36–2 The Muscular System

Guide for Reading

Key Concepts

- What are the three types of muscle tissue?
- How do muscles contract?
- Why is exercise important?

Vocabulary

myosin
actin
neuromuscular junction
acetylcholine
tendon

Reading Strategy: Summarizing As you read, find the main ideas for each paragraph. Write down a few key words from each main idea. Then, use the key words in your summary. Reread your summary, keeping only the most important ideas.

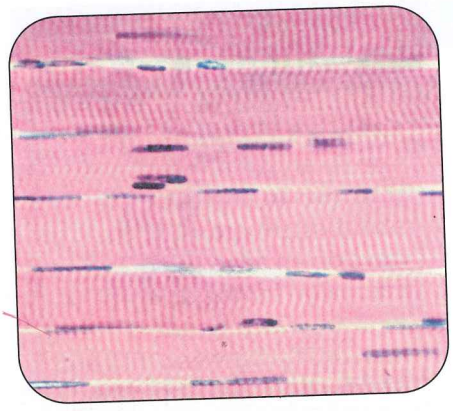
Despite the fantasies of Hollywood horror films, a skeleton cannot move by itself. Movement is the function of the muscular system. More than 40 percent of the mass of the average human body is muscle. The muscular system includes the large muscles displayed by some athletes. It also includes thousands of tiny muscles throughout the body that help to regulate blood pressure, move food through the digestive system, and power every movement of the body—from the blink of an eye to the hint of a smile.

Types of Muscle Tissue

Muscle tissue is found everywhere in the body—not only just beneath the skin but also deep within the body. **There are three different types of muscle tissue: skeletal, smooth, and cardiac.** Each type of muscle is specialized for a specific function in the body. Refer to **Figure 36–6** as you read about the different types of muscles.

Skeletal Muscles Skeletal muscles are usually attached to bones. Skeletal muscles are responsible for such voluntary movements as typing on a computer keyboard, dancing, or winking an eye. When viewed under a microscope at high magnification, skeletal muscle appears to have alternating light and dark bands called striations. For this reason, skeletal muscle is sometimes called striated muscle. Most skeletal muscles are consciously controlled by the central nervous system.

Skeletal muscle cells are large, have many nuclei, and vary in length from 1 millimeter to about 30 centimeters. Because skeletal muscle cells are long and slender, they are often called muscle fibers. Complete skeletal muscles consist of muscle fibers, connective tissues, blood vessels, and nerves. **Figure 36–7** shows the structure of a skeletal muscle in the leg.



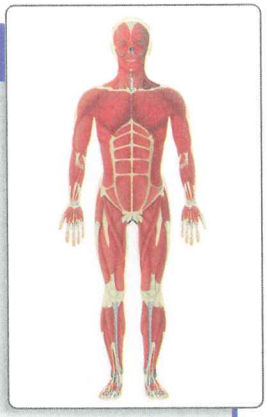
Skeletal Muscle (150×)

Smooth Muscle (400×)

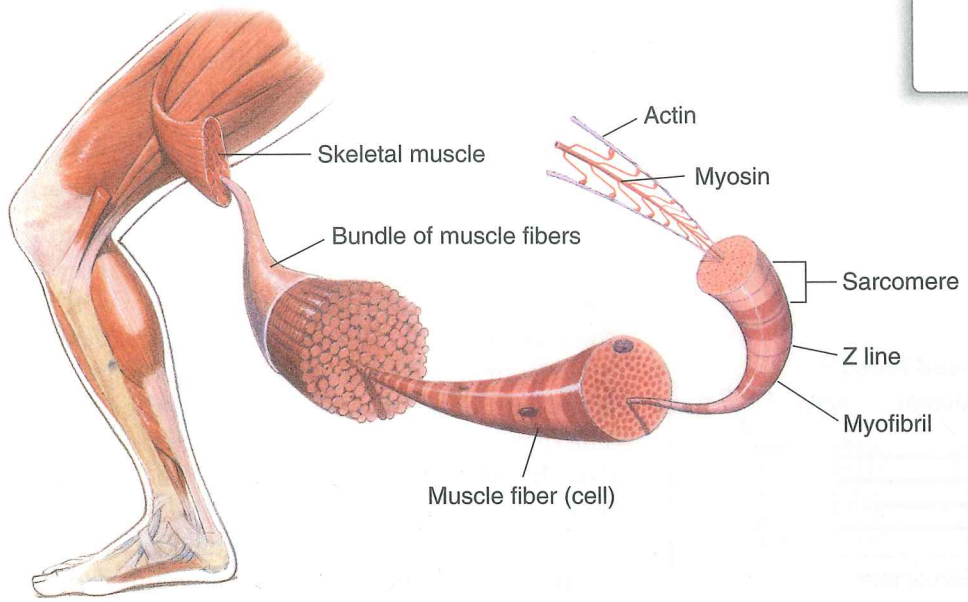
Cardiac Muscle (500×)

Figure 36–6 **There are three types of muscle tissue: skeletal, smooth, and cardiac.** Skeletal muscle cells have striations, or stripes, and many nuclei. Smooth muscle cells are spindle-shaped and have one nucleus and no striations. Cardiac muscle cells have striations and usually only one nucleus.

FIGURE 36–7 SKELETAL MUSCLE STRUCTURE



Skeletal muscles are made up of bundles of muscle fibers, which in turn are composed of myofibrils. Each myofibril contains thin filaments made of actin and thick filaments made of myosin. Muscle fibers are divided into functional units called sarcomeres. **Applying Concepts** *What nervous system structures carry messages to skeletal muscles?*



Smooth Muscles Smooth muscles are usually not under voluntary control. A smooth muscle cell is spindle-shaped, has one nucleus, and is not striated. Smooth muscles are found in the walls of hollow structures such as the stomach, blood vessels, and intestines. Smooth muscles move food through your digestive tract, control the way blood flows through your circulatory system, and decrease the size of the pupils of your eyes in bright light. Most smooth muscle cells can function without nervous stimulation. They are connected to one another by gap junctions that allow electrical impulses to travel directly from one muscle cell to a neighboring muscle cell.

Cardiac Muscle Cardiac muscle is found in just one place in the body—the heart. The prefix *cardio* comes from a Greek word meaning "heart." Cardiac muscle shares features with both skeletal muscle and smooth muscle. Cardiac muscle is striated like skeletal muscle, although its cells are smaller. Cardiac muscle cells usually have one nucleus, but they may have two. Cardiac muscle is similar to smooth muscle because it is usually not under the direct control of the central nervous system and cardiac cells are connected to their neighbors by gap junctions. You will learn more about cardiac muscle in Chapter 37.

CHECKPOINT *What kind of muscle tissue lines the blood vessels?*

Muscle Contraction

The muscle fibers in skeletal muscles are composed of smaller structures called myofibrils. Each myofibril is made up of even smaller structures called filaments. The striations in skeletal muscle cells are formed by an alternating pattern of thick and thin filaments. The thick filaments contain a protein called **myosin** (MY-uh-sin). The thin filaments are made up mainly of a protein called **actin.** The filaments are arranged along the muscle fiber in units called sarcomeres, which are separated from each other by regions called Z lines. As **Figure 36–8** shows, when a muscle is relaxed, there are no thin filaments in the center of a sarcomere.

The tiny myosin and actin filaments are the force-producing engines that cause a muscle to contract. **A muscle contracts when the thin filaments in the muscle fiber slide over the thick filaments.** This process is called the sliding-filament model of muscle contraction. For a muscle to contract, the thick myosin filament must form a cross-bridge with the thin actin filament. As the cross-bridge changes shape, it pulls on the actin filament, which slides toward the center of the sarcomere. The distance between the Z lines decreases. The cross-bridge detaches from the actin filament. The cycle is repeated when the myosin binds to another site on the actin filament.

When hundreds of thousands of myosin cross-bridges change shape in a fraction of a second, the muscle fiber shortens with considerable force. The energy for muscle contraction is supplied by ATP. Because one molecule of ATP supplies the energy for one interaction between a myosin cross-bridge and an actin filament, the cell needs plenty of ATP molecules for a strong contraction. Recall that the cell can produce ATP in two ways—by cellular respiration and by fermentation.

CHECKPOINT *What is actin? What is myosin?*

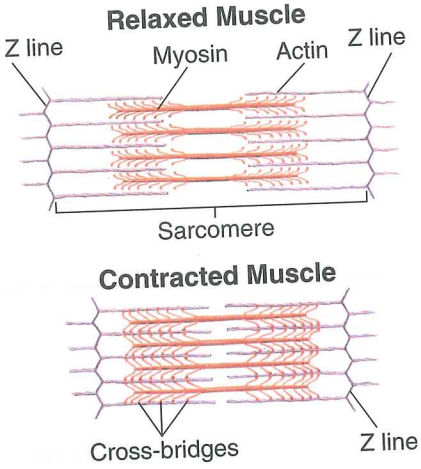
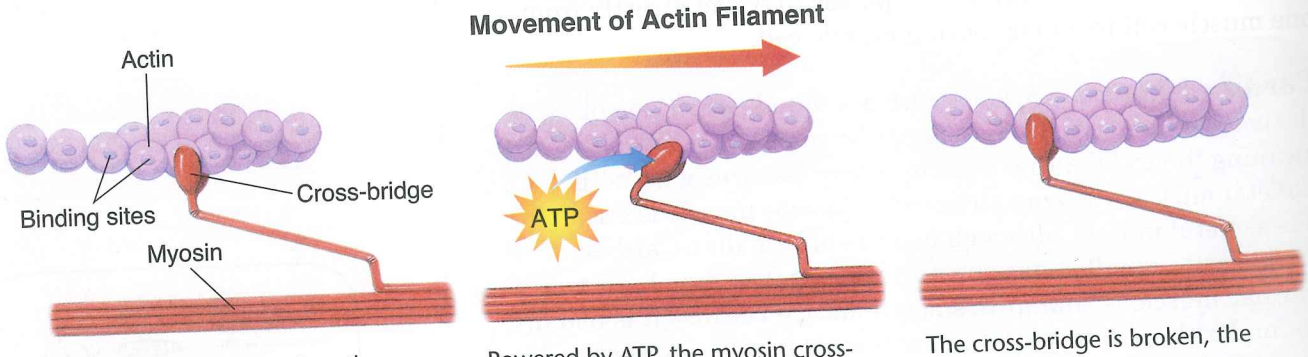


Figure 36–8 During muscle contraction, the actin filaments slide over the myosin filaments, decreasing the distance between the Z lines.



During muscle contraction, the knoblike head of a myosin filament attaches to a binding site on actin, forming a cross-bridge.

Powered by ATP, the myosin cross-bridge changes shape and pulls the actin filament toward the center of the sarcomere.

The cross-bridge is broken, the myosin binds to another site on the actin filament, and the cycle begins again.

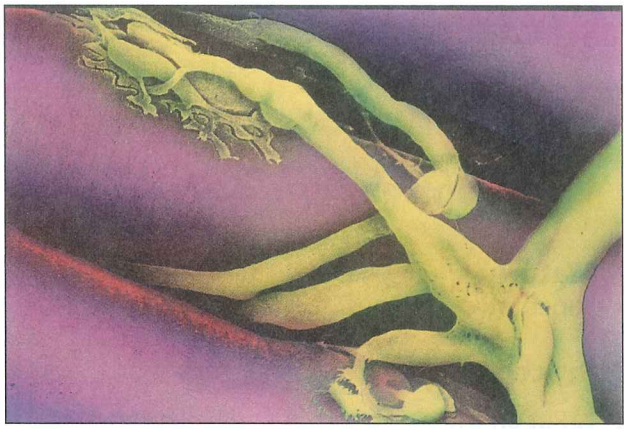
Control of Muscle Contraction

Skeletal muscles are useful only if they contract in a controlled fashion. Remember that motor neurons connect the central nervous system to skeletal muscle cells. Impulses from motor neurons control the contraction of skeletal muscle fibers.

Figure 36–9 shows a **neuromuscular** (noo-roh-MUS-kyoo-lur) **junction,** which is the point of contact between a motor neuron and a skeletal muscle cell. Vesicles, or pockets, in the axon terminals of the motor neuron release a neurotransmitter called **acetylcholine** (as-ih-til-KOH-leen). Acetylcholine molecules diffuse across the synapse, producing an impulse in the cell membrane of the muscle fiber. The impulse causes the release of calcium ions (Ca^{2+}) within the fiber. The calcium ions affect regulatory proteins that allow actin and myosin filaments to interact. From the time a nerve impulse reaches a muscle cell, it is only a few milliseconds before these events occur and the muscle cell contracts.

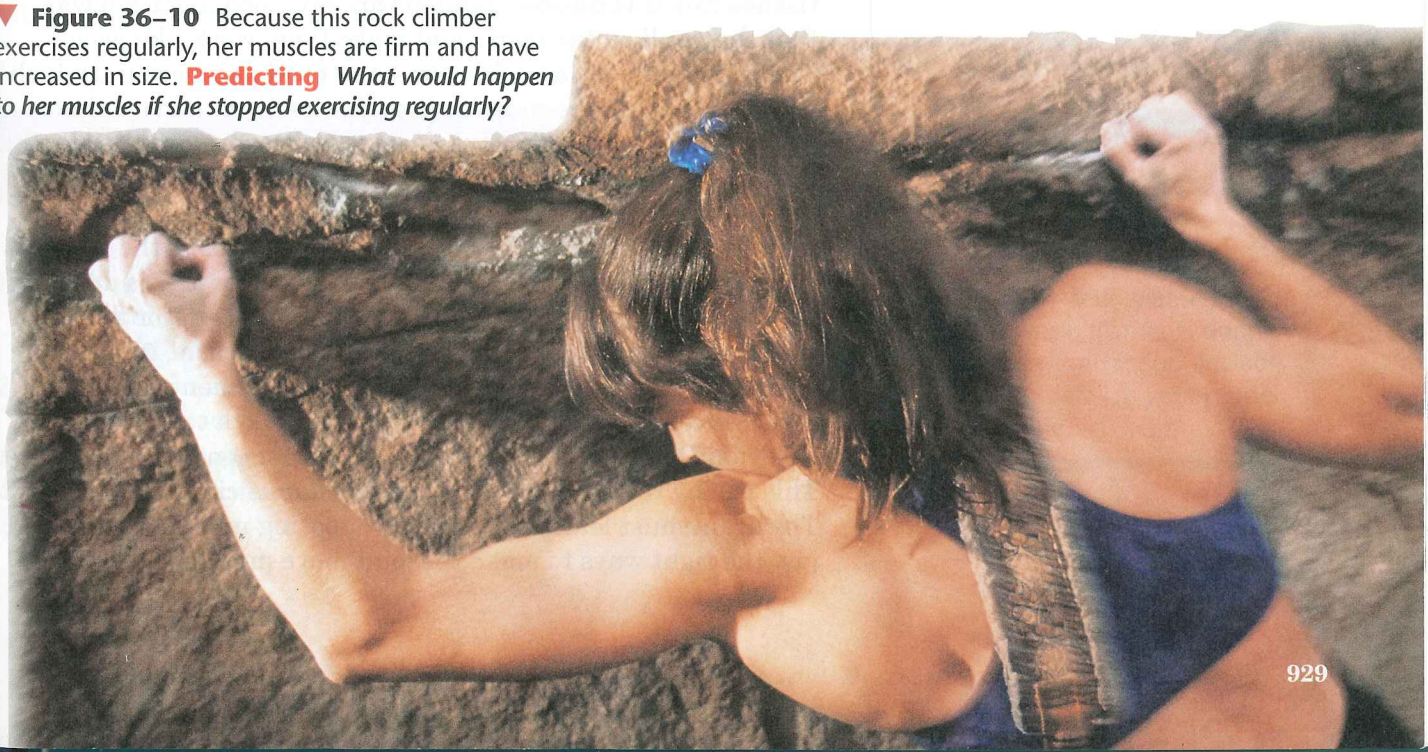
A muscle cell remains contracted until the release of acetylcholine stops and an enzyme produced at the axon terminal destroys any remaining acetylcholine. Then, the cell pumps calcium ions back into storage, the cross-bridges stop forming, and contraction ends.

What is the difference between a strong contraction and a weak contraction? Each muscle contains hundreds of cells. When you lift something light, such as a sheet of paper, your brain stimulates only a few cells in your arm muscles to contract. However, as you exert maximum effort, as the rock climber in **Figure 36–10** is doing, almost all the muscle cells in your arm are stimulated to contract.



▲ **Figure 36–9** The long green axon of a motor neuron makes contact with a long pink muscle fiber at the neuromuscular junction. (Note that color has been added to this SEM.)

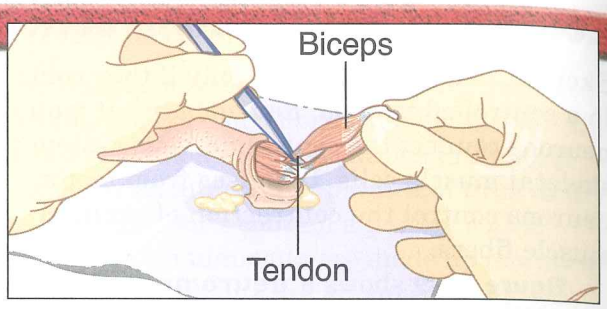
▼ **Figure 36–10** Because this rock climber exercises regularly, her muscles are firm and have increased in size. **Predicting** *What would happen to her muscles if she stopped exercising regularly?*



Quick Lab

What do tendons do?

Materials raw chicken wing treated with bleach, paper towels, forceps, scissors, scalpel



Procedure

1. Put on the plastic gloves and lab apron. **CAUTION:** *Do not touch your face with your hands during the lab. Be careful with the scissors and scalpel.*
2. Put a chicken wing on a paper towel. Peel back or cut away the skin and fat of the largest wing segment to expose the large muscle. This muscle is called the biceps. Find the tendon that attaches the biceps to the bones of the middle segment of the wing. Tendons are the tough, shiny white cords that join the muscles to the bones.
3. Use forceps to pull on the tendon of the biceps and observe what happens to the chicken wing.
4. Clean your tools and dispose of the chicken wing and gloves according to your teacher's instructions. Wash your hands with soap and warm water.
5. Next, observe the back of your hand as you move each of your fingers in turn. Compare what you see to how the chicken wing moved.

Analyze and Conclude

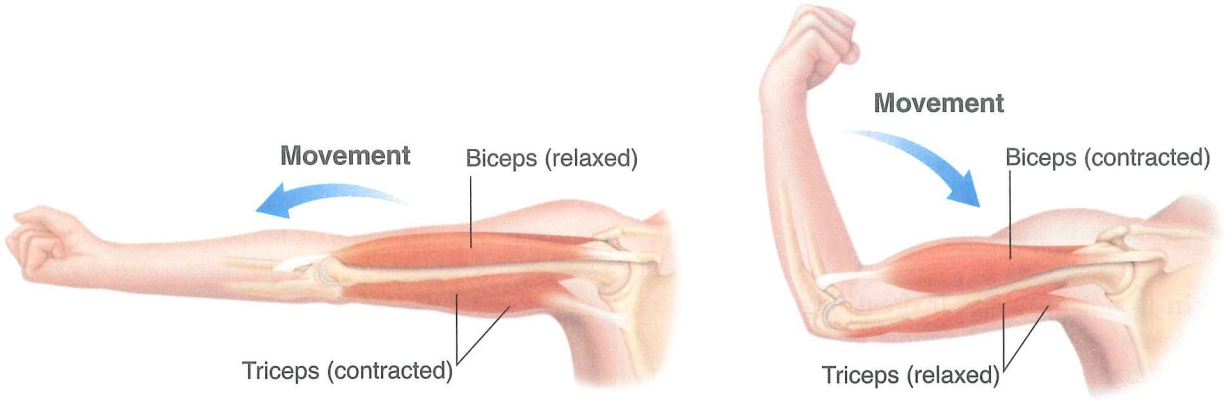
1. **Applying Concepts** What happened when you pulled on the tendon? In a live chicken, what structure would pull on the tendon to move the wing?
2. **Comparing and Contrasting** How is the way the wing moves similar to the way your fingers move?

How Muscles and Bones Interact

Skeletal muscles generate force and produce movement by contracting, or pulling on body parts. Individual muscles can only pull in one direction. Yet, you know from experience that your legs bend when you sit and extend when you stand up. How is this possible?

Skeletal muscles are joined to bones by tough connective tissues called **tendons.** Tendons are attached in such a way that they pull on the bones and make them work like levers. The joint functions as a fulcrum—the fixed point around which the lever moves. The muscles provide the force to move the lever. Usually, there are several muscles surrounding each joint that pull in different directions.

Most skeletal muscles work in opposing pairs. When one muscle contracts, the other relaxes. The muscles of the upper arm shown in **Figure 36–11** are a good example of this dual action. When the biceps muscle contracts, it bends, or flexes, the elbow joint. When the triceps muscle contracts, it opens, or extends, the elbow joint. A controlled movement, however, requires contraction by both muscles. To hold a tennis racket or a violin, both the biceps and triceps must contract in balance. This is why the training of athletes and musicians is so difficult. The brain must learn how to work opposing muscle groups in just the right ways to make the joint move precisely.



▲ **Figure 36–11** By contracting and relaxing, the triceps and biceps in the upper arm enable you to bend or straighten your elbow. **Applying Concepts** *Which skeletal muscle must contract in order for you to straighten your elbow?*

Exercise and Health

Skeletal muscles generally remain in a state of partial contraction called resting muscle tone. Muscle tone is responsible for keeping the back and legs straight and the head upright, even when you are relaxed.

Regular exercise is important in maintaining muscular strength and flexibility. Muscles that are exercised regularly stay firm and increase in size and strength by adding actin and myosin filaments. Muscles that are not used become weak and can visibly decrease in size.

Aerobic exercises—such as running and swimming—cause the body's systems to become more efficient. For example, aerobic exercise helps your heart and lungs become more efficient. This, in turn, increases physical endurance—the ability to perform an activity without fatigue. Regular exercise also strengthens your bones, making them thicker and stronger. Strong bones and muscles are less likely to become injured.

Resistance exercises, such as weight lifting, increase muscle size and strength. Resistance exercises also decrease body fat and increase muscle mass. Over time, weight-training exercises will help to maintain coordination and flexibility.

36–2 Section Assessment

1. **Key Concept** List the three types of muscle tissue and explain the function of each.
2. **Key Concept** Explain how a muscle contracts.
3. **Key Concept** Describe the importance of regular exercise.
4. What is the function of the muscular system?
5. What is the role of acetylcholine in the process of muscle contraction?
6. **Critical Thinking** **Predicting** If a muscle cell receives a second stimulus while it is contracting, will it respond to the second stimulus? Explain.

Sharpen Your Skills

Using Models

Create your own model to show how actin filaments slide over myosin filaments during a muscle contraction. Include as much detail in your model as possible.