergistically to result in any movement of the girdle.

Treatment of advanced stages of *breast cancer* requires the surgical removal of both pectoralis major and pectoralis minor muscles in a procedure called a *radical mastectomy*. Postoperative physical therapy is primarily geared toward strengthening the synergistic muscles of this area. As the muscles that act on the brachium are learned, determine which are synergists with the pectoralis major.

Muscles That Move the Humerus at the Shoulder Joint

Of the nine muscles that span the shoulder joint to insert on the humerus, only two—the *pectoralis major* and *latissimus dorsi*—do not originate on the scapula (table 9.11). These two

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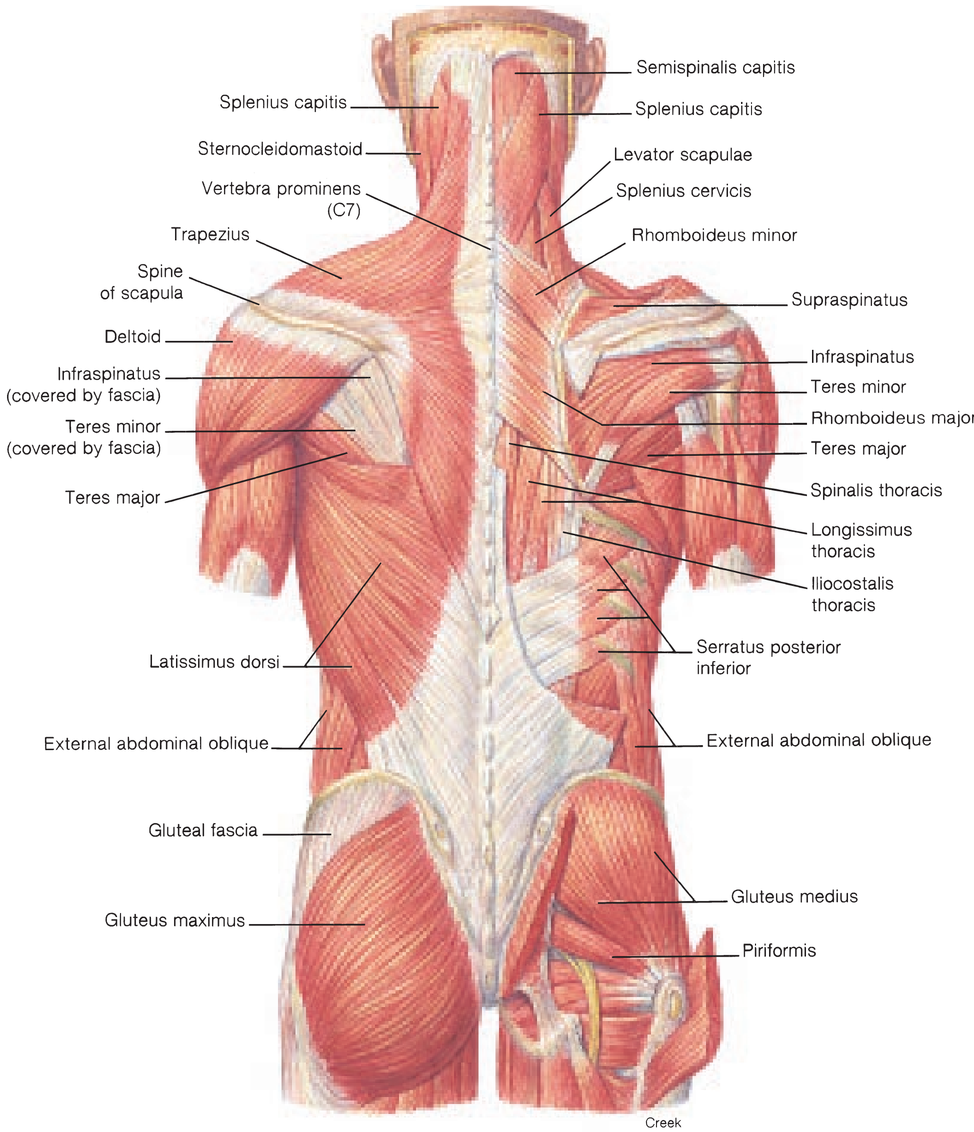

FIGURE 9.27 Muscles of the posterior neck, shoulder, trunk, and gluteal regions. The superficial muscles are illustrated on the left, and the deep muscles are illustrated on the right.

are designated as axial muscles, whereas the remaining seven are scapular muscles. The muscles of this region are shown in figures 9.26 and 9.27, and the attachments of all the muscles that either originate or insert on the scapula are shown in figure 9.28.

In terms of their development, the pectoralis major and the latissimus dorsi muscles are not axial muscles at all. They develop in the forelimb and extend to the trunk secondarily. They are considered axial muscles only because their origins of attachment are on the axial skeleton.

Axial Muscles

The **pectoralis major** is a large, fan-shaped chest muscle (see fig. 9.26) that binds the humerus to the pectoral girdle. It is the principal flexor muscle of the shoulder joint. The large, flat, triangular **latissimus dorsi** (*la-tis'ĭ-mus dor'si*) muscle covers the inferior half of the thoracic region of the back (see fig. 9.27) and is the antagonist to the pectoralis major muscle. The latissimus dorsi is frequently called the "swimmer's muscle" because it powerfully extends the shoulder joint, drawing the arm downward and backward while

TABLE 9.11 Muscles That Act on the Pectoral Girdle and That Move the Shoulder Joint

Muscle	Origin	Insertion	Action	Innervation
Serratus anterior	Upper eight or nine ribs	Anterior vertebral border of scapula	Pulls scapula forward and downward	Long thoracic n.
Pectoralis minor	Sternal ends of third, fourth, and fifth ribs	Coracoid process of scapula	Pulls scapula forward and downward	Medial and lateral pectoral nn.
Subclavius	First rib	Subclavian groove of clavicle	Draws clavicle downward	Spinal nerves C5, C6
Trapezius	Occipital bone and spines of seventh cervical and all thoracic vertebrae	Clavicle, spine of scapula, and acromion	Elevates, depresses, and adducts scapula; hyperextends neck; braces shoulder	Accessory nerve
Levator scapulae	First to fourth cervical vertebrae	Medial border of scapula	Elevates scapula	Dorsal scapular n.
Rhomboideus major	Spines of second to fifth thoracic vertebrae	Medial border of scapula	Elevates and adducts scapula	Dorsal scapular n.
Rhomboideus minor	Seventh cervical and first thoracic vertebrae	Medial border of scapula	Elevates and adducts scapula	Dorsal scapular n.
Pectoralis major	Clavicle, sternum, and costal cartilages of second to sixth rib; rectus sheath	Crest of greater tubercle of humerus	Flexes, adducts, and rotates shoulder joint medially	Medial and lateral pectoral nn.
Latissimus dorsi	Spines of sacral, lumbar, and lower thoracic vertebrae; iliac crest and lower four ribs	Intertubercular groove of humerus	Extends, adducts, and rotates shoulder joint medially	Thoracodorsal n.
Deltoid	Clavicle, acromion, and spine of scapula	Deltoid tuberosity of humerus	Abducts, extends, or flexes shoulder joint	Axillary n.
Supraspinatus	Supraspinous fossa	Greater tubercle of humerus	Abducts and laterally rotates shoulder joint	Suprascapular n.
Infraspinatus	Infraspinous fossa	Greater tubercle of humerus	Rotates shoulder joint laterally	Suprascapular n.
Teres major	Inferior angle and lateral border of scapula	Crest of lesser tubercle of humerus	Extends shoulder joint, or adducts and rotates shoulder joint medially	Lower subscapular n.
Teres minor	Axillary border of scapula	Greater tubercle and groove of humerus	Rotates shoulder joint laterally	Axillary n.
Subscapularis	Subscapular fossa	Lesser tubercle of humerus	Rotates shoulder joint medially	Subscapular nn.
Coracobrachialis	Coracoid process of scapula	Body of humerus	Flexes and adducts shoulder joint	Musculocutaneous n.

serratus: L. *serratus*, saw-shaped
trapezius: Gk. *trapezoeides*, trapezoid-shaped
rhomboideus: Gk. *rhomboides*, rhomboid-shaped
pectoralis: L. *pectus*, chest
latissimus: L. *latissimus*, widest
deltoid: Gk. *delta*, triangular
teres: L. *teres*, rounded

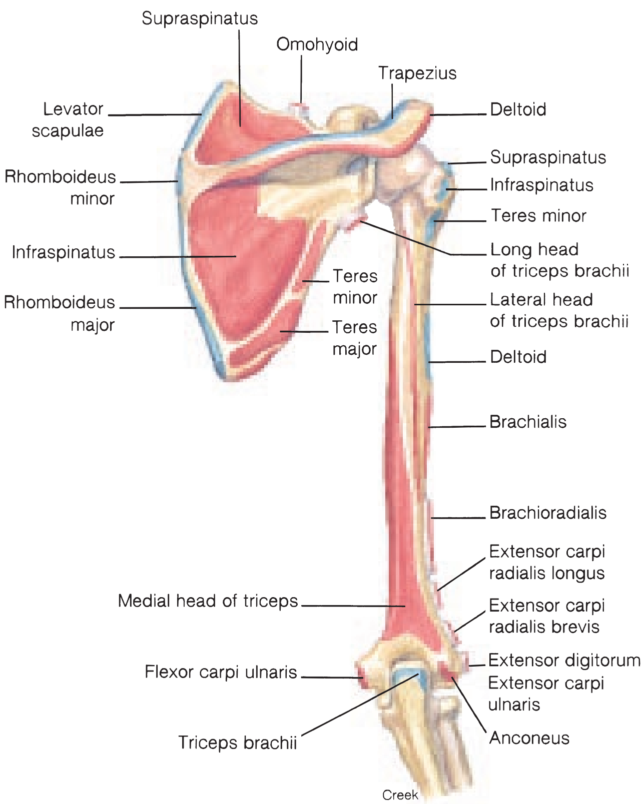

FIGURE 9.28 A posterior view of the scapula and humerus showing the areas of attachment of the associated muscles. (Points of origin are color coded red, and points of insertion are color coded blue.)

it rotates medially. Extension of the shoulder joint is in reference to anatomical position and is therefore a backward, retracting (increasing the shoulder joint angle) movement of the arm.

A latissimus dorsi muscle, conditioned with pulsated electrical impulses, will in time come to resemble cardiac muscle tissue in that it will be indefatigable, using oxygen at a steady rate. Following conditioning, the muscle may be used in an autotransplant to repair a surgically removed portion of a patient's diseased heart. The procedure involves detaching the latissimus dorsi muscle from its vertebral origin, leaving the blood supply and innervation intact, and slipping it into the pericardial cavity where it is wrapped around the heart like a towel. A pacemaker is required to provide the continuous rhythmic contractions.

Scapular Muscles

The nonaxial scapular muscles include the *deltoid*, *supraspinatus*, *infraspinatus*, *teres major*, *teres minor*, *subscapularis*, and *coracobrachialis* muscles.

The **deltoid** (*deltoideus*) is a thick, powerful muscle that caps the shoulder joint (figs. 9.29 and 9.30). Although it has several functions (table 9.11), its principal action is abduction of the shoulder joint. Functioning together, the pectoralis major and the latissimus dorsi muscles are antagonists to the deltoid muscle in that they cause adduction of the shoulder joint. The deltoid muscle is a common site for intramuscular injections.

The remaining six scapular muscles also help stabilize the shoulder and have specific actions at the shoulder joint (table 9.11). The **supraspinatus** (*soo''pra-spi-na'tus*) muscle laterally rotates the arm and is synergistic with the deltoid muscle in abducting the shoulder joint. The **infraspinatus** muscle rotates the arm laterally. The action of the **teres** (*tĕ'rēz*) **major** muscle is similar to that of the latissimus dorsi, adducting and medially rotating the shoulder joint. The **teres minor** muscle works with the infraspinatus muscle in laterally rotating the arm at shoulder joint. The **subscapularis** muscle is a strong stabilizer of the shoulder and also aids in medially rotating the arm at the shoulder joint. The **coracobrachialis** (*kor''ă-ko-bra''ke-al'is*) muscle is a synergist to the pectoralis major in flexing and adducting the shoulder joint.

Four of the nine muscles that cross the shoulder joint, the supraspinatus, infraspinatus, teres minor, and subscapularis, are commonly called the *musculotendinous cuff,* or *rotator cuff.* Their distal tendons blend with and reinforce the fibrous capsule of the shoulder joint en route to their points of insertion on the humerus. This structural arrangement plays a major role in stabilizing the shoulder joint. Musculotendinous cuff injuries are common among baseball players. When throwing a baseball, an abduction of the shoulder is followed by a rapid and forceful rotation and flexion of the shoulder joint, which may strain the musculotendinous cuff.

Muscles That Move the Forearm at the Elbow Joint

The powerful muscles of the brachium are responsible for flexion and extension of the elbow joint. These muscles are the *biceps brachii*, *brachialis*, *brachioradialis*, and *triceps brachii* (figs. 9.29 and 9.30). In addition, a short triangular muscle, the *anconeus*, is positioned over the distal end of the triceps brachii muscle, near the elbow. A transverse section through the brachium in figure 9.31 provides a different perspective of the brachial region.

The powerful **biceps brachii** (*bi'ceps bra'ke-i*) muscle, positioned on the anterior surface of the humerus, is the most familiar muscle of the arm, yet it has no attachments on the humerus. This muscle has a dual origin: a medial tendinous head, the **short head,** arises from the coracoid process of the scapula, and the **long head** originates on the superior tuberosity of the glenoid cavity, passes through the shoulder joint, and descends in the intertubercular groove on the humerus (see fig. 8.8). Both heads of the biceps brachii muscle insert on the radial tuberosity. The **brachialis** (*bra''ke-al'is*) muscle is located on the distal anterior half of the humerus, deep to the biceps brachii. It is synergistic to the biceps brachii in flexing the elbow joint.

The **brachioradialis** (*bra''ke-o-ra''de-ă'lis*) (fig. 9.30) is the prominent muscle positioned along the lateral (radial) surface of the forearm. It, too, flexes the elbow joint.

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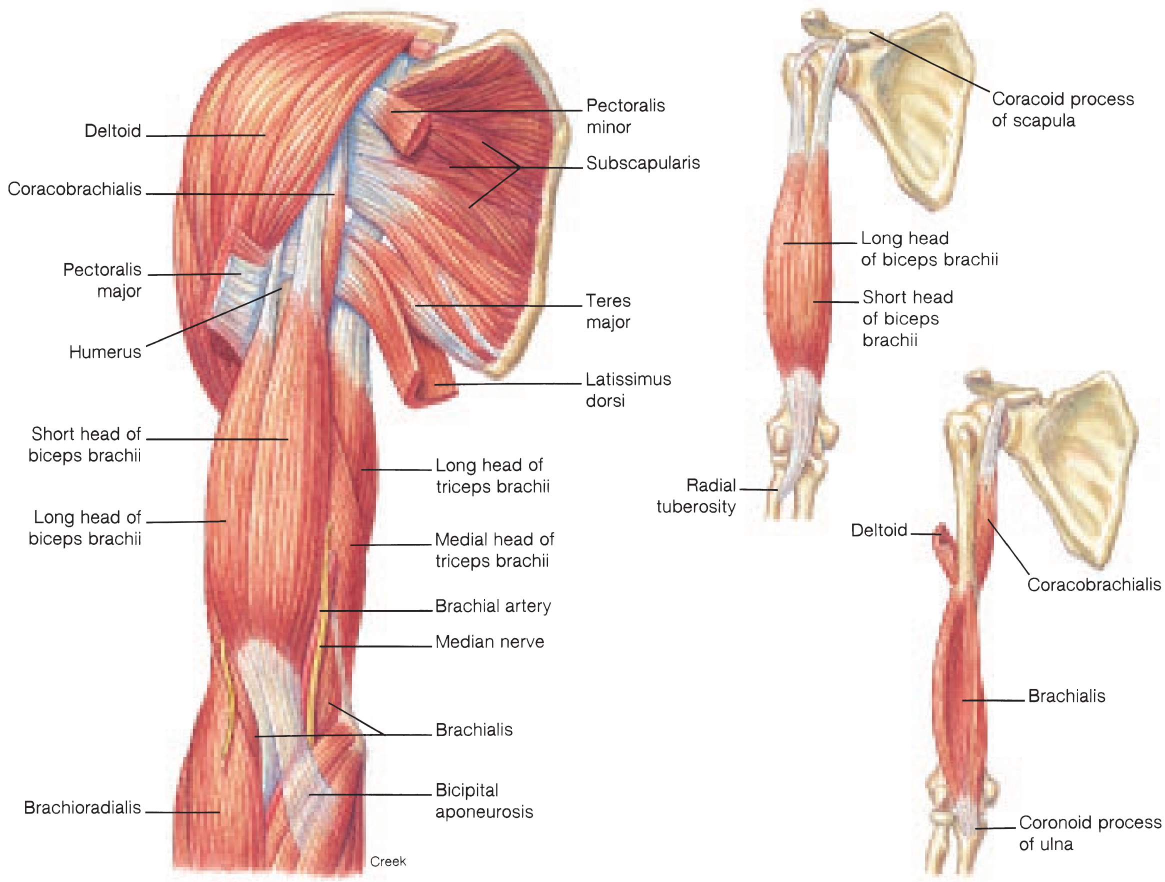


FIGURE 9.29 Muscles of the right anterior shoulder and brachium.

The **triceps brachii** muscle, located on the posterior surface of the brachium, extends the forearm at the elbow joint, in opposition to the action of the biceps brachii. Thus, these two muscles are antagonists. The triceps brachii has three heads, or origins. Two of the three, the **lateral head** and **medial head,** arise from the humerus, whereas the **long head** arises from the infraglenoid tuberosity of the scapula. A common tendinous insertion attaches the triceps brachii muscle to the olecranon of the ulna. The small **anconeus** (*an-ko'ne-us*) muscle is a synergist of the triceps brachii in elbow extension (fig. 9.30.)

Refer to table 9.12 for a summary of the muscles that act on the forearm at the elbow joint.

Muscles of the Forearm That Move the Joints of the Wrist, Hand, and Fingers

The muscles that cause most of the movements in the joints of the wrist, hand, and fingers are positioned along the forearm (figs. 9.32 and 9.33). Several of these muscles act on two joints—the elbow and wrist. Others act on the joints of the wrist, hand, and digits. Still others produce rotational movement at the radioulnar joint. The four primary movements typically effected at the hand and digits are: supination, pronation, flexion, and extension. Other movements of the hand include adduction and abduction.

Supination and Pronation of the Hand

The **supinator** (*soo''pĭ-na'tor*) muscle wraps around the upper posterior portion of the radius (fig. 9.33), where it works synergistically with the biceps brachii muscle to supinate the hand. Two muscles are responsible for pronating the hand—the pronator teres and pronator quadratus. The **pronator teres** muscle is located on the upper medial side of the forearm, whereas the deep, anteriorly positioned **pronator quadratus** muscle extends between the ulna and radius on the distal fourth of the forearm. These two muscles work synergistically to rotate the palm of the hand posteriorly and position the thumb medially.

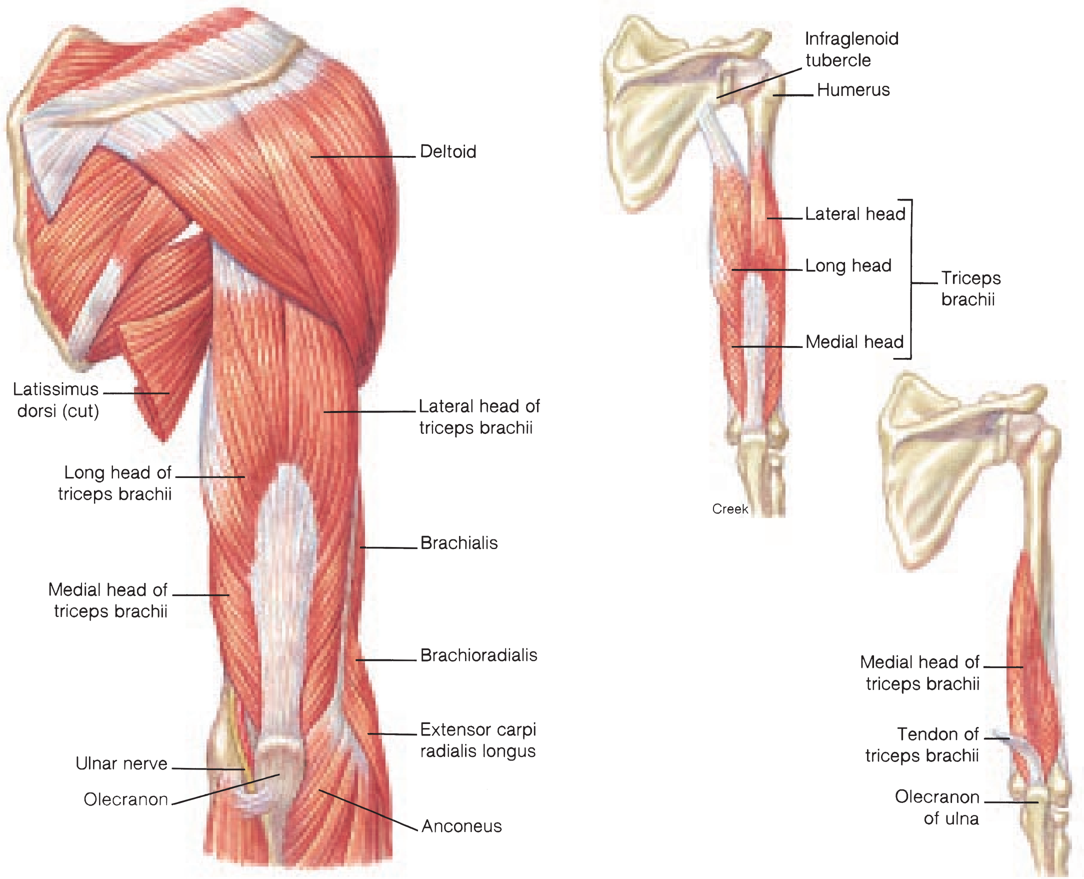


FIGURE 9.30 Muscles of the right posterior shoulder and brachium.

Flexion of the Wrist, Hand, and Fingers

Six of the muscles that flex the joints of the wrist, hand, and fingers will be described from lateral to medial and from superficial to deep (figs. 9.32 and 9.33). Although four of the six arise from the medial epicondyle of the humerus (see table 9.13), their actions on the elbow joint are minimal. The brachioradialis, already described, is an obvious reference muscle for locating the muscles of the forearm that flex the joints of the hand.

The **flexor carpi radialis** muscle extends diagonally across the anterior surface of the forearm, and its distal cordlike tendon crosses the wrist under the *flexor retinaculum*. This muscle is an important landmark for locating the radial artery, where the pulse is usually taken.

The narrow **palmaris longus** muscle is superficial in position on the anterior surface of the forearm. It has a long, slender tendon that attaches to the *palmar aponeurosis*, where it assists in flexing the wrist joints.

The palmaris longus is the most variable muscle in the body. It is totally absent in approximately 8% of all people, and in 4% it is absent in one or the other forearm. Furthermore, it is absent more often in females than males, and on the left side in both sexes. Because of the superficial position of the palmaris longus muscle, you can readily determine whether it is present in your own forearm by flexing the wrist while touching the thumb and little finger, and then examining for its tendon just proximal to the wrist (see figs. 10.37 and 10.41*b*).

The **flexor carpi ulnaris** muscle is positioned on the medial anterior side of the forearm, where it assists in flexing the wrist joints and adducting the hand.

The broad **superficial digital flexor** (*flexor digitorum superficialis*) muscle lies directly beneath the three flexor muscles just described (figs. 9.32 and 9.33). It has an extensive origin, involving the humerus, ulna, and radius (see table 9.13). The tendon at the distal end of this muscle is united across the wrist joint but then splits to attach to the middle phalanx of digits II through V.

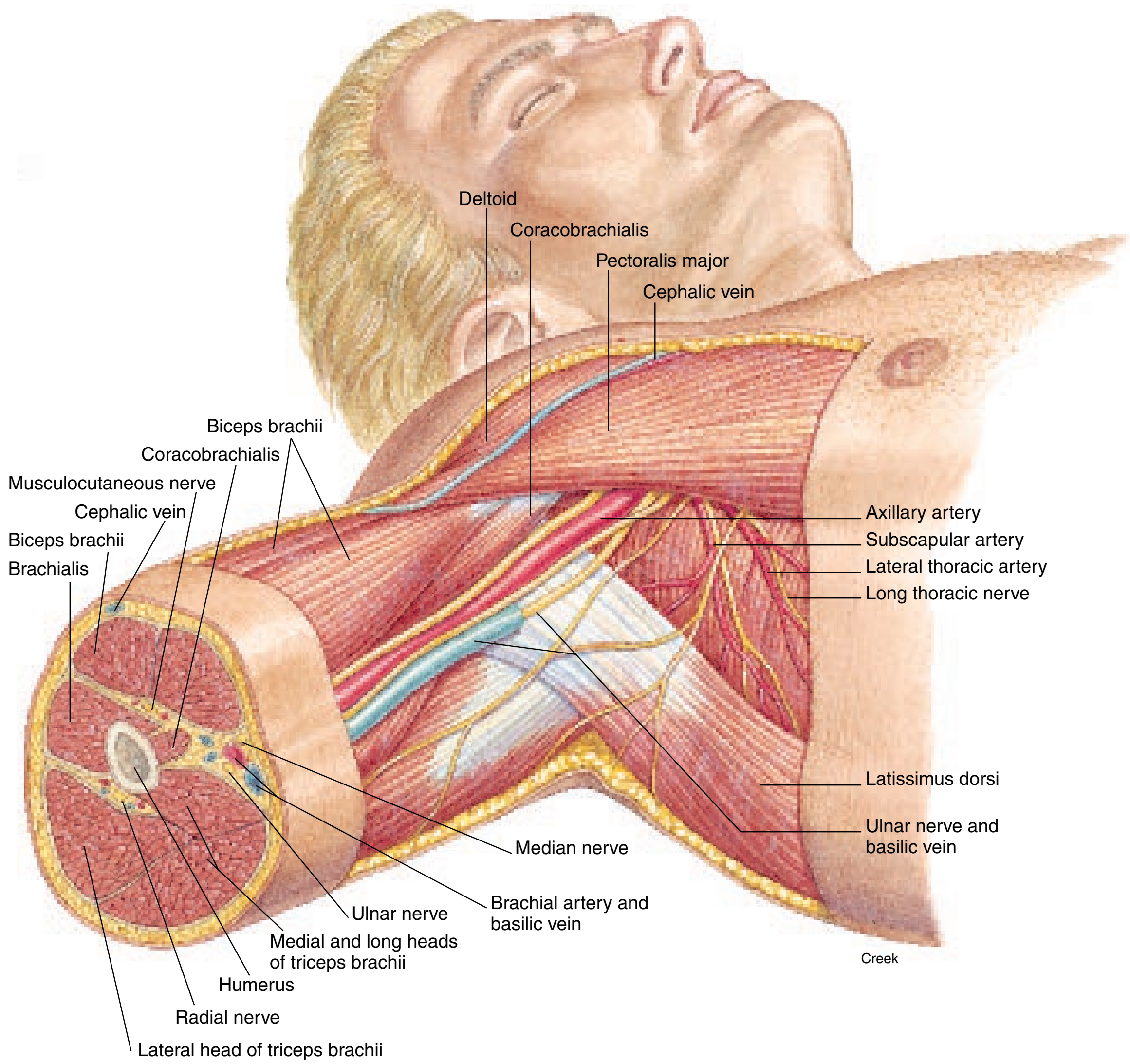


FIGURE 9.31 The axillary region and a transverse section through the brachium.

TABLE 9.12 Muscles That Act on the Forearm at the Elbow Joint

Muscle	Origin	Insertion	Action	Innervation
Biceps brachii	Coracoid process and tuberosity above glenoid cavity of scapula	Radial tuberosity	Flexes elbow joint; supinates forearm and hand at radioulnar joint	Musculocutaneous n.
Brachialis	Anterior body of humerus	Coronoid process of ulna	Flexes elbow joint	Musculocutaneous n.
Brachioradialis	Lateral supracondylar ridge of humerus	Proximal to styloid process of radius	Flexes elbow joint	Radial n.
Triceps brachii	Tuberosity below glenoid cavity; lateral and medial surfaces of humerus	Olecranon of ulna	Extends elbow joint	Radial n.
Anconeus	Lateral epicondyle of humerus	Olecranon of ulna	Extends elbow joint	Radial n.

biceps: L. *biceps*, two heads
triceps: L. *triceps*, three heads
anconeus: Gk. *ancon*, elbow

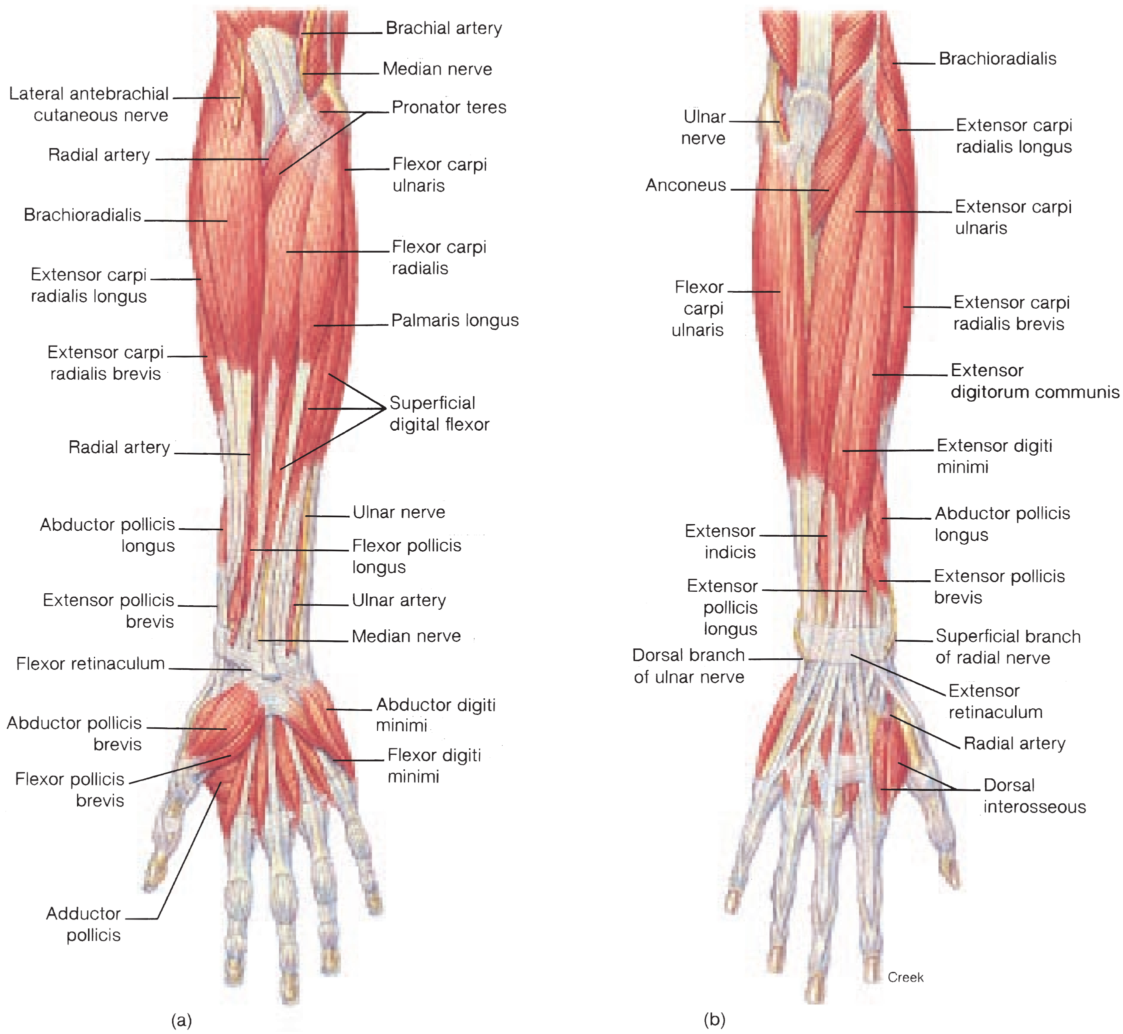


FIGURE 9.32 Superficial muscles of the right forearm. (*a*) An anterior view and (*b*) a posterior view.

The **deep digital flexor** (*flexor digitorum profundus*) muscle lies deep to the superficial digital flexor. It inserts on the distal phalanges two (II) through five (V). These two muscles flex the joints of the wrist, hand, and the second, third, fourth, and fifth digits.

The **flexor pollicis longus** muscle is a deep lateral muscle of the forearm. It flexes the joints of the thumb, assisting the grasping mechanism of the hand.

The tendons of the muscles that flex the joints of the hand can be seen on the wrist as a fist is made. These tendons are securely positioned by the flexor retinaculum (fig. 9.32*a*), which crosses the wrist area transversely.

Extension of the Hand

The muscles that extend the joints of the hand are located on the posterior side of the forearm. Most of the primary extensor muscles can be seen superficially in figure 9.32*b* and will be discussed from lateral to medial.

The long, tapered **extensor carpi radialis longus** muscle is medial to the brachioradialis muscle. It extends the carpal joint and abducts the hand at the wrist. Immediately medial to the extensor carpi radialis longus is the **extensor carpi radialis brevis,** which performs approximately the same functions. The origin and insertion of the latter muscle are different, however (see table 9.13).

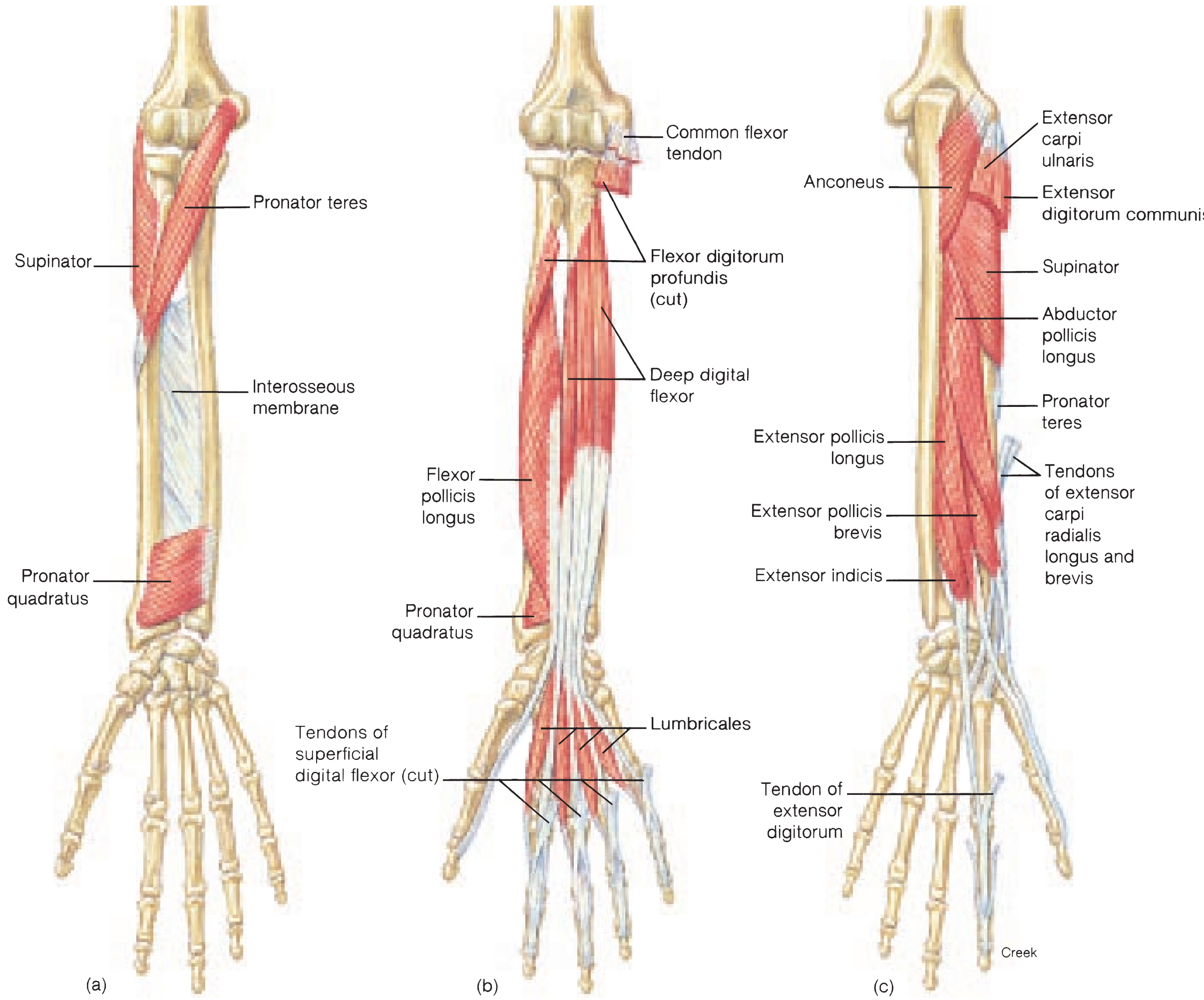


FIGURE 9.33 Deep muscles of the right forearm. (*a*) rotators, (*b*) flexors, and (*c*) extensors.

The **extensor digitorum communis** muscle is positioned in the center of the forearm, along the posterior surface. It originates on the lateral epicondyle of the humerus. Its tendon of insertion divides at the wrist, beneath the extensor retinaculum, into four tendons that attach to the distal tip of the medial phalanges of digits II through V.

The **extensor digiti minimi** is a long, narrow muscle located on the ulnar side of the extensor digitorum communis muscle. Its tendinous insertion fuses with the tendon of the extensor digitorum communis going to the fifth digit.

The **extensor carpi ulnaris** is the most medial muscle on the posterior surface of the forearm. It inserts on the base of the fifth metacarpal bone, where it functions to extend and adduct the joints of the hand.

The **extensor pollicis longus** muscle arises from the midulnar region, crosses the lower two-thirds of the forearm, and inserts on the base of the distal phalanx of the thumb (fig. 9.33). It extends the joints of the thumb and abducts the hand. The **extensor pollicis brevis** muscle arises from the lower midportion of the radius and inserts on the base of the proximal phalanx of the thumb (fig. 9.33). The action of this muscle is similar to that of the extensor pollicis longus.

As its name implies, the **abductor pollicis longus** muscle abducts the joints of the thumb and hand. It originates on the interosseous ligament, between the ulna and radius, and inserts on the base of the first metacarpal bone.

The muscles that act on the wrist, hand, and digits are summarized in table 9.13.

TABLE 9.13 Muscles of the Forearm That Move the Joints of the Wrist, Hand, and Digits

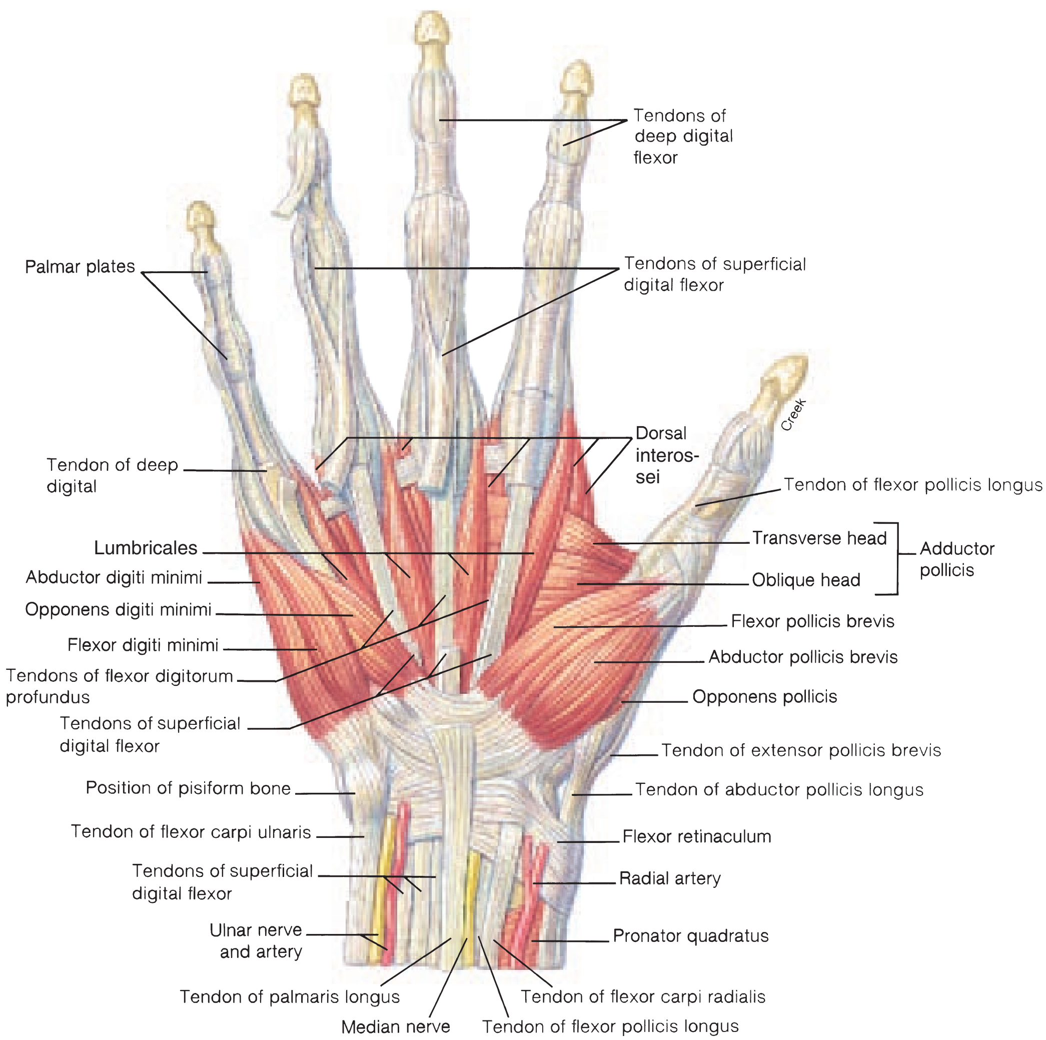
Muscle	Origin	Insertion	Action	Innervation
Supinator	Lateral epicondyle of humerus and crest of ulna	Lateral surface of radius	Supinates forearm and hand	Radial n.
Pronator teres	Medial epicondyle of humerus	Lateral surface of radius	Pronates forearm and hand	Median n.
Pronator quadratus	Distal fourth of ulna	Distal fourth of radius	Pronates forearm and hand	Median n.
Flexor carpi radialis	Medial epicondyle of humerus	Base of second and third metacarpal bones	Flexes and abducts hand at wrist	Median n.
Palmaris longus	Medial epicondyle of humerus	Palmar aponeurosis	Flexes wrist	Median n.
Flexor carpi ulnaris	Medial epicondyle and olecranon	Carpal and metacarpal bones	Flexes and adducts wrist	Ulnar n.
Superficial digital flexor	Medial epicondyle, coronoid process, and anterior border of radius	Middle phalanges of digits II–V	Flexes wrist and digits at metacarpophalangeal and interphalangeal joints	Median n.
Deep digital flexor	Proximal two-thirds of ulna and interosseous ligament	Distal phalanges of digits III–V	Flexes wrist and digits at metacarpophalangeal and interphalangeal joints	Median and ulnar nn.
Flexor pollicis longus	Body of radius, interosseous ligament, and coronoid process of ulna	Distal phalanx of thumb	Flexes joints of thumb	Median n.
Extensor carpi radialis longus	Lateral supracondylar ridge of humerus	Second metacarpal bone	Extends and abducts wrist	Radial n.
Extensor carpi radialis brevis	Lateral epicondyle of humerus	Third metacarpal bone	Extends and abducts wrist	Radial n.
Extensor digitorum communis	Lateral epicondyle of humerus	Posterior surfaces of digits II–V	Extends wrist and phalanges at joints of carpophalangeal and interphalangeal joints	Radial n.
Extensor digiti minimi	Lateral epicondyle of humerus	Extensor aponeurosis of fifth digit	Extends joints of fifth digit and wrist	Radial n.
Extensor carpi ulnaris	Lateral epicondyle of humerus and olecranon	Base of fifth metacarpal bone	Extends and adducts wrist	Radial n.
Extensor pollicis longus	Middle of body of ulna, lateral side	Base of distal phalanx of thumb	Extends joints of thumb; abducts joints of hand	Radial n.
Extensor pollicis brevis	Distal body of radius and interosseous ligament	Base of first phalanx of thumb	Extends joints of thumb; abducts joints of hand	Radial n.
Abductor pollicis longus	Distal radius and ulna and interosseous ligament	Base of first metacarpal bone	Abducts joints of thumb and joints of hand	Radial n.

supinator: L. *supin*, bend back
pronator: L. *pron*, bend forward
palmaris: L. *palma*, flat of hand
pollicis: L. *pollex*, thumb

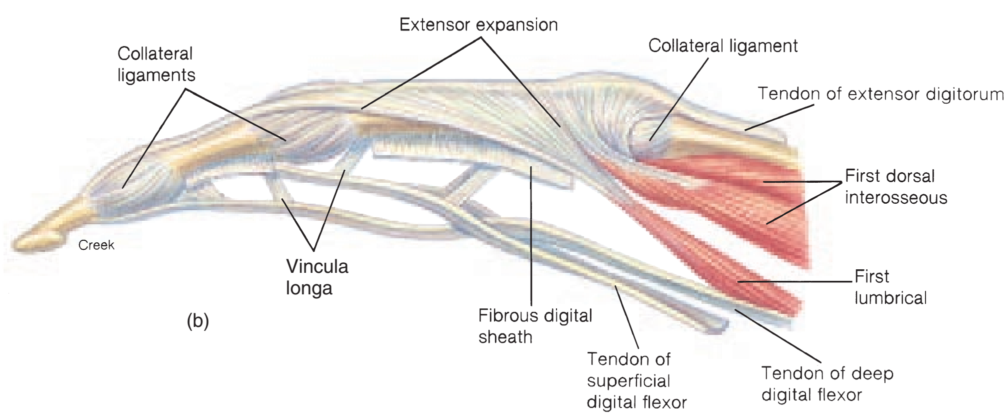
Notice that the joints of your hand are partially flexed even when the hand is relaxed. The antebrachial muscles that flex these joints are larger and stronger than those that extend the joints. Thus, they also have a greater degree of tonus causing the relaxed hand to be in a grasping position. People who receive strong electrical shocks through the arms will tightly flex the joints of their wrist and hands and cling to a cord or wire. All the muscles of the antebrachium are stimulated to contract, but the flexors, being larger and stronger, cause the hands to close tightly.

Muscles of the Hand

The hand is a marvelously complex structure, adapted to permit an array of intricate movements. Flexion and extension movements of the hand and phalanges are accomplished by the muscles of the forearm just described. Precise finger movements that require coordinating abduction and adduction with flexion and extension are the function of the small intrinsic muscles of the



(a)



(b)

FIGURE 9.34 Muscles of the hand. (*a*) An anterior view and (*b*) a lateral view of the second digit (index finger).

TABLE 9.14 Intrinsic Muscles of the Hand

Muscle	Origin	Insertion	Action	Innervation
Thenar Muscles				
Abductor pollicis brevis	Flexor retinaculum, scaphoid, and trapezium	Proximal phalanx of thumb	Abducts joints of thumb	Median n.
Flexor pollicis brevis	Flexor retinaculum and trapezium	Proximal phalanx of thumb	Flexes joints of thumb	Median n.
Opponens pollicis	Trapezium and flexor retinaculum	First metacarpal bone	Opposes joints of thumb	Median n.
Intermediate Muscles				
Adductor pollicis (oblique and transverse heads)	Oblique head, capitate; transverse head, second and third metacarpal bones	Proximal phalanx of thumb	Adducts joints of thumb	Ulnar n.
Lumbricales (4)	Tendons of flexor digitorum profundus	Extensor expansions of digits II–V	Flexes digits at metacarpophalangeal joints; extends digits at interphalangeal joints	Median and ulnar nn.
Palmar interossei (4)	Medial side of second metacarpal bone; lateral sides of fourth and fifth metacarpal bones	Proximal phalanges of index, ring, and little fingers and extensor digitorum communis	Adducts fingers toward middle finger at metacarpophalangeal joints	Ulnar n.
Dorsal interossei (4)	Adjacent sides of metacarpal bones	Proximal phalanges of index and middle fingers (lateral sides) plus proximal phalanges of middle and ring fingers (medial sides) and extensor digitorum communis	Abducts fingers away from middle finger at metacarpophalangeal joints	Ulnar n.
Hypothenar Muscles				
Abductor digiti minimi	Pisiform and tendon of flexor carpi ulnaris	Proximal phalanx of digit V	Abducts joints of digit V	Ulnar n.
Flexor digiti minimi	Flexor retinaculum and hook of hamate	Proximal phalanx of digit V	Flexes joints of digit V	Ulnar n.
Opponens digiti minimi	Flexor retinaculum and hook of hamate	Fifth metacarpal bone	Opposes joints of digit V	Ulnar n.

opponens: L. *opponens,* against

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hand. These muscles and associated structures of the hand are depicted in figure 9.34. The position and actions of the muscles of the hand are listed in table 9.14.

The muscles of the hand are divided into **thenar** (*the'nar*), **hypothenar** (*hi-poth'ĕ-nar*), and **intermediate** groups. The *thenar eminence* is the fleshy base of the thumb and is formed by three muscles: the **abductor pollicis brevis,** the **flexor pollicis brevis,** and the **opponens pollicis.** The most important of the thenar muscles is the opponens pollicis, which opposes the thumb to the palm of the hand.

The *hypothenar eminence* is the elongated, fleshy bulge at the base of the little finger. It also is formed by three muscles: the **abductor digiti minimi** muscle, the **flexor digiti minimi** muscle, and the **opponens digiti minimi** muscle.

Muscles of the intermediate group are positioned between the metacarpal bones in the region of the palm. This group includes the **adductor pollicis** muscle, the **lumbricales** (*lum'brĭ-ka'lēz*) and the **palmar** and **dorsal interossei** (*in''ter-os'e-i*) muscles.

Muscles That Move the Thigh at the Hip Joint

The muscles that move the thigh at the hip joint originate from the pelvic girdle and the vertebral column and insert on various places on the femur. These muscles stabilize a highly movable hip joint and provide support for the body during bipedal stance and locomotion. The most massive muscles of the body are found in this region, along with some extremely small muscles. The muscles that move the thigh at the hip joint are divided into anterior, posterior, and medial groups.

Anterior Muscles

The anterior muscles that move the thigh at the hip joint are the *iliacus* and *psoas major* (figs. 9.35 and 9.36).

The triangular **iliacus** (*il''e-ak'us; ĭ-li'ă-kus*) muscle arises from the iliac fossa and inserts on the lesser trochanter of the femur.

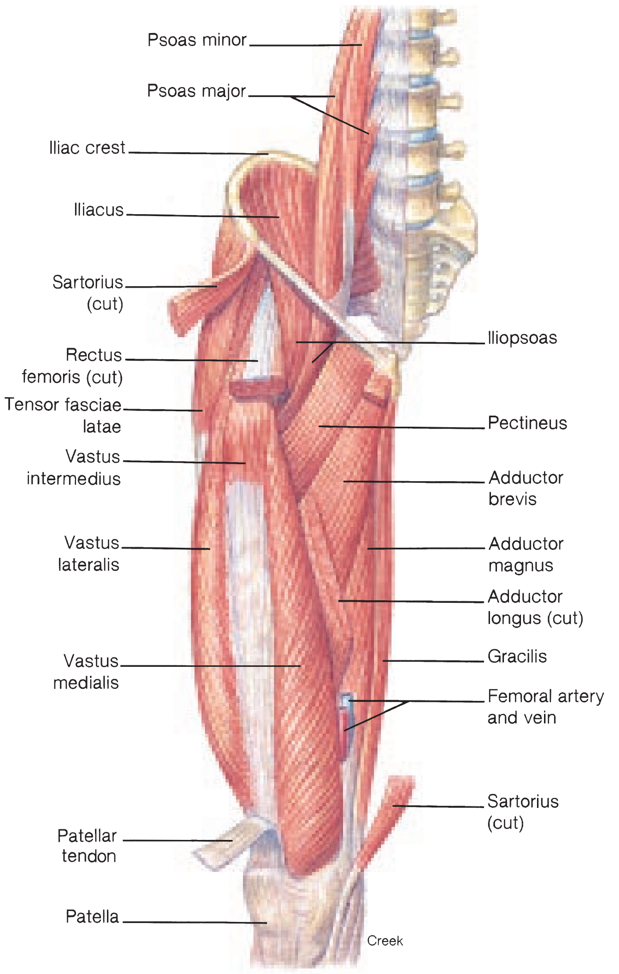

FIGURE 9.35 Muscles of the right anterior pelvic and thigh regions.

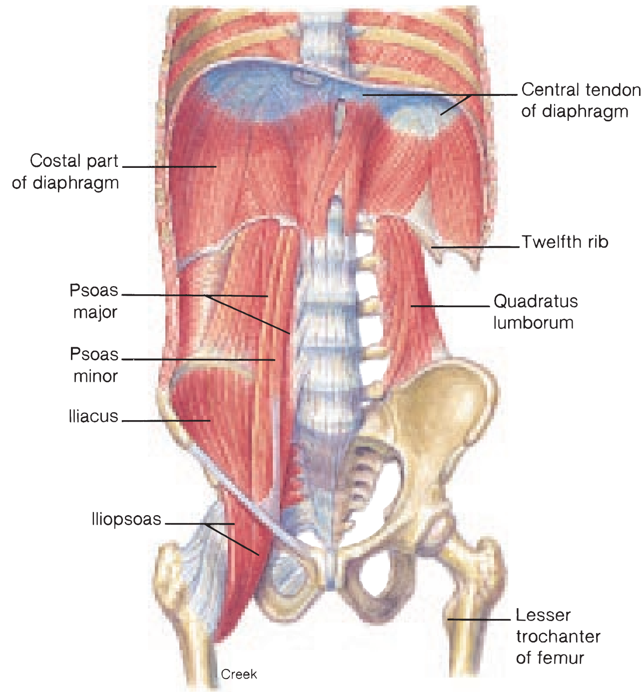

FIGURE 9.36 Anterior pelvic muscles that move the hip.

The long, thick **psoas** (*so'as*) **major** muscle originates on the bodies and transverse processes of the lumbar vertebrae; it inserts, along with the iliacus muscle, on the lesser trochanter (fig. 9.36). The psoas major and the iliacus work synergistically in flexing and rotating the hip joint and flexing the vertebral column. These two muscles are collectively called the **iliopsoas** (*il''e-o-so'-as*) muscle.

Posterior and Lateral (Buttock) Muscles

The posterior muscles that move the thigh at the hip joint include the *gluteus maximus*, *gluteus medius*, *gluteus minimis*, and *tensor fasciae latae*.

The large **gluteus** (*gloo'te-us*) **maximus** muscle forms much of the prominence of the buttock (figs. 9.37 and 9.40). It is a powerful extensor muscle of the hip joint and is very important for bipedal stance and locomotion. The gluteus maximus originates on the ilium, sacrum, coccyx, and aponeurosis of the lumbar region. It inserts on the gluteal tuberosity of the femur and the *iliotibial tract*, a thickened tendinous region of the fascia lata extending down the thigh (see fig. 9.39).

The **gluteus medius** muscle is located immediately deep to the gluteus maximus (fig. 9.37). It originates on the lateral surface of the ilium and inserts on the greater trochanter of the femur. The gluteus medius abducts and medially rotates the hip joint. The mass of this muscle is of clinical significance as a site for intramuscular injections.

The **gluteus minimus** muscle is the smallest and deepest of the gluteal muscles (fig. 9.37). It also arises from the lateral surface of the ilium, and it inserts on the lateral surface of the greater trochanter, where it acts synergistically with the gluteus medius and tensor fasciae latae muscles to abduct the hip joint.

The quadrangular **tensor fasciae latae** (*fash'e-e la'te*) muscle is positioned superficially on the lateral surface of the hip (see fig. 9.39). It originates on the iliac crest and inserts on a broad lateral fascia of the thigh called the *iliotibial tract*. The tensor fas-

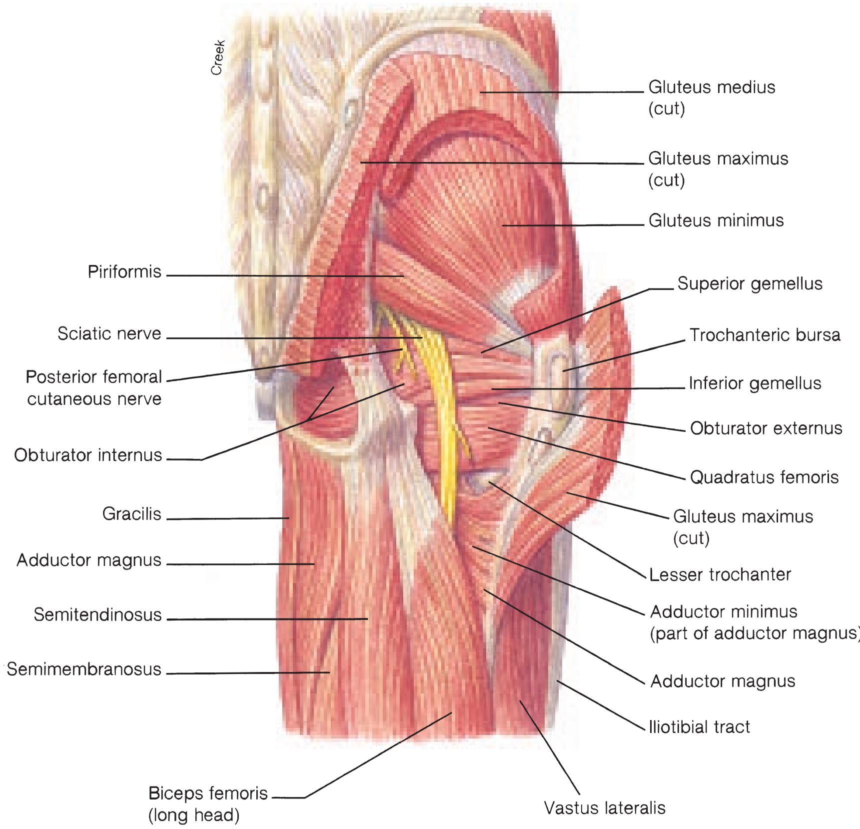

FIGURE 9.37 Deep gluteal muscles.

ciae latae muscle and the gluteus medius muscle are synergistic abductor muscles of the hip joint.

A deep group of six lateral rotator muscles of the hip joint is positioned directly over the posterior aspect of the hip. These muscles are not discussed here but are identified in figure 9.37 from superior to inferior as the **piriformis,** (*pĭ-rĭ-for'mis*), **superior gemellus** (*je-mel'us*) **obturator internus, inferior gemellus, obturator externus,** and **quadratus femoris** muscles.

The anterior and posterior group of muscles that move the hip joint are summarized in table 9.15.

Medial, or Adductor, Muscles

The medial muscles that move the hip joint include the *gracilis pectineus*, *adductor longus*, *adductor brevis*, and *adductor magnus* muscles (figs. 9.38, 9.39, 9.40, and 9.41).

The long, thin **gracilis** (*gras'ĭ-lis*) muscle is the most superficial of the medial thigh muscles. It is a two-joint muscle and can adduct the hip joint or flex the knee.

The **pectineus** (*pek-tin'e-us*) muscle is the uppermost of the medial muscles that move the hip joint. It is a flat, quadrangular muscle that flexes and adducts the hip.

The **adductor longus** muscle is located immediately lateral to the gracilis on the upper third of the thigh; it is the most anterior of the adductor muscles. The **adductor brevis** muscle is a triangular muscle located deep to the adductor longus and pectineus muscles, which largely conceal it. The **adductor magnus** muscle is a large, thick muscle, somewhat triangular in shape. It is located deep to the other two adductor muscles. The adductor longus, adductor brevis, and the adductor magnus are synergistic in adducting, flexing, and laterally rotating the hip joint.

TABLE 9.15 Anterior and Posterior Muscles That Move the Thigh at the Hip Joint

Muscle	Origin	Insertion	Action	Innervation
Iliacus	Iliac fossa	Lesser trochanter of femur, along with psoas major	Flexes and rotates thigh laterally at the hip joint; flexes joints of vertebral column	Femoral n.
Psoas major	Transverse processes of all lumbar vertebrae	Lesser trochanter, along with iliacus	Flexes and rotates thigh laterally at the hip joint; flexes joints of vertebral column	Spinal nerves L2, L3
Gluteus maximus	Iliac crest, sacrum, coccyx, and aponeurosis of the lumbar region	Gluteal tuberosity and iliotibial tract	Extends and rotates thigh laterally at the hip joint	Inferior gluteal n.
Gluteus medius	Lateral surface of ilium	Greater trochanter	Abducts and rotates thigh medially at the hip joint	Superior gluteal n.
Gluteus minimus	Lateral surface of lower half of ilium	Greater trochanter	Abducts thigh at the hip joint	Superior gluteal n.
Tensor fasciae latae	Anterior border of ilium and iliac crest	Iliotibial tract	Abducts thigh at the hip joint	Superior gluteal n.

psoas: Gk. *psoa*, loin
gluteus: Gk. *gloutos*, rump

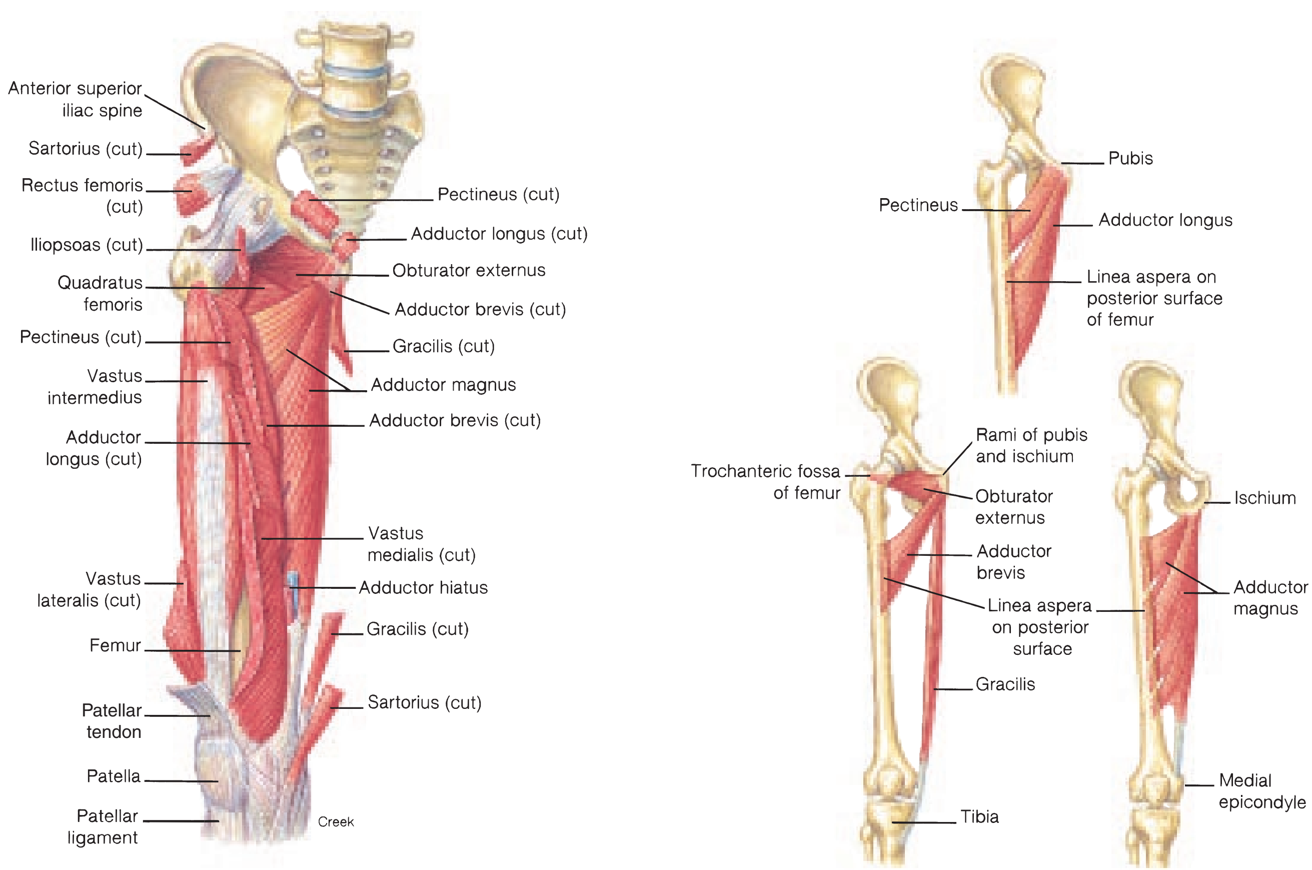

FIGURE 9.38 Adductor muscles of the right thigh.

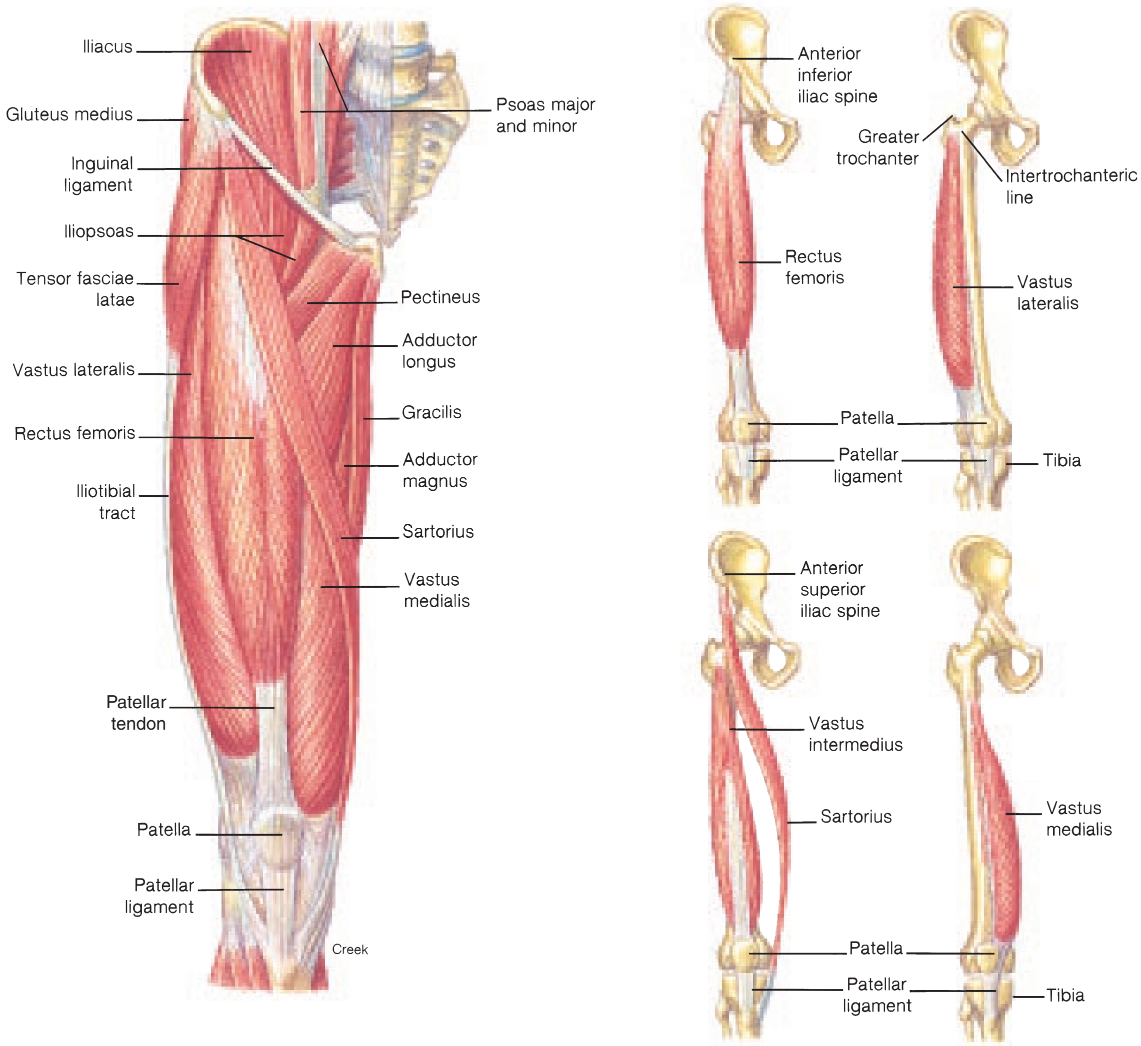

FIGURE 9.39 Muscles of the right anterior thigh.

The muscles that adduct the hip joint are summarized in table 9.16.

Muscles of the Thigh That Move the Knee Joint

The muscles that move the knee originate on the pelvic girdle or thigh. They are surrounded and compartmentalized by tough fascial sheets, which are a continuation of the fascia lata and iliotibial tract. These muscles are divided according to function and position into two groups: anterior extensors and posterior flexors.

Anterior, or Extensor, Muscles

The anterior muscles that move the knee joint are the *sartorius* and *quadriceps femoris* muscles (fig. 9.38).

The long, straplike **sartorius** (*sar'to're-us*) muscle obliquely crosses the anterior aspect of the thigh. It can act on both the hip and knee joints to flex and rotate the hip laterally, and also to assist in flexing the knee joint and rotating it medially. The sartorius is the longest muscle of the body. It is frequently called the "tailor's muscle" because it helps effect the cross-legged sitting position in which tailors are often depicted.

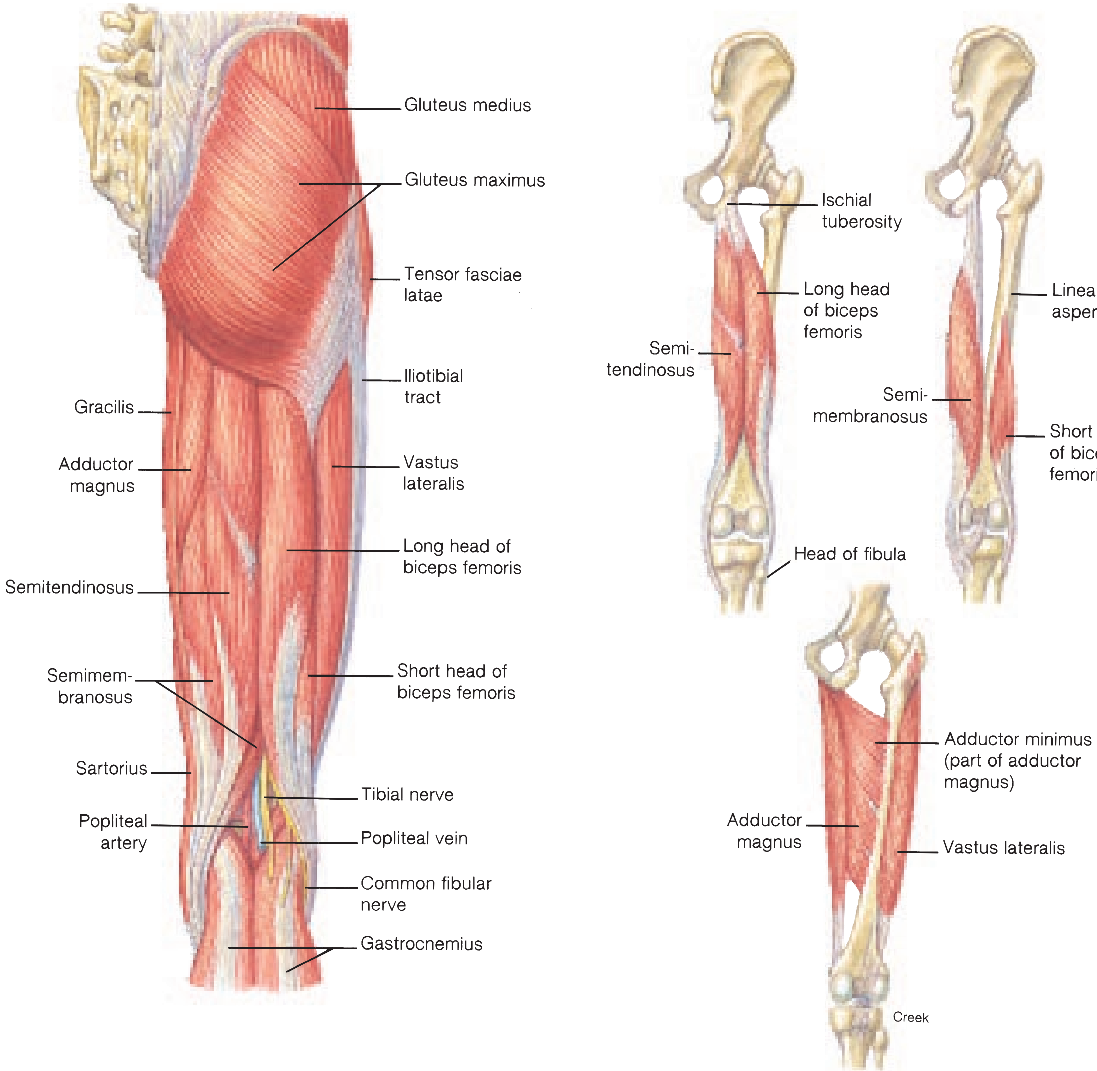

FIGURE 9.40 Muscles of the right posterior thigh.

The **quadriceps femoris** muscle is actually a composite of four distinct muscles that have separate origins but a common insertion on the patella via the patellar tendon. The patellar tendon is continuous over the patella and becomes the *patellar ligament* as it attaches to the tibial tuberosity (fig. 9.39). These muscles function synergistically to extend the knee, as in kicking a football. The four muscles of the quadriceps femoris muscle are the *rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius.*

The **rectus femoris** muscle occupies a superficial position and is the only one of the four quadriceps that functions in both the hip and knee joints. The laterally positioned **vastus lateralis** is the largest muscle of the quadriceps femoris. It is a common intramuscular injection site in infants who have small, underdeveloped buttock and shoulder muscles. The **vastus medialis** muscle occupies a medial position along the thigh. The **vastus intermedius** muscle lies deep to the rectus femoris.

The anterior thigh muscles that move the knee joint are summarized in table 9.17.

Posterior, or Flexor, Muscles

There are three posterior thigh muscles, which are antagonistic to the quadriceps femoris muscles in flexing the knee joint. These muscles are known as the **hamstrings** (fig. 9.40; also see fig. 10.46). The name derives from the butchers' practice of using the tendons of these muscles at the knee of a hog to hang a ham for curing.

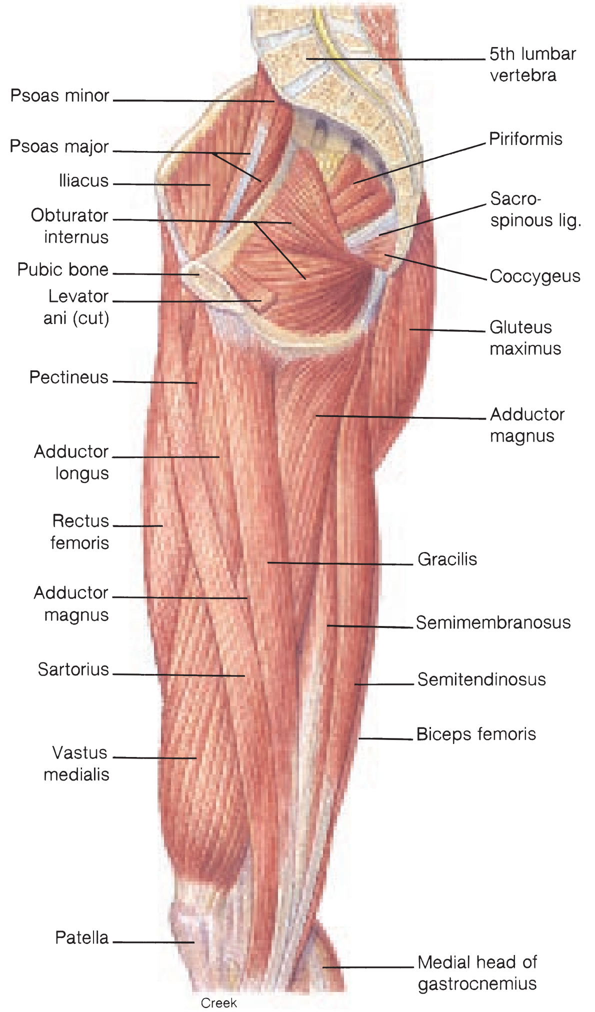

FIGURE 9.41 Muscles of the right medial thigh.

The **biceps femoris** muscle occupies the posterior lateral aspect of the thigh. It has a superficial long head and a deep short head, and causes movement at both the hip and knee joints. The superficial **semitendinosus** muscle is fusiform and is located on the posterior medial aspect of the thigh. It also works over two joints. The flat **semimembranosus** muscle lies deep to the semitendinosus on the posterior medial aspect of the thigh.

The posterior thigh muscles that move the leg at the knee joint are summarized in table 9.18. The relative positions of the muscles of the thigh are illustrated in figure 9.42.

Hamstring injuries are a common occurrence in some sports. The injury usually occurs when sudden lateral or medial stress to the knee joint tears the muscles or tendons. Because of its structure and the stress applied to it in competition, the knee joint is highly susceptible to injury. Altering the rules in contact sports could reduce the incidence of knee injury. At the least, additional support and protection should be provided for this vulnerable joint.

Muscles of the Leg That Move the Joints of the Ankle, Foot, and Toes

The muscles of the leg, the **crural muscles,** are responsible for the movements of the foot. There are three groups of crural muscles: *anterior*, *lateral*, *and posterior*. The anteromedial aspect of the leg along the body of the tibia lacks muscle attachment.

Anterior Crural Muscles

The anterior crural muscles include the *tibialis anterior*, *extensor digitorum longus*, *extensor hallucis longus*, and *peroneus tertius* muscles (figs. 9.43, 9.44, and 9.45).

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TABLE 9.16 Medial Muscles That Move the Thigh at the Hip Joint

Muscle	Origin	Insertion	Action	Innervation
Gracilis	Inferior edge of symphysis pubis	Proximal medial surface of tibia	Adducts thigh at hip joint; flexes and rotates leg at knee joint	Obturator n.
Pectineus	Pectineal line of pubis	Distal to lesser trochanter of femur	Adducts and flexes thigh at hip joint	Femoral n.
Adductor longus	Pubis—below pubic crest	Linea aspera of femur	Adducts, flexes, and laterally rotates thigh at hip joint	Obturator n.
Adductor brevis	Inferior ramus of pubis	Linea aspera of femur	Adducts, flexes, and laterally rotates thigh at hip joint	Obturator n.
Adductor magnus	Inferior ramus of ischium and pubis	Linea aspera and medial epicondyle of femur	Adducts, flexes, and laterally rotates thigh at hip joint	Obturator and tibial nn.

gracilis: Gk. *gracilis*, slender

TABLE 9.17 Anterior Thigh Muscles That Move the Knee Joint

Muscle	Origin	Insertion	Action	Innervation
Sartorius	Anterior superior iliac spine	Medial surface of tibia	Flexes knee and hip joints; abducts hip joint; rotates thigh laterally at hip joint; and rotates leg medially at knee joint	Femoral n.
Quadriceps femoris		Patella by patellar tendon, which continues as patellar ligament to tibial tuberosity	Extends leg at knee joint	Femoral n.
Rectus femoris	Anterior superior iliac spine and lip of acetabulum			
Vastus medialis	Greater trochanter and linea aspera of femur			
Vastus lateralis	Medial surface and linea aspera of femur			
Vastus intermedius	Anterior and lateral surfaces of femur			

sartorius: L. *sartor*, a tailor (muscle used to cross legs in a tailor's position)

TABLE 9.18 Posterior Thigh Muscles That Move the Knee Joint*

Muscle	Origin	Insertion	Action
Biceps femoris	Long head—ischial tuberosity; short head—linea aspera of femur	Head of fibula and lateral epicondyle of tibia	Flexes knee joint; extends and laterally rotates thigh at hip joint
Semitendinosus	Ischial tuberosity	Proximal portion of medial surface of body of tibia	Flexes knee joint; extends and medially rotates thigh at hip joint
Semimembranosus	Ischial tuberosity	Proximomedial surface	Flexes knee joint; extends and medially rotates thigh at hip joint

*Each of the posterior thigh muscles that flex the knee joint is innervated by the tibial nerve.

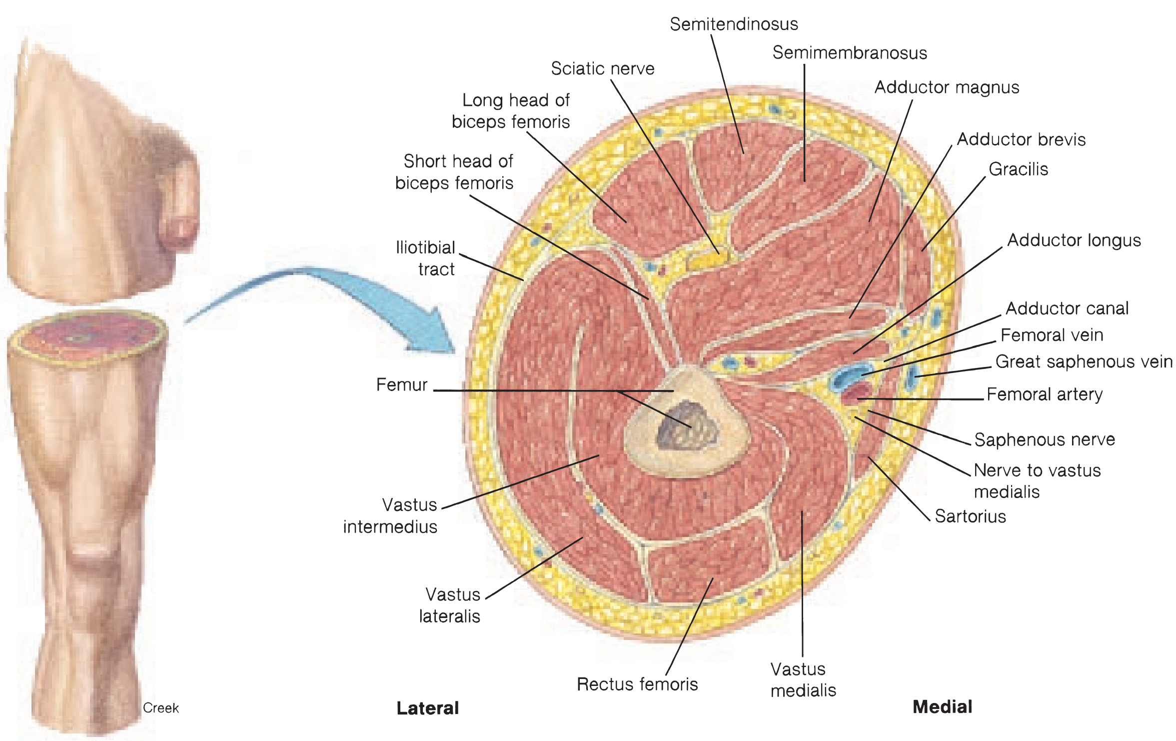


FIGURE 9.42 A transverse section of the right thigh as seen from above. (Note the position of the vessels and nerves.)

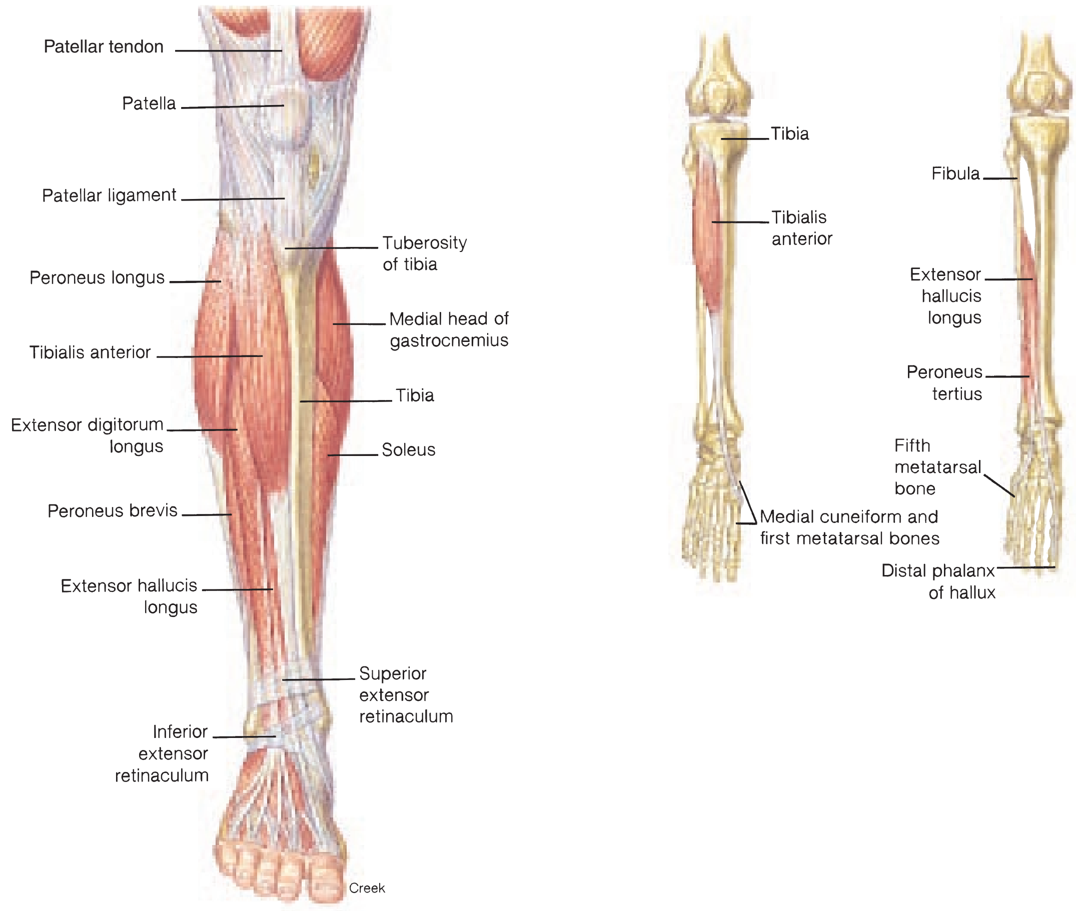


FIGURE 9.43 Anterior crural muscles.

The large, superficial **tibialis anterior** muscle can be easily palpated on the anterior lateral portion of the tibia (fig. 9.43). It parallels the prominent anterior crest of the tibia. The **extensor digitorum longus** muscle is positioned lateral to the tibialis anterior on the anterolateral surface of the leg. The **extensor hallucis** (*hă-loo'sis*) **longus** muscle is positioned deep between the tibialis anterior muscle and the extensor digitorum longus muscle. The **small peroneus tertius** muscle is continuous with the distal portion of the extensor digitorum longus muscle.

Lateral Crural Muscles

The lateral crural muscles are the *peroneus longus* and *peroneus brevis* (figs. 9.43 and 9.44).

The long, flat **peroneus longus** muscle is a superficial lateral muscle that overlies the fibula. The **peroneus brevis** muscle lies deep to the peroneus longus and is positioned closer to the foot. These two muscles are synergistic in flexing the ankle joint and everting the foot (see table 9.19).

Posterior Crural Muscles

The seven posterior crural muscles can be grouped into a superficial and a deep group. The superficial group is composed of the *gastrocnemius*, *soleus*, and *plantaris* muscles (fig. 9.46). The four deep posterior crural muscles are the *popliteus*, *flexor hallucis longus*, *flexor digitorum longus*, and *tibialis posterior* muscles (fig. 9.47).

The **gastrocnemius** (*gas''trok-ne'me-us*) muscle is a large superficial muscle that forms the major portion of the calf of the leg. It consists of two distinct heads that arise from the posterior surfaces of the medial and lateral epicondyles of the femur. This muscle and the deeper soleus muscle insert onto the calcaneus via the common *tendo calcaneus (tendon of Achilles)*. This is the strongest tendon in the body, but it is frequently ruptured from

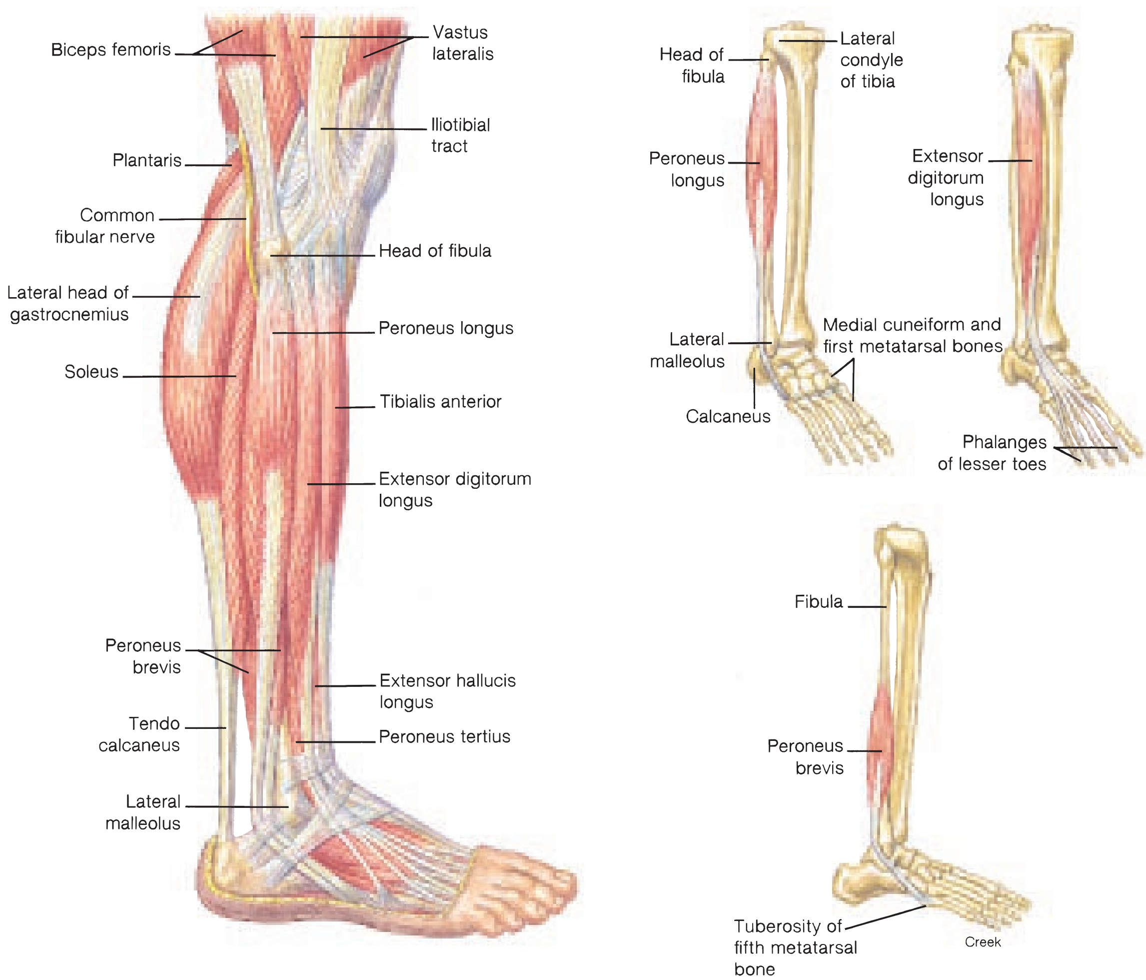


FIGURE 9.44 Lateral crural muscles.

CHAPTER 9

sudden stress during athletic competition. The gastrocnemius acts over two joints to cause flexion of the knee joint and plantar flexion of the foot at the ankle joint.

The **soleus** muscle lies deep to the gastrocnemius. These two muscles are frequently referred to as a single muscle, the **triceps surae** (*sur'e*). The soleus and gastrocnemius muscles have a common insertion, but the soleus acts on only the ankle joint, in plantar flexing the foot.

The small **plantaris** muscle arises just superior to the origin of the lateral head of the gastrocnemius muscle on the lateral supracondylar ridge of the femur. It has a very long, slender tendon of insertion onto the calcaneus. The tendon of this muscle is frequently mistaken for a nerve by those dissecting it for the first time. The plantaris is a weak muscle, with limited ability to flex the knee and plantar flex the ankle joint.

The thin, triangular **popliteus** (*pop-lit'e-us*) muscle is situated deep to the heads of the gastrocnemius muscle, where it forms part of the floor of the *popliteal fossa*—the depression on the back side of the knee joint (fig. 9.48). The popliteus muscle is a medial rotator of the knee joint during locomotion. The bipennate **flexor hallucis longus** muscle lies deep to the soleus muscle on the posterolateral side of the leg. It flexes the joints of the great toe (hallux) and assists in plantar flexing ankle joint and inverting the foot.

The **flexor digitorum longus** muscle also lies deep to the soleus, and it parallels the flexor hallucis longus muscle on the medial side of the leg. Its distal tendon passes posterior to the medial malleolus and continues along the plantar surface of the foot, where it branches into four tendinous slips that attach to the bases of the distal phalanges of the second, third,

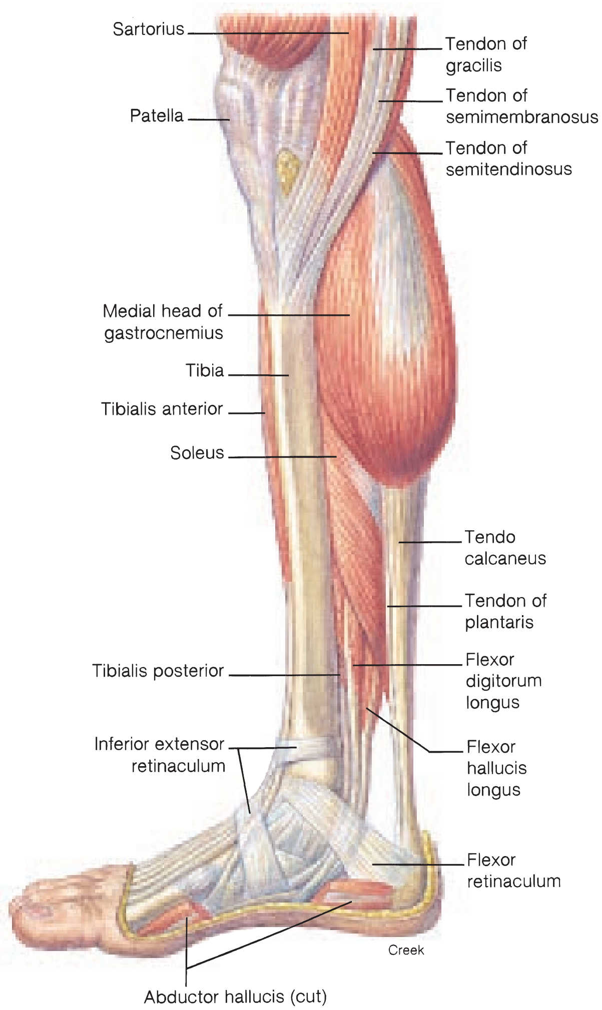


FIGURE 9.45 A medial view of the crural muscles.

fourth, and fifth digits (fig. 9.49). The flexor digitorum longus works over several joints, flexing the joints in four of the digits and assisting in plantar flexing the ankle joint and inverting the foot.

The **tibialis posterior** muscle is located deep to the soleus muscle, between the posterior flexors. Its distal tendon passes behind the medial malleolus and inserts on the plantar surfaces of the navicular, cuneiform, and cuboid bones, and the second, third, and fourth metatarsal bones (fig. 9.49). The tibialis posterior plantar flexes the ankle joint, inverts the foot, and lends support to the arches of the foot.

The crural muscles are summarized in table 9.19.

Muscles of the Foot

With the exception of one additional intrinsic muscle, the **extensor digitorum brevis** (fig. 9.50), the muscles of the foot are similar in name and number to those of the hand. The functions of the muscles of the foot are different, however, because the foot is adapted to provide support while bearing body weight rather than to grasp objects.

The muscles of the foot can be grouped into four layers (fig. 9.49), but these are difficult to dissociate, even in dissection. The muscles function either to move the toes or to support the arches of the foot through their contraction. Because of their complexity, the muscles of the foot will be presented only in illustrations (see figs. 9.49 and 9.50).

Knowledge Check

20. List all the muscles that either originate from or insert on the scapula.
21. On the basis of function, categorize the muscles of the upper extremity as flexors, extensors, abductors, adductors, or rotators. (Each muscle may fit into two or more categories.)
22. Which muscles of the lower extremity span two joints, and therefore have two different actions?

CLINICAL CONSIDERATIONS

Compared to the other systems of the body, the muscular system is extremely durable. If properly conditioned, the muscles of the body can adequately serve a person for a lifetime. Muscles are capable of doing incredible amounts of work; through exercise, they can become even stronger.

Clinical considerations include evaluation of muscle condition, functional conditions in muscles, diseases of muscles, and aging of muscles.

Evaluation of Muscle Condition

The clinical symptoms of muscle diseases include weakness, loss of muscle mass (atrophy), and pain. The most obvious diagnostic procedure is a clinical examination of the patient. Following this, it may be necessary to test muscle function using **electromyography (EMG)** to measure conduction rates and motor unit activity within a muscle. Laboratory tests may include serum enzyme assays or muscle biopsies. A biopsy is perhaps the most definitive diagnostic tool. Progressive atrophy, polymyositis, and metabolic diseases of muscles can be determined through a biopsy.

TABLE 9.19 Muscles of the Leg That Move the Joints of the Ankle, Foot, and Toes

Muscle	Origin	Insertion	Action	Innervation
Tibialis anterior	Proximolateral surface and body of tibia	First metatarsal bone and first cuneiform	Dorsiflexes ankle and inverts foot at ankle	Deep fibular n.
Extensor digitorum longus	Proximolateral surface of tibia and anterior surface of fibula	Extensor expansions of digits II–V	Extends joints of digits II–V and dorsiflexes foot at ankle	Deep fibular n.
Extensor hallucis longus	Anterior surface of fibula and interosseous ligament	Distal phalanx of digit I	Extends joints of great toe and assists dorsiflexion of foot at ankle	Deep fibular n.
Peroneus tertius	Anterior surface of fibula and interosseous ligament	Dorsal surface of fifth metatarsal bone	Dorsiflexes and everts foot at ankle	Deep fibular n.
Peroneus longus	Lateral head of tibia and head and body of fibula	First cuneiform and metatarsal bone I	Plantar flexes and everts foot at ankle	Superficial fibular n.
Peroneus brevis	Lower aspect of fibula	Metatarsal bone V	Plantar flexes and everts foot at ankle	Superficial fibular n.
Gastrocnemius	Lateral and medial epicondyle of femur	Posterior surface of calcaneus	Plantar flexes foot at ankle; flexes knee joint	Tibial n.
Soleus	Posterior aspect of fibula and tibia	Calcaneus	Plantar flexes foot at ankle	Tibial n.
Plantaris	Lateral supracondylar ridge of femur	Calcaneus	Plantar flexes foot at ankle	Tibial n.
Popliteus	Lateral condyle of femur	Upper posterior aspect of tibia	Flexes and medially rotates leg at knee joint	Tibial n.
Flexor hallucis longus	Posterior aspect of fibula	Distal phalanx of great toe	Flexes joint of distal phalanx of great toe	Tibial n.
Flexor digitorum longus	Posterior surface of tibia	Distal phalanges of digits II–V	Flexes joints of distal phalanges of digits II–V	Tibial n.
Tibialis posterior	Tibia and fibula and interosseous ligament	Navicular, cuneiform, cuboid, and metatarsal bones II–IV	Plantar flexes and inverts foot at ankle; supports arches	Tibial n.

hallucis: L. *hallus*, great toe
peroneus tertius: Gk. *perone*, fibula; *tertius*, third
gastrocnemius: Gk. *gaster*, belly; *kneme*, leg
soleus: L. *soleus*, sole of foot
popliteus: L. *poples*, ham of the knee

CHAPTER 9

Functional Conditions in Muscles

Muscles depend on systematic periodic contraction to maintain optimal health. Obviously, overuse or disease will cause a change in muscle tissue. The immediate effect of overexertion on muscle tissue is the accumulation of lactic acid, which results in fatigue and soreness. Excessive contraction of a muscle can also damage the fibers or associated connective tissue, resulting in a **strained muscle.**

A **cramp** within a muscle is an involuntary, painful, prolonged contraction. Cramps can occur while muscles are in use or at rest. The precise cause of cramps is unknown, but evidence indicates that they may be related to conditions within the muscle. They may result from general dehydration, deficiencies of calcium or oxygen, or from excessive stimulation of the motor neurons.

Torticollis (*tor''tĭ-kol'is*), or **wryneck,** is an abnormal condition in which the head is inclined to one side as a result of a contracted state of muscles on that side of the neck. This disorder may be either inborn or acquired.

A condition called **rigor mortis** (rigidity of death) affects skeletal muscle tissue several hours after death, as depletion of ATP within the fibers causes stiffness of the joints. This is similar to *physiological contracture,* in which muscles become incapable of either contracting or relaxing as a result of a lack of ATP.

When skeletal muscles are not contracted, either because the motor nerve supply is blocked or because the limb is immobilized (as when a broken bone is in a cast), the muscle fibers **atrophy** (*at'rŏ-fe*), or diminish in size. Atrophy is reversible if exercise is resumed, as after a healed fracture, but tissue death is inevitable if the nerves cannot be stimulated.

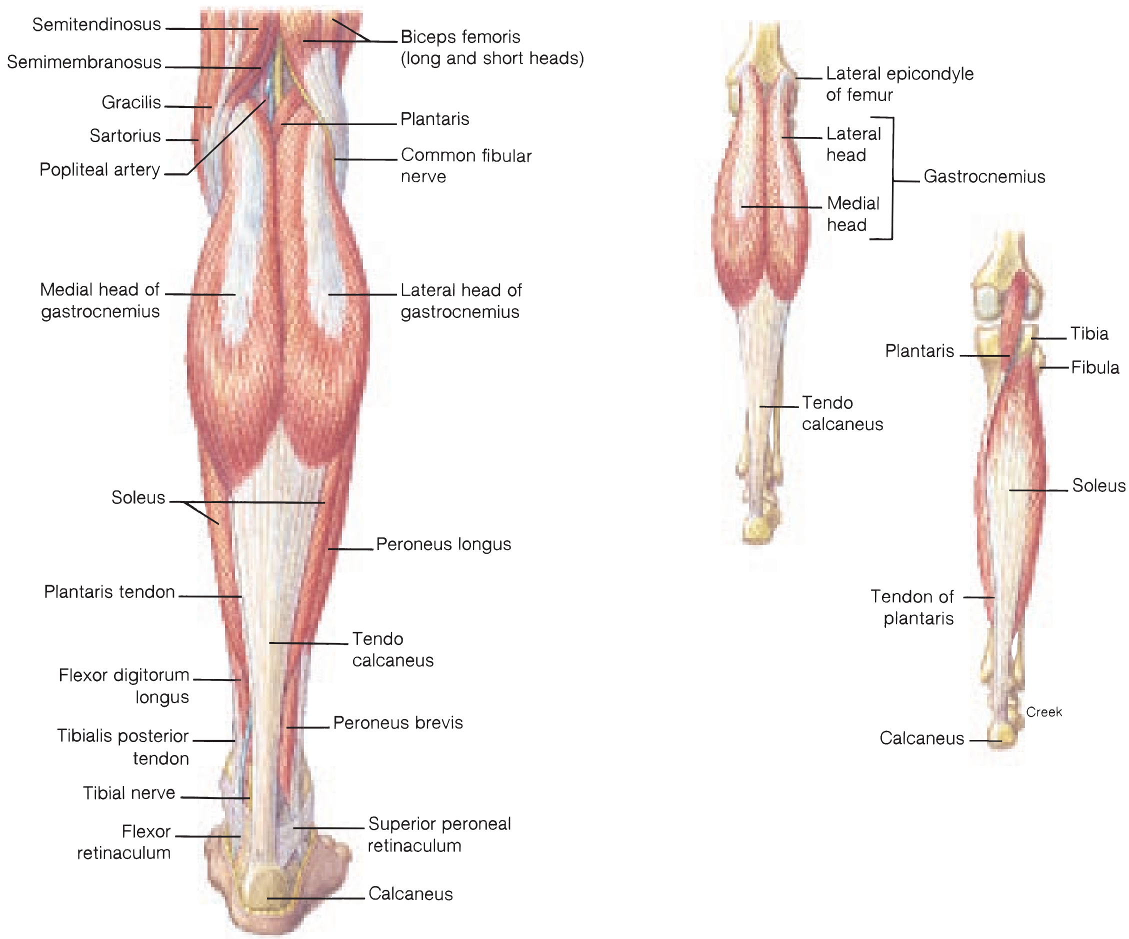


FIGURE 9.46 Posterior crural muscles and the popliteal region.

The fibers in healthy muscle tissue increase in size, or **hypertrophy,** if a muscle is systematically exercised. This increase in muscle size and strength is not due to an increase in the number of muscle cells, but rather to the increased production of myofibrils, accompanied by a strengthening of the associated connective tissue.

Diseases of Muscles

Fibromyositis (*fi′′bro-mi′′ŏ-si′tis*) is an inflammation of both skeletal muscular tissue and the associated connective tissue. Its causes are not fully understood. Pain and tenderness frequently occur in the extensor muscles of the lumbar region of the spinal column, where there are extensive aponeuroses. Fibromyositis of this region is called **lumbago** (*lum-ba′go*) or **rheumatism.**

Muscular dystrophy is a genetic disease characterized by a gradual atrophy and weakening of muscle tissue. There are several kinds of muscular dystrophy, none of whose etiology is completely understood. The most frequent type affects children and is sex-linked to the male child. As muscular dystrophy progresses, the muscle fibers atrophy and are replaced by adipose tissue. Most children who have muscular dystrophy die before the age of 20.

lumbago: L. *lumbus*, loin

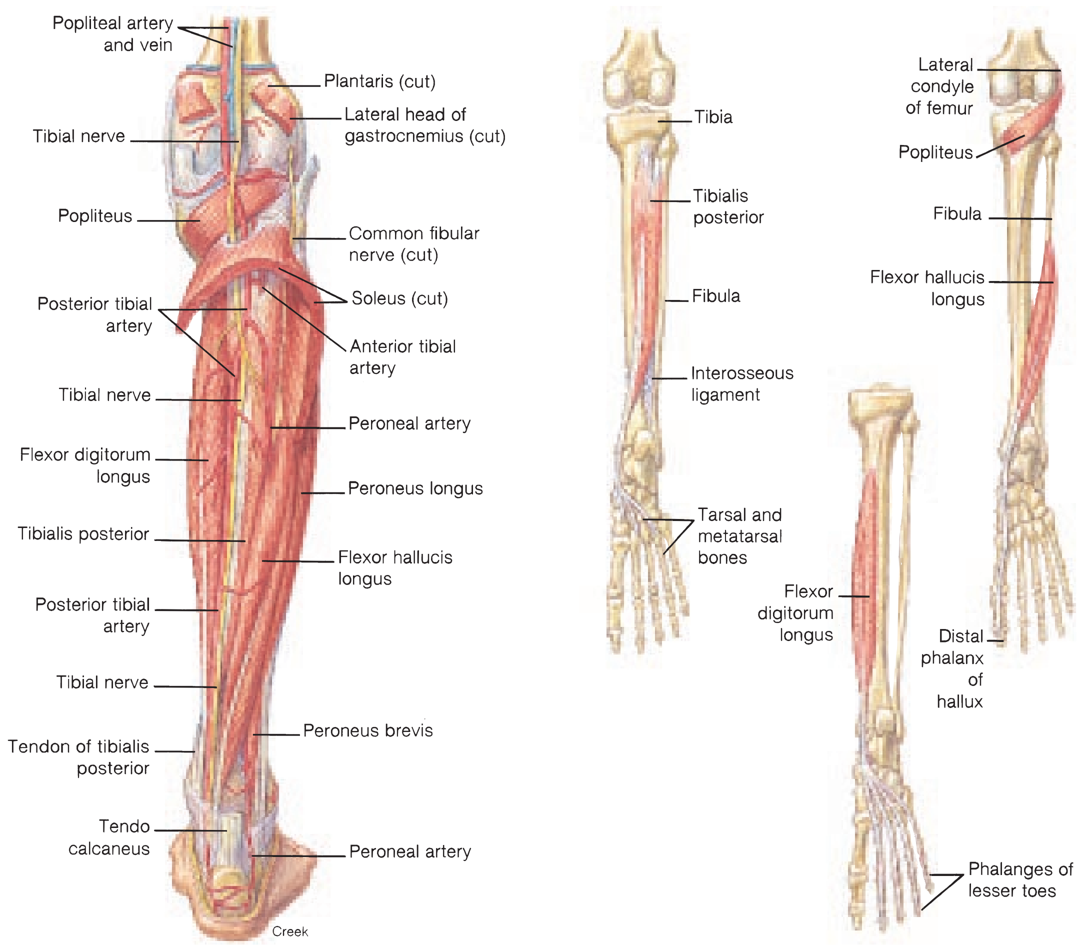


FIGURE 9.47 Deep posterior crural muscles.

The disease **myasthenia gravis** (*mi''as-the'ne-ă grav'is*) is characterized by extreme muscle weakness and low endurance. It results from a defect in the transmission of impulses at the neuromuscular junction. Myasthenia gravis is believed to be an autoimmune disease, and it typically affects women between the ages of 20 and 40.

Poliomyelitis (polio) is actually a viral disease of the nervous system that causes muscle paralysis. The viruses are usually localized in the anterior (ventral) horn of the spinal cord, where they affect the motor nerve impulses to skeletal muscles.

myasthenia: Gk. *myos*, muscle; *astheneia*, weakness
poliomyelitis: Gk. *polios*, gray; *myolos*, marrow

Neoplasms (abnormal growths of new tissue) are rare in muscles, but when they do occur, they are usually malignant. **Rhabdomyosarcoma** (*rab''do-mi''ŏ-sar-ko'mă*) is a malignant tumor of skeletal muscle. It can arise in any skeletal muscle, and most often afflicts young children and elderly people.

Aging of Muscles

Although elderly people experience a general decrease in the strength and fatigue-resistance of skeletal muscle (fig. 9.51), the extent of senescence varies considerably among individuals. Ap-

rhabdomyosarcoma: Gk. *rhabdos*, rod; *myos*, muscle; *oma*, a growth

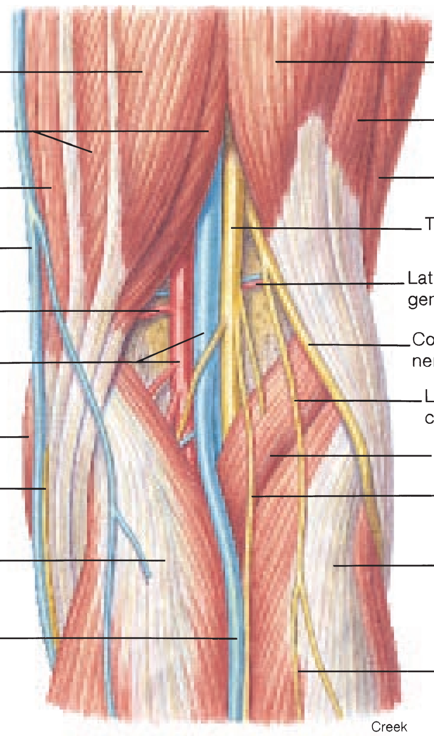


FIGURE 9.48 Muscles that surround the popliteal fossa.

parently, the muscular system is one of the body systems in which a person may actively slow degenerative changes. A decrease in muscle mass is partly due to changes in connective and circulatory tissues. Atrophy of the muscles of the appendages causes the arms and legs to appear thin and bony. Degenerative changes in the nervous system decrease the effectiveness of motor activity. Muscles are slower to respond to stimulation, causing a marked reduction in physical capabilities. The diminished strength of the respiratory muscles may limit the ability of the lungs to ventilate.

Exercise is important at all stages of life but is especially beneficial as one approaches old age (fig. 9.52). Exercise not only strengthens bones and muscles, but it also contributes to a healthy circulatory system and thus ensures an adequate blood supply to all body tissues. If an older person does not maintain muscular strength through exercise, he or she will be more prone to accidents. Loss of strength is a major contributor to falls and fractures. It often results in dependence on others to perform even the routine tasks of daily living.

Clinical Case Study Answer

When cancer of the head or neck involves lymph nodes in the neck, a number of structures on the affected side are removed surgically. This procedure usually includes the sternocleidomastoid muscle. This muscle, which originates on the sternum and clavicle, inserts on the mastoid process of the temporal bone. When it contracts, the mastoid process, which is located posteriorly at the base of the skull, is pulled forward, causing the chin to rotate away from the contracting muscle. This explains why the patient who had his left sternocleidomastoid muscle removed would have difficulty turning his head to the right.

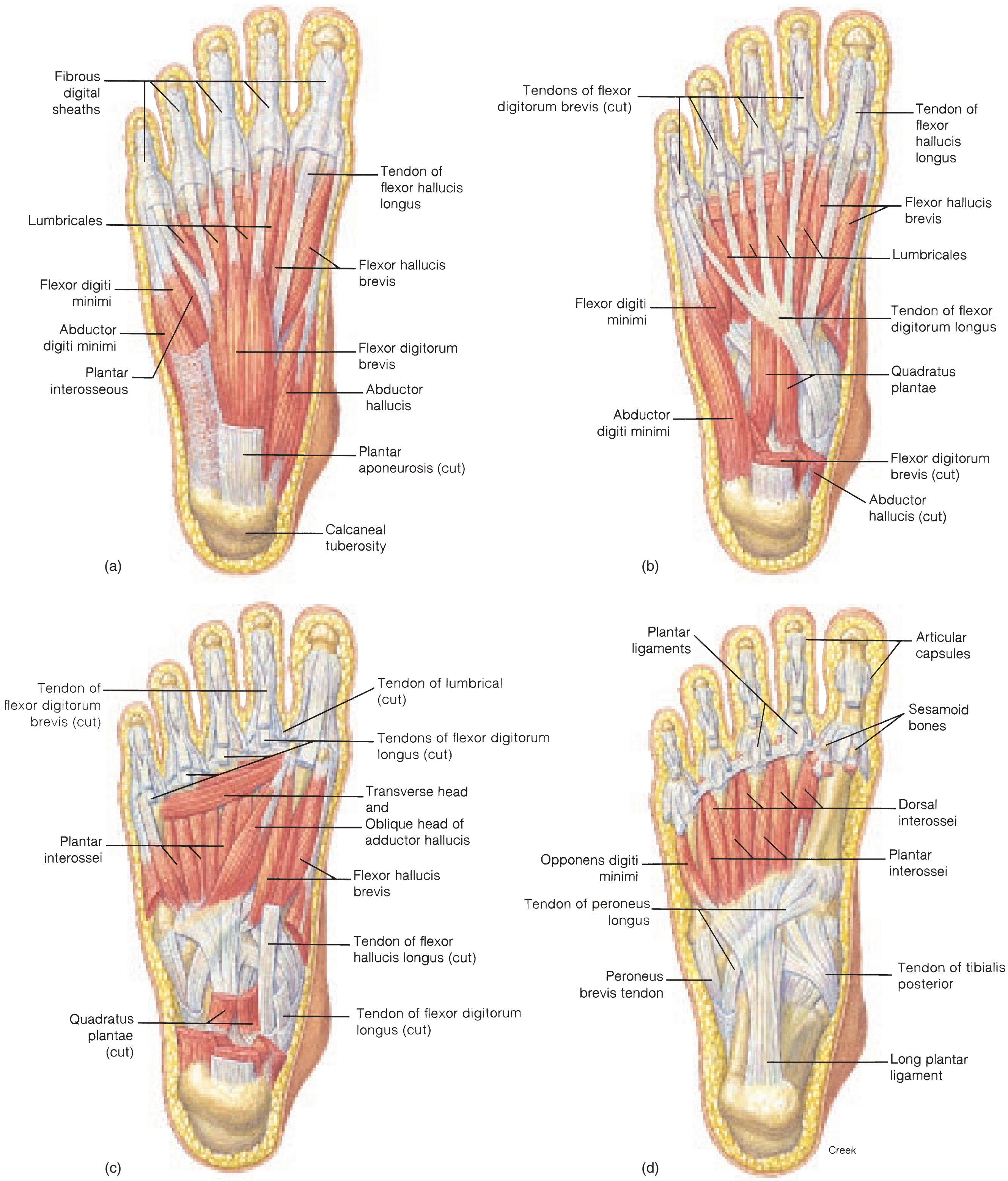


FIGURE 9.49 The four musculotendinous layers of the plantar aspect of the foot: (*a*) superficial layer, (*b*) second layer, (*c*) third layer, and (*d*) deep layer.

CHAPTER 9

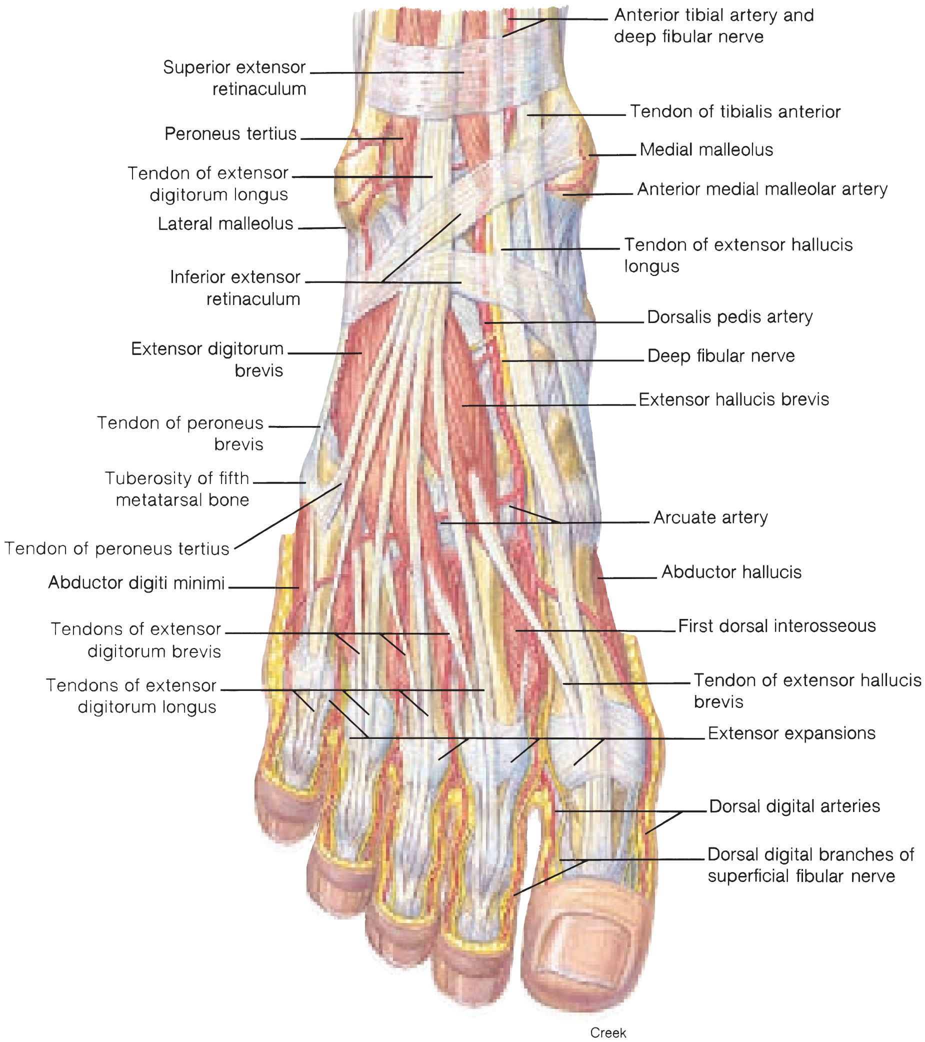


FIGURE 9.50 An anterior view of the dorsum of the foot.

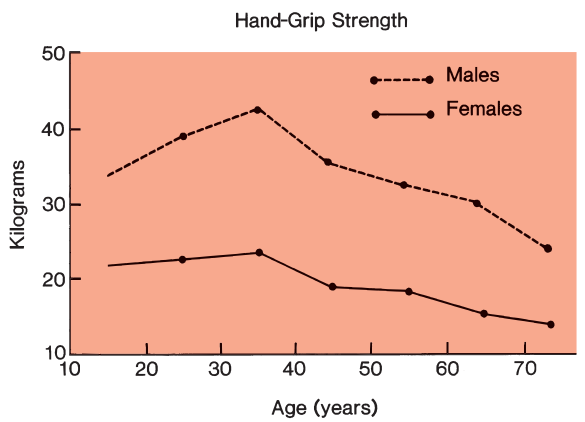


FIGURE 9.51 A gradual diminishing of muscle strength occurs after the age of 35, as shown with a graph of hand-grip strength.
Source: From Hollingsworth JW, Hashizuma A, Jabbn S: Correlations Between Tests of Aging in Hiroshima Subjects: An Attempt to Define Physiologic Age. *Yale Journal of Biology and Medicine,* 38:11–26, 1965. Reprinted by permission.

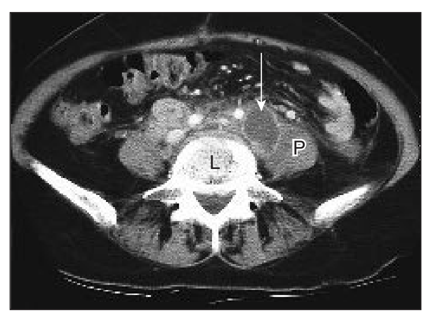
FIGURE 9.52 Competitive runners in late adulthood, recognizing the benefits of exercise.

CLINICAL PRACTICUM 9.1

A 43-year-old female presents at your office with complaints of fatigue, fevers, and some weight loss. She also notes pain in the area of her left hip and left lower quadrant of her abdomen, especially when standing or bearing weight. On physical exam, she has a mild fever and slight tenderness on the left side of her abdomen, and you note that when lying down she holds her hip in a slightly flexed position. You perform the iliopsoas test and elicit a positive psoas sign. Lab results show an elevated white blood cell count consistent with infection. You order a CT scan (L = lumbar vertebrae; P = psoas major muscle).

QUESTIONS

1. What is the fluid collection indicated by the arrow on the CT scan?
2. Why is the psoas sign positive?
3. What is the treatment?

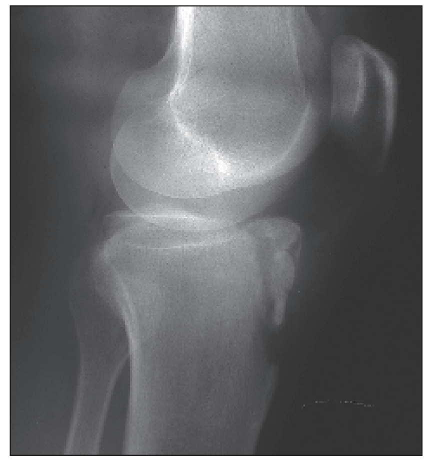


CLINICAL PRACTICUM 9.2

A 27-year-old male arrives at the emergency room after a motor vehicle accident. He complains of intense pain in his knee and cannot extend his leg at the knee. Upon physical exam, you notice that the patella is superiorly displaced, and the knee is extremely swollen. The knee is held in a flexed position. Peripheral pulses and sensation are normal. You order a radiograph of the knee.

QUESTIONS

1. What is the patient's injury?
2. Why is the patient unable to extend the knee?
3. Why is the knee held in a slightly flexed position?



Important Clinical Terminology

convulsion An involuntary, spasmodic contraction of skeletal muscle.

fibrillation (*fib-rĭ-la'shun*) Rapid randomized involuntary contractions of individual motor units within a muscle.

hernia The rupture or protrusion of a portion of the underlying viscera through muscle tissue. Most hernias occur in the normally weak places of the abdominal wall. There are four common hernia types:

1. **femoral**—viscera descending through the femoral ring;
2. **hiatal**—the superior portion of the stomach protruding into the thoracic cavity through the esophageal opening of the diaphragm;
3. **inguinal**—viscera protruding through the inguinal ring into the inguinal canal; and
4. **umbilical**—a hernia occurring at the navel.

intramuscular injection A hypodermic injection into a heavily muscled area to avoid damaging nerves. The most common site is the buttock.

myalgia (*mi-al'je-ă*) Pain in a muscle.

myokymia (*mi-o-ki'me-ă*) Twitching of isolated segments of muscle; also called *kymatism*.

myoma (*mi-o'mă*) A tumor of muscle tissue.

myopathy (*mi-op'ă-the*) Any muscular disease.

myotomy (*mi-ot'ŏ-me*) Surgical cutting or anatomical dissection of muscle tissue.

myotonia (*mi''ŏ-to'ne-ă*) A prolonged muscular spasm.

paralysis The loss of nervous control of a muscle.

shinsplints Tenderness and pain on the anterior surface of the leg generally caused by straining the tibialis anterior or extensor digitorum longus muscle.

Chapter Summary

Introduction to the Muscular System (pp. 234–235)

1. The contraction of skeletal muscle fibers results in body motion, heat production, and the maintenance of posture and body support.
2. The four basic properties characteristic of all muscle tissue are irritability, contractility, extensibility, and elasticity.
3. Axial muscles include facial muscles, neck muscles, and trunk muscles. Appendicular muscles include those that act on the girdles and those that move the segments of the appendages.

Structure of Skeletal Muscles (pp. 235–240)

1. The origin of a muscle is the more stationary attachment. The insertion is the more movable attachment.
2. Individual muscle fibers are covered by endomysium. Muscle bundles, called fasciculi, are covered by perimysium. The entire muscle is covered by epimysium.
3. Synergistic muscles work together to promote a particular movement. Muscles that oppose or reverse the actions of other muscles are antagonists.
4. Muscles may be classified according to fiber arrangement as parallel, convergent, pennate, or sphincteral.
5. Motor neurons conduct nerve impulses to the muscle fiber, stimulating it to contract. Sensory neurons conduct nerve impulses away from the muscle fiber to the central nervous system.

Skeletal Muscle Fibers and Types of Muscle Contraction (pp. 240–246)

1. Each skeletal muscle fiber is a multinucleated, striated cell. It contains a large number of long, threadlike myofibrils and is enclosed by a cell membrane called a sarcolemma.
   (a) Myofibrils have alternating A and I bands. Each I band is bisected by a Z line, and the subunit between two Z lines is called the sarcomere.
   (b) Extending through the sarcoplasm are a network of membranous channels called the sarcoplasmic reticulum and a system of transverse tubules (T tubules).
2. During muscle contraction, shortening of the sarcomeres is produced by sliding of the thin (actin) myofilaments over and between the thick (myosin) myofilaments.
   (a) The actin on each side of the A bands is pulled toward the center.
   (b) The H bands thus appear to be shorter as more actin overlaps the myosin.
   (c) The I bands also appear to be shorter as adjacent A bands are pulled closer together.
   (d) The A bands stay the same length because the myofilaments (both thick and thin) do not shorten during muscle contraction.
3. When a muscle exerts tension without shortening, the contraction is termed isometric; when shortening does occur, the contraction is isotonic.
4. The neuromuscular junction is the area consisting of the motor end plate and the sarcolemma of a muscle fiber. In response to a nerve impulse, the synaptic vesicles of the axon terminal secrete a neurotransmitter, which diffuses across the neuromuscular cleft of the neuromuscular junction and stimulates the muscle fiber.
5. A motor unit consists of a motor neuron and the muscle fibers it innervates.
   (a) Where fine control is needed, each motor neuron innervates relatively few muscle fibers. Where strength is more important than precision, each motor unit innervates a large number of muscle fibers.
   (b) The neurons of small motor units have relatively small cell bodies and tend to be easily excited. Those of large motor units have larger cell bodies and are less easily excited.

Naming of Muscles (pp. 246–247)

1. Skeletal muscles are named on the basis of shape, location, attachment, orientation of fibers, relative position, and function.
2. Most muscles are paired; that is, the right side of the body is a mirror image of the left.

Muscles of the Axial Skeleton (pp. 250–263)

The muscles of the axial skeleton include those responsible for facial expression, mastication, eye movement, tongue movement, neck movement, and respiration, and those of the abdominal wall, the pelvic outlet, and the vertebral column. They are summarized in tables 9.3 through 9.10.

Muscles of the Appendicular Skeleton (pp. 263–292)

The muscles of the appendicular skeleton include those of the pectoral girdle, humerus, forearm, wrist, hand, and fingers, and those of the pelvic girdle, thigh, leg, ankle, foot, and toes. They are summarized in tables 9.11 through 9.19.

CHAPTER 9

Review Activities

Objective Questions

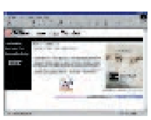
1. The site at which a nerve impulse is transmitted from the motor nerve ending to the skeletal muscle cell membrane is
   (a) the sarcomere.
   (b) the neuromuscular junction.
   (c) the myofilament.
   (d) the Z line.
2. Muscles capable of highly dexterous movements contain
   (a) one motor unit per muscle fiber.
   (b) many muscle fibers per motor unit.
   (c) few muscle fibers per motor unit.
   (d) many motor units per muscle fiber.
3. Which of the following is *not* used as a means of naming muscles?
   (a) location
   (b) action
   (c) shape
   (d) attachment
   (e) strength of contraction
4. Neurotransmitters are stored in synaptic vesicles within
   (a) the sarcolemma.
   (b) the motor units.
   (c) the myofibrils.
   (d) the axon terminals.
5. Which of the following muscles have motor units with the lowest innervation ratio?
   (a) brachial muscles
   (b) muscles of the forearm
   (c) thigh muscles
   (d) abdominal muscles
6. An eyebrow is drawn toward the midline of the face through contraction of which muscle?
   (a) the corrugator supercilli
   (b) the risorius
   (c) the nasalis
   (d) the frontalis
7. A flexor of the shoulder joint is
   (a) the pectoralis major.
   (b) the supraspinatus.
   (c) the teres major.
   (d) the trapezius.
   (e) the latissimus dorsi.
8. Which of the following muscles does *not* have either an origin or insertion on the humerus?
   (a) the teres minor
   (b) the biceps brachii
   (c) the supraspinatus
   (d) the brachialis
   (e) the pectoralis major
9. Which muscle of the four that compose the quadriceps femoris muscle may act on the hip and knee joints?
   (a) the vastus medialis
   (b) the vastus intermedius
   (c) the rectus femoris
   (d) the vastus lateralis
10. Which of the following muscles plantar flexes the ankle joint and inverts the foot as it supports the arches?
    (a) the flexor digitorum longus
    (b) the tibialis posterior
    (c) the flexor hallucis longus
    (d) the gastrocnemius

Essay Questions

1. Describe how muscle fibers are formed and explain why the fibers are multinucleated.
2. Describe the special characteristics of muscle tissue that are essential for muscle contraction.
3. Define *fascia*, *aponeurosis*, and *retinaculum*.
4. Describe the structural arrangement of the muscle fibers and fasciculi within muscle.
5. What are the advantages and disadvantages of pennate-fibered muscles?
6. List the major components of a skeletal muscle fiber and describe the function of each part.
7. What is a motor unit, and what is its role in muscle contraction?
8. Give three examples of synergistic muscle groups within the upper extremity and identify the antagonistic muscle group for each.
9. Attempt to contract, one at a time, each of the neck muscles depicted in figure 9.20.
10. List all the muscles that either originate or insert on the scapula.
11. Give three examples of synergistic muscle groups within the lower extremity and identify the antagonistic muscle group for each.
12. Describe the flexor and extensor compartments of the muscles of the forearm.
13. List the muscles that border the popliteal fossa. Describe the structures that are located in this region.
14. Firmly press your fingers on the front, sides, and back of your ankle as you move your foot. The tendons of which muscles can be palpated anteriorly, laterally, and posteriorly?

Critical-Thinking Questions

1. In the sixteenth century, Andreas Vesalius demonstrated that cutting a muscle along its length has very little effect on its function; on the other hand, a transverse cut puts a muscle out of action. How would you explain Vesalius's findings?
2. As a result of a severe head trauma sustained in an automobile accident, a 17–year-old male lost function of his right oculomotor nerve. Explain what will happen to the function of the affected eye.
3. Discuss the position of flexor and extensor muscles relative to the shoulder, elbow, and wrist joints.
4. Based on function, describe exercises that would strengthen the following muscles: (a) the pectoralis major, (b) the deltoid, (c) the triceps, (d) the pronator teres, (e) the rhomboideus major, (f) the trapezius, (g) the serratus anterior, and (h) the latissimus dorsi.
5. Why is it necessary to have dual (sensory and motor) innervation to a muscle? Give an example of a disease that results in loss of motor innervation to specific skeletal muscles, and describe the effects of this denervation.
6. Compare muscular dystrophy and myasthenia gravis as to causes, symptoms, and the effect they have on muscle tissue.



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