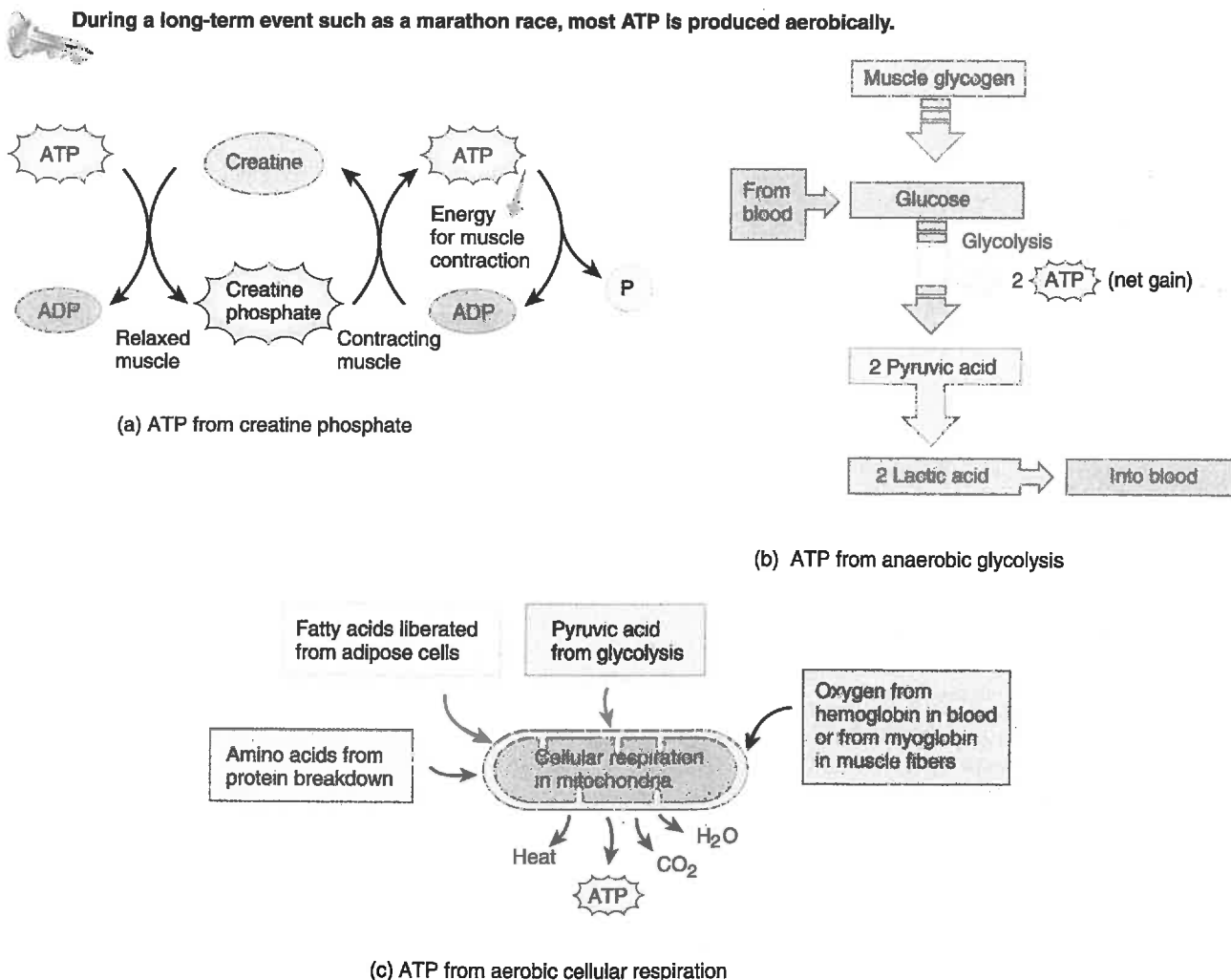


fibers (Figure 8.8a). One of ATP's high-energy phosphate groups is transferred to creatine, forming creatine phosphate and ADP (adenosine diphosphate). **Creatine** is a small, amino acid-like molecule that is synthesized in the liver, kidneys, and pancreas and derived from certain foods (milk, red meat, fish), then transported to muscle fibers. While muscle is contracting, the high-energy phosphate group can be transferred from creatine phosphate back to ADP, quickly forming new ATP molecules. Together, creatine phosphate and ATP provide enough energy for muscles to contract maximally for about 15 seconds. This energy is sufficient for short bursts of intense activity, for example, running a 100-meter dash.

Adults need to synthesize and ingest a total of about 2 grams of creatine daily to make up for the urinary loss of creatinine, the breakdown product of creatine. Some studies have demonstrated improved performance during intense exercise in subjects who had ingested creatine supplements. For example, college football players who received supplements of 15 grams per day for 28 days gained more muscle mass and had larger gains in lifting power and sprinting performance than the control subjects. Other studies, however, have failed to find a performance-enhancing effect of creatine supplementation. In addition,

**Figure 8.8 Production of ATP for muscle contraction.**

(a) Creatine phosphate, formed from ATP while the muscle is relaxed, transfers a high-energy phosphate group to ADP, forming ATP, during muscle contraction. (b) Breakdown of muscle glycogen into glucose and production of pyruvic acid from glucose via glycolysis produce both ATP and lactic acid. Because no oxygen is needed, this is an anaerobic pathway. (c) Within mitochondria, pyruvic acid, fatty acids, and amino acids are used to produce ATP via aerobic cellular respiration, an oxygen-requiring set of reactions.



? Where inside a skeletal muscle fiber are the events shown here occurring?

ingesting extra creatine decreases the body's own synthesis of creatine, and it is not known whether natural synthesis recovers after long-term creatine supplementation. Further research is needed to determine both the long-term safety and the value of **creatine supplementation**.

When muscle activity continues past the 15-second mark, the supply of creatine phosphate is depleted. The next source of ATP is *glycolysis*, a series of cytosolic reactions that produces 2 ATPs by breaking down a glucose molecule to pyruvic acid. Glucose passes easily from the blood into contracting muscle fibers and also is produced within muscle fibers by breakdown of glycogen (Figure 8.8b). When oxygen levels are low as a result of vigorous muscle activity, most of the pyruvic acid is converted to lactic acid, a process called **anaerobic cellular respiration** because it occurs without using oxygen. Anaerobic cellular respiration can provide enough energy for about 30 to 40 seconds of maximal muscle activity. Together, conversion of creatine phosphate and glycolysis can provide enough ATP to run a 400-meter race.

Muscle activity that lasts longer than half a minute depends increasingly on **aerobic cellular respiration**, a series of oxygen-requiring reactions that produce ATP in mitochondria. Muscle fibers have two sources of oxygen: (1) oxygen that diffuses into them from the blood and (2) oxygen released by myoglobin in the sarcoplasm. **Myoglobin** is an oxygen-binding protein found only in muscle fibers. It binds oxygen when oxygen is plentiful and releases oxygen when it is scarce. If enough oxygen is present, pyruvic acid enters the mitochondria, where it is completely oxidized in reactions that generate ATP, carbon dioxide, water, and heat (Figure 8.8c). In comparison with anaerobic cellular respiration, aerobic cellular respiration yields much more ATP, about 36 molecules of ATP from each glucose molecule. In activities that last more than 10 minutes, aerobic cellular respiration provides most of the needed ATP.

## Muscle Fatigue

The inability of a muscle to contract forcefully after prolonged activity is called **muscle fatigue**. One important factor in muscle fatigue is lowered release of calcium ions from the sarcoplasmic reticulum, resulting in a decline of  $\text{Ca}^{2+}$  level in the sarcoplasm. Other factors that contribute to muscle fatigue include depletion of creatine phosphate, insufficient oxygen, depletion of glycogen and other nutrients, buildup of lactic acid and ADP, and failure of nerve impulses in the motor neuron to release enough acetylcholine.

## Oxygen Consumption After Exercise

During prolonged periods of muscle contraction, increases in breathing and blood flow enhance oxygen delivery to muscular tissue. After muscle contraction has stopped, heavy

breathing continues for a period of time, and oxygen consumption remains above the resting level. The term **oxygen debt** refers to the added oxygen, over and above the oxygen consumed at rest, that is taken into the body after exercise. This extra oxygen is used to “pay back” or restore metabolic conditions to the resting level in three ways: (1) to convert lactic acid back into glycogen stores in the liver, (2) to resynthesize creatine phosphate and ATP, and (3) to replace the oxygen removed from myoglobin.

The metabolic changes that occur *during exercise*, however, account for only some of the extra oxygen used *after exercise*. Only a small amount of resynthesis of glycogen occurs from lactic acid. Instead, glycogen stores are replenished much later from dietary carbohydrates. Much of the lactic acid that remains after exercise is converted back to pyruvic acid and used for ATP production via aerobic cellular respiration. Ongoing changes after exercise also boost oxygen use. First, the elevated body temperature after strenuous exercise increases the rate of chemical reactions throughout the body. Faster reactions use ATP more rapidly, and more oxygen is needed to produce ATP. Second, the heart and muscles used in breathing are still working harder than they were at rest, and thus they consume more ATP. Third, tissue repair processes are occurring at an increased pace. For these reasons, **recovery oxygen uptake** is a better term than oxygen debt for the elevated use of oxygen after exercise.

### CHECKPOINT

8. What are the sources of ATP for muscle fibers?
9. What factors contribute to muscle fatigue?
10. Why is the term *recovery oxygen uptake* more accurate than *oxygen debt*?

## CONTROL OF MUSCLE TENSION

**OBJECTIVES** • Explain the three phases of a twitch contraction.

- Describe how the frequency of stimulation and motor unit recruitment affect muscle tension.
- Compare the three types of skeletal muscle fibers.
- Distinguish between isotonic and isometric contractions.

The contraction that results from a single muscle action potential, a muscle twitch, has significantly smaller force than the maximum force or tension the fiber is capable of producing. The total tension that a *single* muscle fiber can produce depends mainly on the rate at which nerve impulses arrive at its neuromuscular junction. The number of impulses per second is the *frequency of stimulation*. When considering the contraction of a *whole* muscle, the total tension it can produce

depends on the number of muscle fibers that are contracting in unison.

## Twitch Contraction

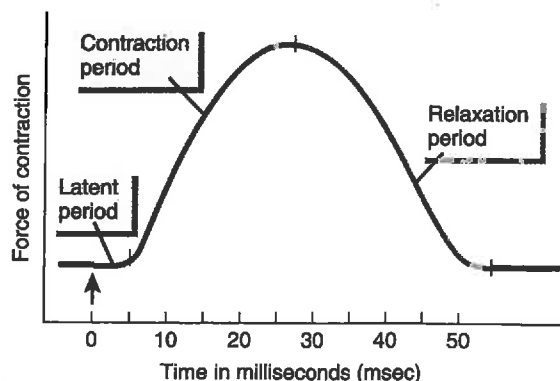
A **twitch contraction** is a brief contraction of all the muscle fibers in a motor unit in response to a single action potential in its motor neuron. Figure 8.9 shows a recording of a muscle contraction, called a **myogram**. Note that a brief delay, called the **latent period**, occurs between application of the stimulus (time zero on the graph) and the beginning of contraction. During the latent period, the muscle action potential sweeps over the sarcolemma and calcium ions are released from the sarcoplasmic reticulum. During the second phase, the **contraction period** (upward tracing), repetitive power strokes are occurring, generating tension or force of contraction. In the third phase, the **relaxation period** (downward tracing), power strokes cease because the level of  $\text{Ca}^{2+}$  in the sarcoplasm is decreasing to the resting level. (Recall that calcium ions are actively transported back into the sarcoplasmic reticulum.)

## Frequency of Stimulation

If a second stimulus occurs before a muscle fiber has completely relaxed, the second contraction will be stronger than the first because the second contraction begins when the fiber is at a higher level of tension (Figure 8.10a, b). This phenomenon, in which stimuli arriving one after the other cause larger contractions, is called **wave summation**. When a skeletal muscle fiber is stimulated at a rate of 20 to 30 times per second, it can only partially relax between stimuli. The result is a sustained but wavering contraction called **unfused (incomplete) tetanus** (*tetan-* = rigid, tense; Figure 8.10c). When a skeletal muscle fiber is stimulated at a higher rate of

**Figure 8.9 Myogram of a twitch contraction.** The arrow indicates the time at which the stimulus occurred.

A myogram is a record of a muscle contraction.



? During which period do sarcomeres shorten?

80 to 100 times per second, it does not relax at all. The result is **fused (complete) tetanus**, a sustained contraction in which individual twitches cannot be detected (Figure 8.10d).

## Motor Unit Recruitment

The process in which the number of contracting motor units is increased is called **motor unit recruitment**. Normally, the various motor neurons to a whole muscle fire **asynchronously** (at different times): While some motor units are contracting, others are relaxed. This pattern of motor unit activity delays muscle fatigue by allowing alternately contracting motor units to relieve one another, so that the contraction can be sustained for long periods.

Recruitment is one factor responsible for producing smooth movements rather than a series of jerky movements. Precise movements are brought about by small changes in muscle contraction. Typically, the muscles that produce precise movements are composed of small motor units. In this way, when a motor unit is recruited or turned off, only slight changes occur in muscle tension. On the other hand, large motor units are active where large tension is needed and precision is less important.

## Types of Skeletal Muscle Fibers

Skeletal muscles contain three types of muscle fibers, which are present in varying proportions in different muscles of the body: The fiber types are (1) slow oxidative fibers, (2) fast oxidative–glycolytic fibers, and (3) fast glycolytic fibers.

**Slow oxidative (SO) fibers** or **red fibers** are small in diameter and appear dark red because they contain a large amount of myoglobin. Because they have many large mitochondria, SO fibers generate ATP mainly by aerobic cellular respiration, which is why they are called oxidative fibers. These fibers are said to be “slow” because the contraction cycle proceeds at a slower pace than in “fast” fibers. SO fibers are very resistant to fatigue and are capable of prolonged, sustained contractions.

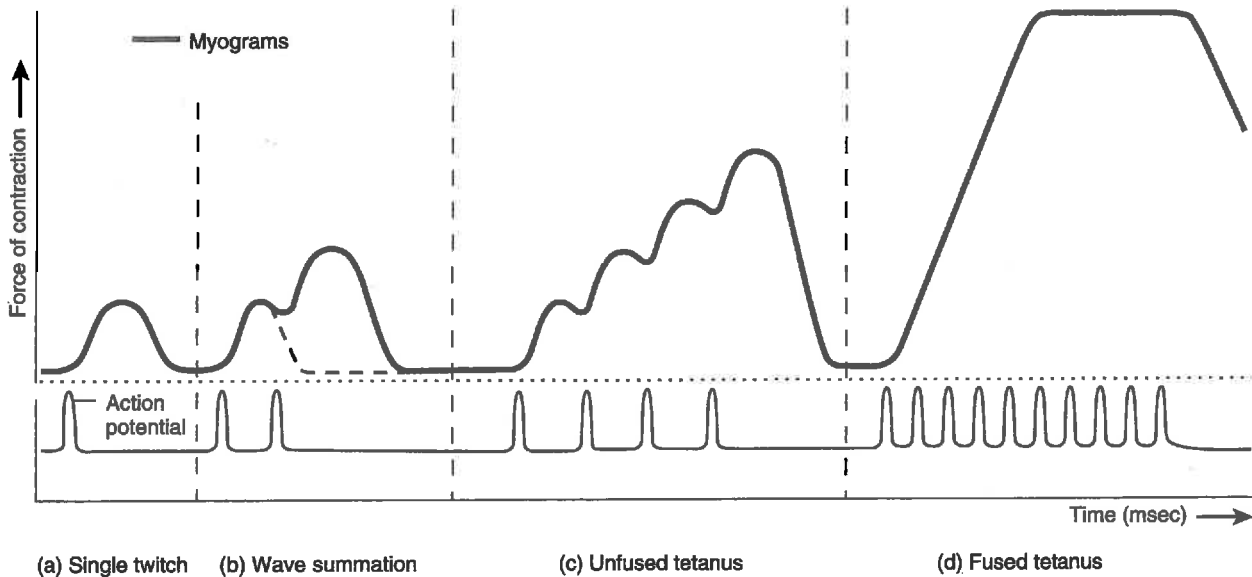
**Fast oxidative–glycolytic (FOG) fibers** are intermediate in diameter between the other two types. Like slow oxidative fibers, they contain a large amount of myoglobin, and thus appear dark red. FOG fibers can generate considerable ATP by aerobic cellular respiration, which gives them a moderately high resistance to fatigue. Because their glycogen content is high, they also generate ATP by anaerobic glycolysis. These fibers are “fast” because they contract and relax more quickly than SO fibers.

**Fast glycolytic (FG) fibers** or **white fibers** are largest in diameter, contain the most myofibrils, and generate the most powerful and most rapid contractions. They have a low myoglobin content and few mitochondria. FG fibers contain large amounts of glycogen and generate ATP mainly by anaerobic glycolysis. They are used for intense movements of short duration, but they fatigue quickly. Strength-training

**Figure 8.10 Myograms showing the effects of different frequencies of stimulation.** (a) Single twitch. (b) When a second stimulus occurs before the muscle has relaxed, wave summation occurs, and the second contraction is stronger than the first. (The dashed line indicates the force of contraction expected in a single twitch.) (c) In unfused tetanus, the curve looks jagged due to partial relaxation of the muscle between stimuli. (d) In fused tetanus, the contraction force is steady and sustained.



Due to wave summation, the tension produced during a sustained contraction is greater than during a single twitch.



? What frequency of stimulation is needed to produce fused tetanus?

programs that engage a person in activities requiring great strength for short times produce increases in the size, strength, and glycogen content of FG fibers.

Most skeletal muscles are a mixture of all three types of skeletal muscle fibers, about half of which are SO fibers. The proportions vary somewhat, depending on the action of the muscle, the person's training program, and genetic factors. For example, the continually active postural muscles of the neck, back, and legs have a high proportion of SO fibers. Muscles of the shoulders and arms, in contrast, are not constantly active but are used intermittently and briefly to produce large amounts of tension, such as in lifting and throwing. These muscles have a high proportion of FG fibers. Leg muscles, which not only support the body but are also used for walking and running, have large numbers of both SO and FOG fibers.

Even though most skeletal muscles are a mixture of all three types of skeletal muscle fibers, the skeletal muscle fibers of any given motor unit are all of the same type. The different motor units in a muscle are recruited in a specific order, depending on need. For example, if weak contractions suffice to perform a task, only SO motor units are activated. If more force is needed, the motor units of FOG fibers are also recruited. Finally, if maximal force is required, motor units of FG fibers are also called into action.

## Isometric and Isotonic Contractions

Muscle contractions are classified as either isotonic or isometric. In an **isotonic contraction** (*iso-* = equal; *-tonic* = tension), the tension (force of contraction) developed by the muscle remains almost constant while the muscle changes its length. Isotonic contractions are used for body movements and for moving objects. For example, picking up a book from a table involves isotonic contractions of the biceps brachii muscle in the arm.

In an **isometric contraction** (*-metro* = measure or length), the tension generated is not enough to exceed the resistance of the object to be moved and the muscle does not change its length. Isometric contractions occur when you try to lift a box but the box does not move because it is too heavy. Isometric contractions are important for maintaining posture and supporting objects in a fixed position.

### CHECKPOINT

11. Define the following terms: myogram, twitch contraction, wave summation, unfused tetanus, and fused tetanus.
12. What characteristics distinguish the three types of skeletal muscle fibers?
13. Provide examples of isometric and isotonic contractions.

## EXERCISE AND SKELETAL MUSCLE TISSUE

**OBJECTIVE •** Describe the effects of exercise on skeletal muscle tissue.

The relative ratio of fast glycolytic (FG) and slow oxidative (SO) fibers in each muscle is genetically determined and helps account for individual differences in physical performance. For example, people with a higher proportion of FG fibers often excel in activities that require periods of intense activity, such as weight lifting or sprinting. People with higher percentages of SO fibers are better at activities that require endurance, such as long-distance running.

Although the total number of skeletal muscle fibers usually does not increase, the characteristics of those present can change to some extent. Various types of exercises can induce changes in the fibers in a skeletal muscle. Endurance-type (aerobic) exercises, such as running or swimming, cause a gradual transformation of some FG fibers into fast oxidative-glycolytic (FOG) fibers. The transformed muscle fibers show slight increases in diameter, number of mitochondria, blood supply, and strength. Endurance exercises also result in cardiovascular and respiratory changes that cause skeletal muscles to receive better supplies of oxygen and nutrients but do not increase muscle mass. By contrast, exercises that require great strength for short periods produce an increase in the size and strength of FG fibers. The increase in size is due to increased synthesis of thick and thin filaments. The overall result is muscle enlargement (hypertrophy), as evidenced by the bulging muscles of body builders.

### ■ CHECKPOINT

14. Explain how the characteristics of skeletal muscle fibers may change with exercise.

## CARDIAC MUSCLE TISSUE

**OBJECTIVE •** Describe the structure and function of cardiac muscle tissue.

Most of the heart consists of *cardiac muscle tissue*. Like skeletal muscle, cardiac muscle is also *striated*, but its action is *involuntary*. Its alternating cycles of contraction and relaxation are not consciously controlled. Cardiac muscle fibers often are branched; are shorter in length and larger in diameter than skeletal muscle fibers; and have a single, centrally located nucleus (see Figure 15.2b on page 366). Cardiac muscle fibers interconnect with one another by irregular transverse thickenings of the sarcolemma called *intercalated discs* (in-TER-ka-lāt-ed = to insert between).

The intercalated discs hold the fibers together and contain *gap junctions*, which allow muscle action potentials to spread quickly from one cardiac muscle fiber to another.

A major difference between skeletal muscle and cardiac muscle is the source of stimulation. We have seen that skeletal muscle tissue contracts only when stimulated by acetylcholine released by a nerve impulse in a motor neuron. In contrast, the heart beats because some of the cardiac muscle fibers act as a pacemaker to initiate each cardiac contraction. The built-in or intrinsic rhythm of heart contractions is called *autorhythmicity* (aw-tō-rith-MIS-i-tē). Several hormones and neurotransmitters can increase or decrease heart rate by speeding or slowing the heart's pacemaker.

Under normal resting conditions, cardiac muscle tissue contracts and relaxes an average of about 75 times a minute. Thus, cardiac muscle tissue requires a constant supply of oxygen and nutrients. The mitochondria in cardiac muscle fibers are larger and more numerous than in skeletal muscle fibers and produce most of the needed ATP via aerobic cellular respiration. In addition, cardiac muscle fibers can use lactic acid, released by skeletal muscle fibers during exercise, to make ATP.

### ■ CHECKPOINT

15. What are the major structural and functional differences between cardiac and skeletal muscle tissue?

## SMOOTH MUSCLE TISSUE

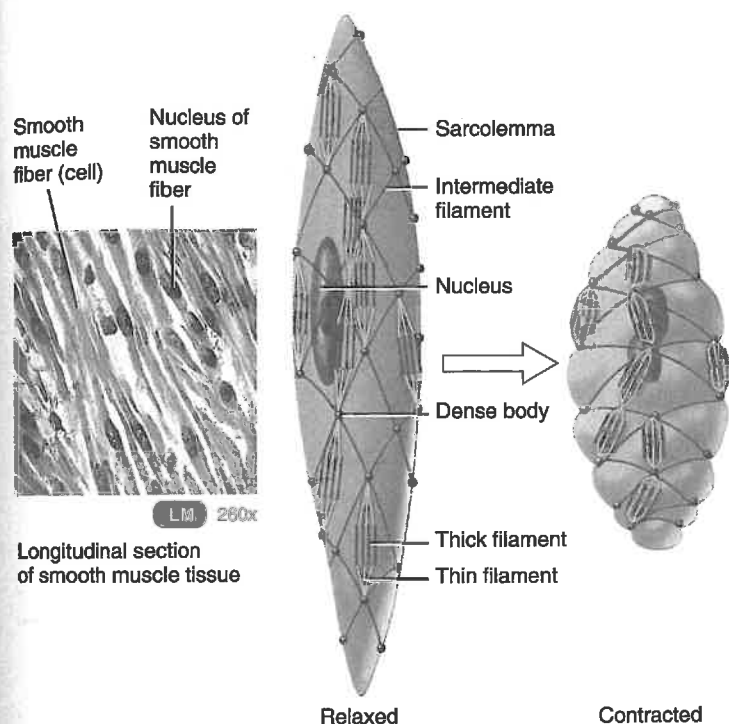
**OBJECTIVE •** Describe the structure and function of smooth muscle tissue.

*Smooth muscle tissue* is found in many internal organs and blood vessels. Like cardiac muscle, smooth muscle is *involuntary*. Smooth muscle fibers are considerably smaller in length and diameter than skeletal muscle fibers and are tapered at both ends. Within each fiber is a single, oval, centrally located nucleus (Figure 8.11). In addition to thick and thin filaments, smooth muscle fibers also contain *intermediate filaments*. Because the various filaments have no regular pattern of overlap, smooth muscle fibers lack alternating dark and light bands and thus appear *nonstriated*, or smooth.

In smooth muscle fibers, the thin filaments attach to structures called *dense bodies*, which are functionally similar to Z discs in striated muscle fibers. Some dense bodies are dispersed throughout the sarcoplasm; others are attached to the sarcolemma. Bundles of intermediate filaments also attach to dense bodies and stretch from one dense body to another. During contraction, the sliding filament mechanism involving thick and thin filaments generates tension that is

**Figure 8.11 Histology of smooth muscle tissue.** A smooth muscle fiber is shown in the relaxed state (left) and the contracted state (right).

Smooth muscle lacks striations—it looks “smooth”—because the thick and thin filaments and intermediate filaments are irregularly arranged.



? Which type of smooth muscle is found in the walls of hollow organs?

transmitted to intermediate filaments. These, in turn, pull on the dense bodies attached to the sarcolemma, causing a lengthwise shortening of the muscle fiber.

There are two kinds of smooth muscle tissue, visceral and multiunit. The more common type is *visceral (single-unit) muscle tissue*. It is found in sheets that wrap around to form part of the walls of small arteries and veins and hollow viscera such as the stomach, intestines, uterus, and urinary bladder. The fibers in visceral muscle tissue are tightly bound together in a continuous network. Like cardiac muscle, visceral smooth muscle is autorhythmic. Because the fibers connect to one another by gap junctions, muscle action potentials spread throughout the network. When a neurotransmitter, hormone, or autorhythmic signal stimulates one fiber, the muscle action potential spreads to neighboring fibers, which then contract in unison, as a single unit.

The second kind of smooth muscle tissue, *multiunit smooth muscle tissue*, consists of individual fibers, each with its own motor nerve endings. Unlike stimulation of a single visceral muscle fiber, which causes contraction of many adjacent fibers, stimulation of a single multiunit smooth muscle

fiber causes contraction of that fiber only. Multiunit smooth muscle tissue is found in the walls of large arteries, in large airways to the lungs, in the arrector pili muscles attached to hair follicles, and in the internal eye muscles.

Compared with contraction in a skeletal muscle fiber, contraction in a smooth muscle fiber starts more slowly and lasts much longer. Calcium ions enter smooth muscle fibers slowly and also move slowly out of the muscle fiber when excitation declines, which delays relaxation. The prolonged presence of  $\text{Ca}^{2+}$  in the cytosol provides for *smooth muscle tone*, a state of continued partial contraction. Smooth muscle tissue can thus sustain long-term tone, which is important in the walls of blood vessels and in the walls of organs that maintain pressure on their contents. Finally, smooth muscle can both shorten and stretch to a greater extent than other muscle types. Stretchiness permits smooth muscle in the wall of hollow organs such as the uterus, stomach, intestines, and urinary bladder to expand as their contents enlarge, while still retaining the ability to contract.

Most smooth muscle fibers contract or relax in response to nerve impulses from the autonomic (involuntary) nervous system. In addition, many smooth muscle fibers contract or relax in response to stretching; hormones; or local factors such as changes in pH, oxygen and carbon dioxide levels, temperature, and ion concentrations. For example, the hormone epinephrine, released by the adrenal medulla, causes relaxation of smooth muscle in the airways and in some blood vessel walls.

Table 8.1 presents a summary of the major characteristics of the three types of muscular tissue.

## ■ CHECKPOINT


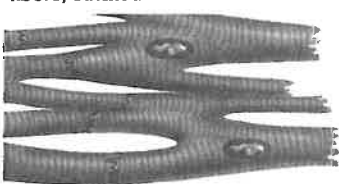

16. How do visceral and multiunit smooth muscle differ?
17. What are the major structural and functional differences between smooth and skeletal muscle tissue?

# AGING AND MUSCULAR TISSUE

**OBJECTIVE** • Explain the effects of aging on skeletal muscle.

Beginning at about 30 years of age, humans undergo a slow, progressive loss of skeletal muscle mass that is replaced largely by fibrous connective tissue and adipose tissue. In part, this decline is due to decreased levels of physical activity. Accompanying the loss of muscle mass is a decrease in maximal strength, a slowing of muscle reflexes, and a loss of flexibility. In some muscles, a selective loss of muscle fibers of a given type may occur. With aging, the relative number of slow oxidative fibers appears to increase. This could be due either to atrophy of the other fiber types or their conversion into slow oxidative fibers. Whether this is an effect of aging

Table 8.1 Summary of the Principal Features of Muscular Tissue

Characteristics	Skeletal Muscle	Cardiac Muscle	Smooth Muscle
<b>Cell Appearance and Features</b>	Long cylindrical fiber with many peripherally located nuclei; striated; unbranched 	Branched cylindrical fiber, usually with one centrally located nucleus; intercalated discs join neighboring fibers; striated 	Fiber is thickest in the middle, tapered at each end, has one centrally located nucleus; not striated 
<b>Location</b>	Primarily attached to bones by tendons	Heart	Walls of hollow viscera, airways, blood vessels, iris and ciliary body of the eye, arrector pili of hair follicles
<b>Fiber Diameter</b>	Very large (10–100 μm)*	Large (10–20 μm)	Small (3–8 μm)
<b>Fiber Length</b>	Very large (100 μm–30 cm)	Small (50–100 μm)	Intermediate (30–200 μm)
<b>Sarcomeres</b>	Yes	Yes	No
<b>Transverse Tubules</b>	Yes, aligned with each A–I band junction	Yes, aligned with each Z disc	No
<b>Speed of Contraction</b>	Fast	Moderate	Slow
<b>Nervous Control</b>	Voluntary	Involuntary	Involuntary
<b>Capacity for Regeneration</b>	Limited	Limited	Considerable compared with other muscle tissues, but limited compared with tissues such as epithelium

\*1 micrometer (μm) = 1/25,000 of an inch.

itself or mainly reflects the more limited physical activity of older people is still an unresolved question. Nevertheless, aerobic activities and strength training programs are effective in older people and can slow or even reverse the age-associated decline in muscular performance.

## ■ CHECKPOINT

18. Why does muscle strength decrease with aging?

## HOW SKELETAL MUSCLES PRODUCE MOVEMENT

**OBJECTIVE** • Describe how skeletal muscles cooperate to produce movement.

Now that you have a basic understanding of the structure and functions of muscular tissue, we will examine how skeletal muscles cooperate to produce various body movements.

### Origin and Insertion

Based on the description of muscular tissue, we can define a *skeletal muscle* as an organ composed of several different

types of tissues. These include skeletal muscle tissue, vascular tissue (blood vessels and blood), nervous tissue (motor neurons), and several types of connective tissues.

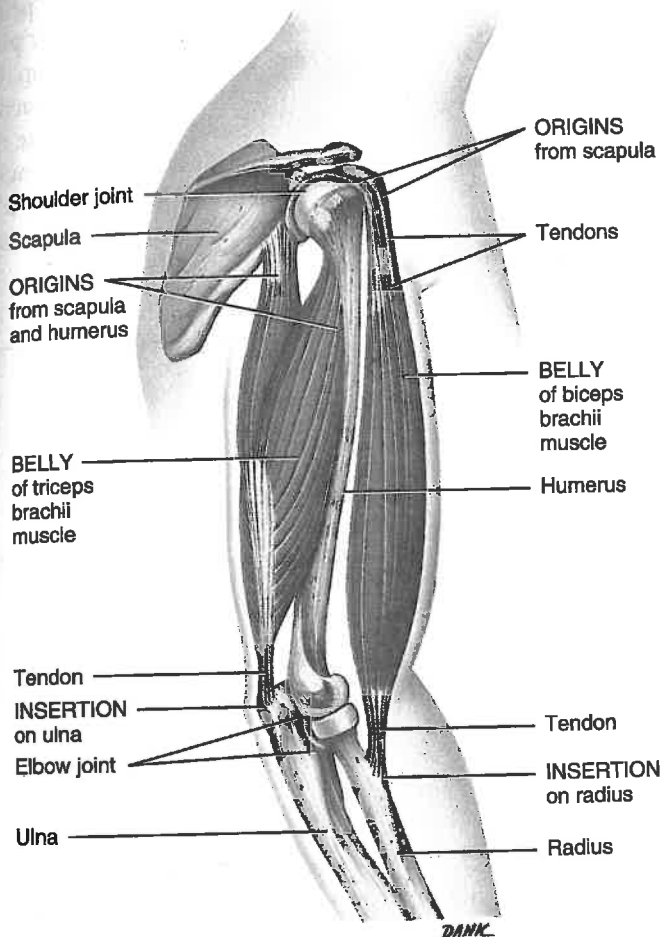
Skeletal muscles are not attached directly to bones; they produce movements by pulling on tendons, which, in turn, pull on bones. Most skeletal muscles cross at least one joint and are attached to the articulating bones that form the joint (Figure 8.12). When the muscle contracts, it draws one bone toward the other. The two bones do not move equally. One is held nearly in its original position; the attachment of a muscle (by means of a tendon) to the stationary bone is called the *origin*. The other end of the muscle is attached by means of a tendon to the movable bone at a point called the *insertion*. The fleshy portion of the muscle between the tendons of the origin and insertion is called the *belly*. A good analogy is a spring on a door. The part of the spring attached to the door represents the insertion, the part attached to the frame is the origin, and the coils of the spring are the belly.

**Tenosynovitis** (ten'-ō-sin-ō-Vĭ-tis), commonly known as **tendinitis**, is a painful inflammation of the tendons, tendon sheaths, and synovial membranes of joints. The tendons most often affected are at the wrists, shoulders, elbows (resulting in *tennis elbow*), finger joints (resulting in *trigger finger*), ankles, and feet. The affected sheaths some-



**Figure 8.12 Relationship of skeletal muscles to bones.**  
Skeletal muscles produce movements by pulling on tendons attached to bones.

In the limbs, the origin of a muscle is proximal and the insertion is distal.



Origin and insertion of a skeletal muscle

? Which muscle produces the desired action?

times become visibly swollen due to fluid accumulation. The joint is tender, and movement of the body part often causes pain. Trauma, strain, or excessive exercise may cause tenosynovitis. For instance, tying shoelaces too tightly may cause tenosynovitis of the dorsum of the foot. Also, gymnasts are prone to developing the condition because of chronic, repetitive, and maximum hyperextension at the wrists.

## Group Actions

Most movements occur because several skeletal muscles are acting in groups rather than individually. Also, most skeletal

muscles are arranged in opposing pairs at joints, that is, flexors—extensors, abductors—adductors, and so on. A muscle that causes a desired action is referred to as the **prime mover** or **agonist** (= leader). Often, another muscle, called the **antagonist** (*ant-* = against), relaxes while the prime mover contracts. The antagonist has an effect opposite to that of the prime mover; that is, the antagonist stretches and yields to the movement of the prime mover. When you bend (flex) your elbow, the biceps brachii is the prime mover. While the biceps brachii is contracting, the triceps brachii, the antagonist, is relaxing (see Figure 8.20). Do not assume, however, that the biceps brachii is always the prime mover and the triceps brachii is always the antagonist. For example, when straightening (extending) the elbow, the triceps brachii serves as the prime mover and the biceps brachii functions as the antagonist. If the prime mover and antagonist contracted together with equal force, there would be no movement, as in an isometric contraction.

Most movements also involve muscles called **synergists** (SIN-er-gists; *syn-* = together; *erg-* = work), which help the prime mover function more efficiently by reducing unnecessary movement. Some muscles in a group also act as **fixators**, stabilizing the origin of the prime mover so that the prime mover can act more efficiently. Under different conditions and depending on the movement, many muscles act at various times as prime movers, antagonists, synergists, or fixators.

## ■ CHECKPOINT

19. Distinguish between the origin and insertion of a skeletal muscle.
20. Explain why most body movements occur because several skeletal muscles act in groups rather than individually.

# PRINCIPAL SKELETAL MUSCLES

**OBJECTIVES** • List and describe the ways that skeletal muscles are named.

- Describe the location of skeletal muscles in various regions of the body and identify their functions.

The names of most of the nearly 700 skeletal muscles are based on specific characteristics. Learning the terms used to indicate specific characteristics will help you remember the names of the muscles (Table 8.2 on page 191).

Exhibits 8.1 through 8.13 list the principal skeletal muscles of the body with their origins, insertions, and actions. (By no means have all the muscles of the body been included.) For each exhibit, an overview section provides a general orientation to the muscles and their functions or unique characteristics. To make it easier for you to learn to say the names of skeletal muscles and understand how they are named, we have provided phonetic pronunciations and word roots that



## FOCUS ON WELLNESS

### Effective Stretching Increases Muscle Flexibility

A certain degree of elasticity is an important attribute of skeletal muscles and their connective tissue attachments. Greater elasticity contributes to a greater degree of *flexibility*, increasing the range of motion of a joint. A joint's *range of motion (ROM)* is the maximum ability to move the bones about the joint through an arc of a circle. For example, a person may normally be able to extend the knee joint from 30° when it is maximally flexed to 170° when fully extended. The ROM or degree of flexibility is then  $170 - 30^\circ = 140^\circ$ . Physical therapists measure improvements in flexibility by increases in ROM.

#### Stretching It

When a relaxed muscle is physically stretched, its ability to lengthen is limited by connective tissue structures, such as fasciae. Regular stretching gradually lengthens these structures, but the process occurs very slowly. To see an improvement in flexibility, stretching exercises must be performed regularly—daily, if possible—for many weeks.

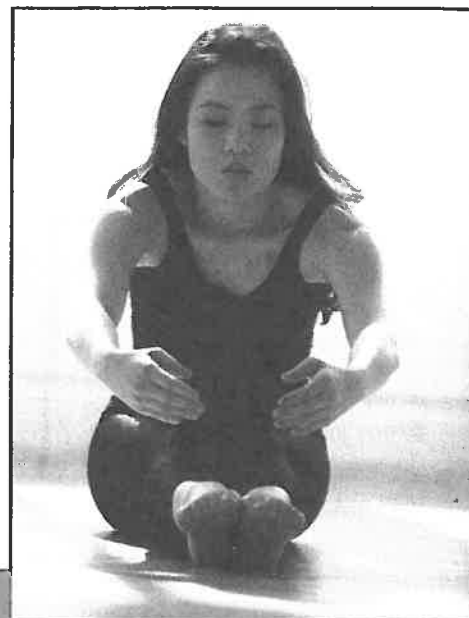
Tissues stretch best when slow, gentle force is applied at elevated tissue temperatures. An external source of heat, such as hot packs or ultrasound, can be used. But 10 or more minutes of muscular contraction is also a good way to raise muscle temperature. Exercise heats the muscle more deeply and thoroughly. That's where the term "warm-up" comes from. It's important to warm up *before* stretching, not vice versa. Stretching cold muscles does not increase flexibility and may even cause injury.

#### Just Relax . . .

The easiest and safest way to increase flexibility is with static stretching. A good static stretch is slow and gentle. After warming up, you get into a comfortable stretching position and relax. Continuing to relax and breathe deeply, you reach just a little farther, and a little farther, holding the stretch for at least 30 seconds. If you have difficulty relaxing, you know you have stretched too far. Ease up until you feel a stretch but no strain.

When stretching, it is important to relax. Sounds simple, right? But if you

ever visit an exercise class, you'll notice some people who are all tense, rigid, and hunched up, because the stretching positions are uncomfortable. As a result, their muscles tighten up in protest. These people figure they'd better push a little harder, and they tense up even more. They are unintentionally activating the motor neurons that initiate muscular contraction in the very muscles they are supposed to be relaxing, which of course interferes with the muscle's ability to elongate and stretch.



#### ► THINK IT OVER . . .

- Using the information presented in this chapter, try to figure out which muscles are being stretched when you place one foot (keep that leg straight) up on a bar or chair.

indicate how the muscles are named (refer also to Table 8.2). Once you have mastered the naming of the muscles, their actions will have more meaning and be easier to remember.

The muscles are divided into groups according to the part of the body on which they act. Figure 8.13 on pages 192–193 shows general anterior and posterior views of the muscular system. As you study groups of muscles in the following exhibits, refer to Figure 8.13 to see how each group is related to all others.

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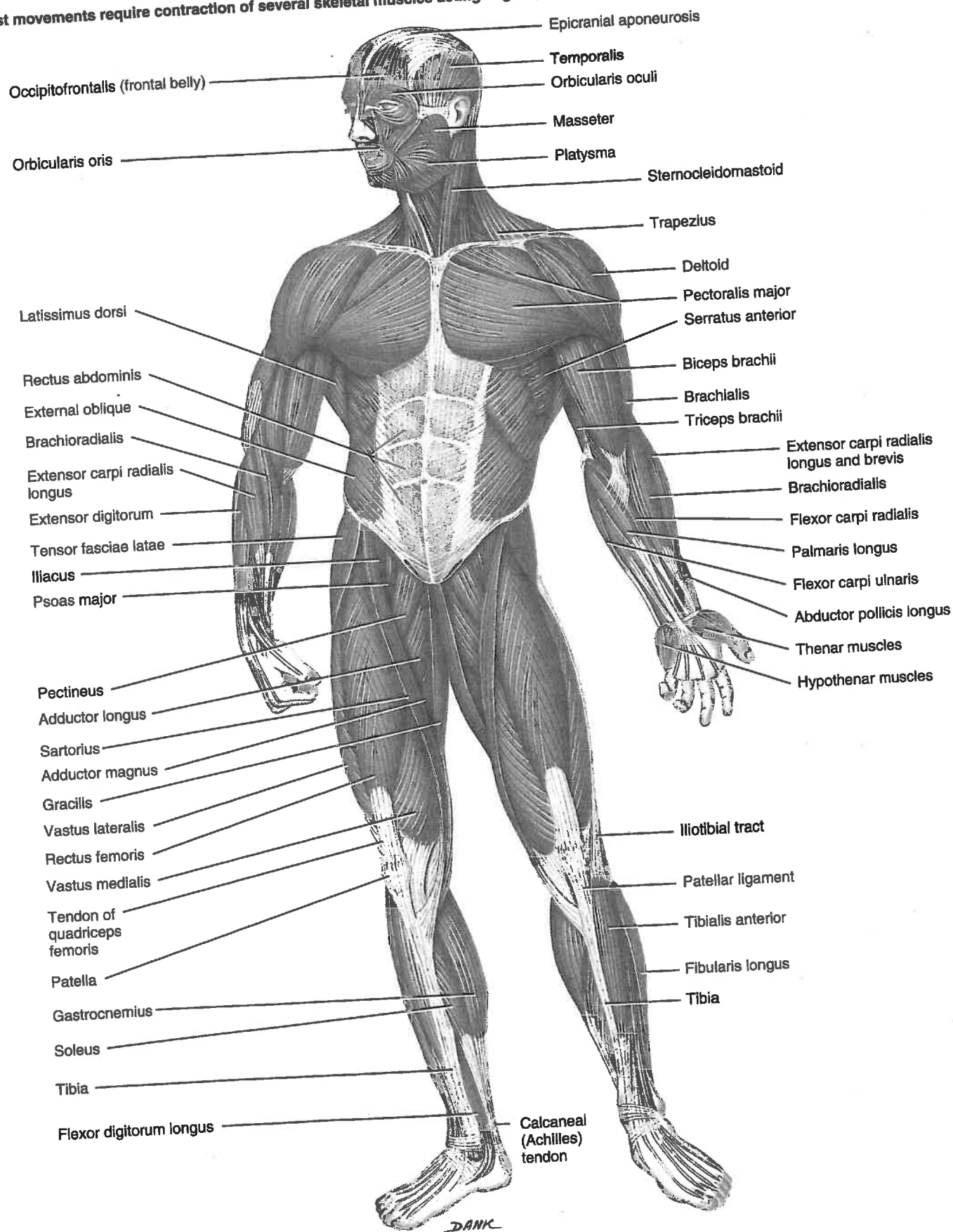
To appreciate the many ways that the muscular system contributes to homeostasis of other body systems, examine Focus on Homeostasis: The Muscular System on page 218. Next, in Chapter 9, we will see how the nervous system is organized, how neurons generate nerve impulses that activate muscle tissues as well as other neurons, and how synapses function.

Table 8.2 Characteristics Used to Name Skeletal Muscles

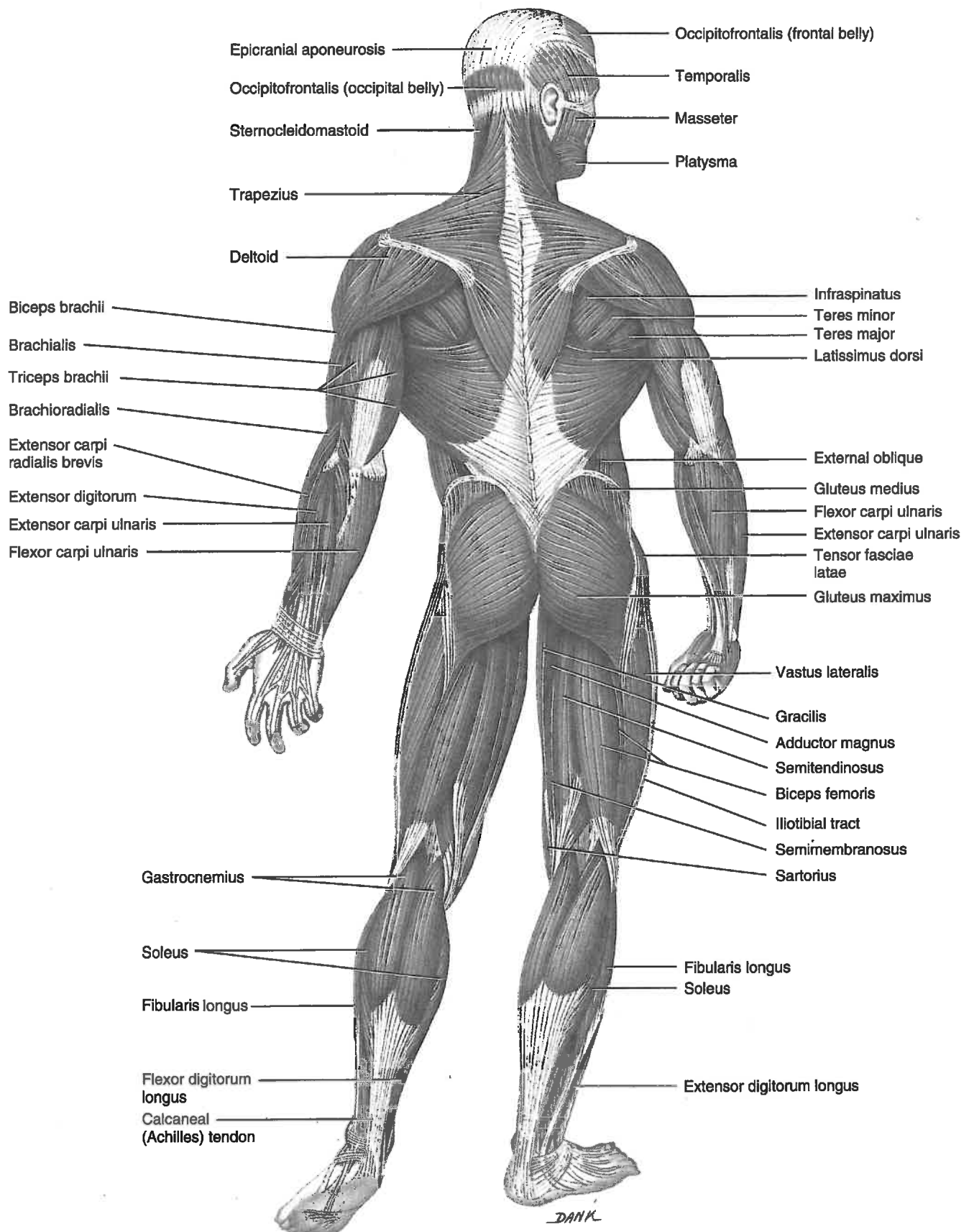
Name	Meaning	Example	Figure
<b>Direction: Orientation of muscle fibers relative to the body's midline</b>			
Rectus	Parallel to midline	Rectus abdominis	8.16b
Transverse	Perpendicular to midline	Transverse abdominis	8.16b
Oblique	Diagonal to midline	External oblique	8.16a
<b>Size: Relative size of the muscle</b>			
Maximus	Largest	Gluteus maximus	8.23b
Minimus	Smallest	Gluteus minimus	8.23b
Longus	Longest	Adductor longus	8.23a
Latissimus	Widest	Latissimus dorsi	8.13b
Longissimus	Longest	Longissimus muscles	8.22
Magnus	Large	Adductor magnus	8.23b
Major	Larger	Pectoralis major	8.13a
Minor	Smaller	Pectoralis minor	8.19a
Vastus	Great	Vastus lateralis	8.23a
<b>Shape: Relative shape of the muscle</b>			
Deltoid	Triangular	Deltoid	8.13b
Trapezius	Trapezoid	Trapezius	8.13b
Serratus	Saw-toothed	Serratus anterior	8.13a
Rhomboid	Diamond-shaped	Rhomboid major	8.18b
Orbicularis	Circular	Orbicularis oculi	8.14
Pectinate	Comblike	Pectineus	8.23a
Piriformis	Pear-shaped	Piriformis	8.23b
Platys	Flat	Platysma	8.13a
Quadratus	Square	Quadratus lumborum	8.17b
Gracilis	Slender	Gracilis	8.23a
<b>Action: Principal action of the muscle</b>			
Flexor	Decreases joint angle	Flexor carpi radialis	8.21a
Extensor	Increases joint angle	Extensor carpi ulnaris	8.21b
Abductor	Moves bone away from midline	Abductor pollicis longus	8.21b
Adductor	Moves bone closer to midline	Adductor longus	8.23a
Levator	Produces superior movement	Levator scapulae	8.18
Depressor	Produces inferior movement	Depressor labii inferioris	
Supinator	Turns palm anteriorly	Supinator	
Pronator	Turns palm posteriorly	Pronator teres	8.21a
Sphincter	Decreases size of opening	External anal sphincter	19.15b
Tensor	Makes a body part rigid	Tensor fasciae latae	8.23a
<b>Number of Origins: Number of tendons of origin</b>			
Biceps	Two origins	Biceps brachii	8.20a
Triceps	Three origins	Triceps brachii	8.20b
Quadriceps	Four origins	Quadriceps femoris	8.23a
<b>Location: Structure near which a muscle is found</b>			
Example: Temporalis, a muscle near the temporal bone (Figure 8.14).			
<b>Origin and Insertion: Sites where muscle originates and inserts</b>			
Example: Brachioradialis, originating on the humerus and inserting on the radius (Figure 8.21a).			

Figure 8.13 Principal superficial skeletal muscles.

Most movements require contraction of several skeletal muscles acting in groups rather than individually.



(a) Anterior view



(b) Posterior view

? Which is an example of a muscle named for the following characteristics: direction of fibers, shape, action, size, origin and insertion, location, and number of origins?