

The Muscular System

Key Questions

- What are the principal types of muscle tissue?
- How do muscles contract?
- How do muscle contractions produce movement?

Vocabulary

muscle fiber • myofibril • myosin • actin • sarcomere • neuromuscular junction • acetylcholine • tendon

Taking Notes

Concept Map As you read, make a concept map that shows the relationship among the terms in this section.

THINK ABOUT IT How much of your body do you think is muscle? Ten percent? Maybe fifteen percent, if you're really in shape? As surprising as it might seem, about one third of the mass of an average person's body is muscle, and that's true even if you're not a well-conditioned varsity athlete. What's all that muscle doing? Some of the answers might surprise you.

Muscle Tissue

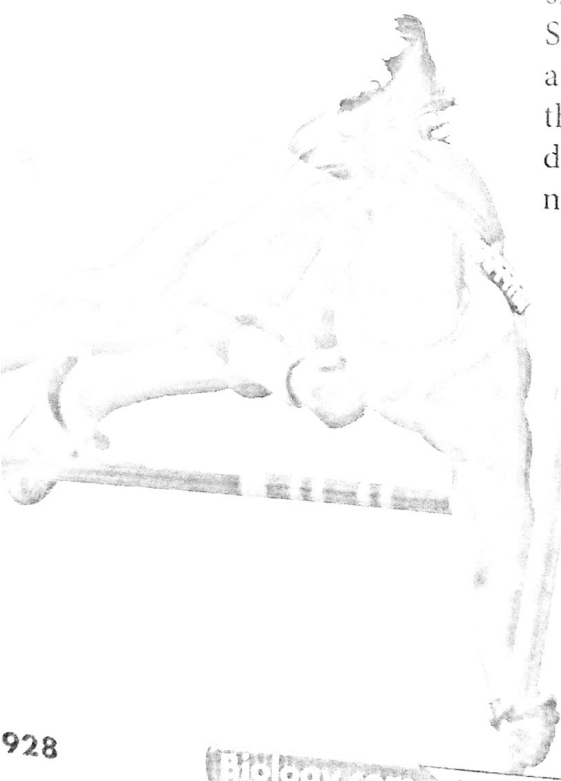
What are the principal types of muscle tissue?

Despite the fantasies of Hollywood horror films, a skeleton cannot move by itself. That's the job of the muscular system. Naturally, this system includes the large muscles in your arms and legs. However, it also includes thousands of tiny muscles throughout the body that help to regulate blood pressure and move food through the digestive system. In fact, muscles power every movement of the body—from a leap in the air to the hint of a smile.

Muscle tissue is found everywhere in the body—not just right beneath the skin but also deep within the body. Not only is muscle tissue found where you might least expect it, but also there is more than one kind of muscle tissue. **There are three different types of muscle tissue: skeletal, smooth, and cardiac.** Each type of muscle, shown in **Figure 32–6**, is specialized for specific functions in the body. Skeletal muscle is often found, as its name implies, attached to bones, and it is usually under voluntary control. Smooth muscle is found throughout the body and is usually not under voluntary control. Cardiac muscle makes up most of the mass of the heart, and, like smooth muscle, it is not under voluntary control.

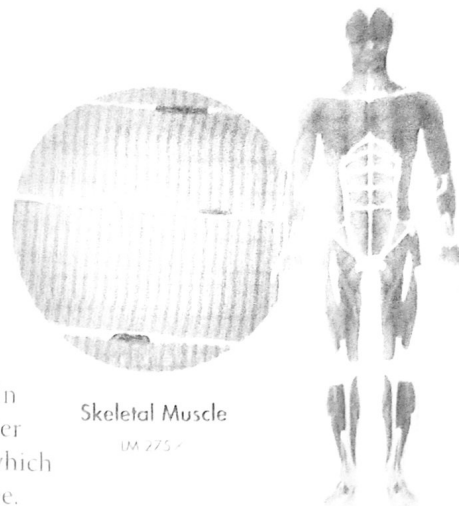
In Your Notebook Make a two-column chart to describe the three types of muscle tissue. Label the first column *Type* and the second column *Function*.

FIGURE 32–5 Muscles in Action This pole-vaulter's skeletal muscles are clearly defined as she propels herself forward.



Skeletal Muscles Skeletal muscles are usually attached to bones. They are responsible for such voluntary movements as typing on a 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 said to be striated. Most skeletal muscle movements are consciously controlled by the central nervous system (the brain and spinal cord).

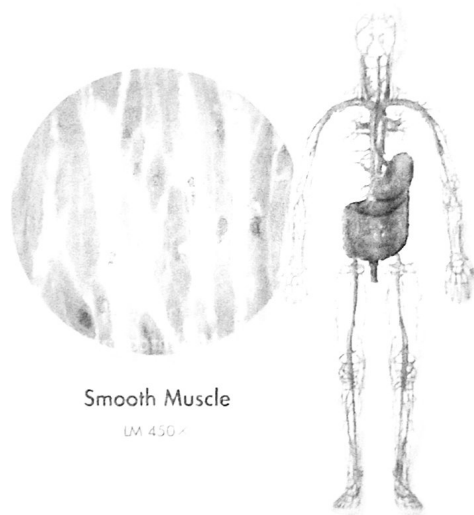
Skeletal muscle cells are large, have many nuclei, and vary in length. The shortest skeletal muscle, which is about 1 millimeter long, is found in the middle ear. The longest skeletal muscle, which may be as long as 30 centimeters, runs from the hip to the knee. Because skeletal muscle cells are long and slender, they are often called **muscle fibers**.



Skeletal Muscle

LM 275×

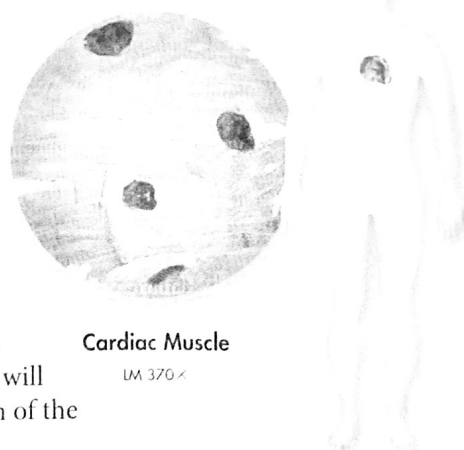
Smooth Muscle Smooth muscle cells are so named because they don't have striations and, therefore, look "smooth" under the microscope. These cells are spindle-shaped and usually have a single nucleus. Smooth muscle movements are usually involuntary. They are found throughout the body and form part of 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 even decrease the size of the pupils of your eyes in bright light. Powerful smooth muscle contractions are also responsible for pushing a baby out of its mother's uterus during childbirth. Most smooth muscle cells can function without direct stimulation by the nervous system. The cells in smooth muscle tissue are connected to one another by gap junctions that allow electrical impulses to travel directly from one muscle cell to a neighboring muscle cell.



Smooth Muscle

LM 450×

Cardiac Muscle Cardiac muscle is found in just one place in the body—the heart. It shares features with both skeletal muscle and smooth muscle. Cardiac muscle is striated like skeletal muscle, although its cells are smaller and usually have just one or two nuclei. Cardiac muscle is similar to smooth muscle because it is not under the direct control of the central nervous system. Like smooth muscle cells, cardiac muscle cells can contract on their own and are connected to their neighbors by gap junctions. You will learn more about cardiac muscle and its role in the function of the heart in Chapter 33.



Cardiac Muscle

LM 370×

FIGURE 32-6 Muscle Tissue The three types of muscle tissue look different under a microscope, but all muscle tissue has the ability to produce movement. **Compare and Contrast** What is the key difference between control of skeletal muscle contraction and smooth muscle contraction?

Muscle Contraction

How do muscles contract?

Muscles produce movements by shortening, or contracting, from end to end. How do cells generate such force? The answer can be found in the way in which two kinds of muscle protein filaments interact.

BUILD Vocabulary

PREFIXES The prefix *myo-* in **myofibril** means "muscle." The word comes from the Greek word for mouse. Artists and sculptors once thought well-developed muscles looked like mice under the skin.

VISUAL SUMMARY

SKELETAL MUSCLE STRUCTURE

FIGURE 32-7 Skeletal muscles are made up of bundles of muscle fibers composed of myofibrils. Each myofibril contains actin and myosin filaments. *Interpret Visuals* What type of unit are actin and myosin filaments arranged in?

Muscle Fiber Structure Skeletal muscle cells, or fibers, are filled with tightly packed filament bundles called **myofibrils**. Each myofibril contains thick filaments of a protein called **myosin** (MY uh sin) and thin filaments of a protein called **actin**. These filaments are arranged in an overlapping pattern that produces the stripes or striations so visible through a microscope. The thin actin filaments are bound together in areas called Z lines. Two Z lines and the filaments between them make up a unit called a **sarcomere**. Figure 32-7 shows the structure of a muscle fiber.

The Sliding-Filament Model Myosin and actin filaments are actually tiny force-producing engines. **During a muscle contraction, myosin filaments form cross-bridges with actin filaments. The cross-bridges then change shape, pulling the actin filaments toward the center of the sarcomere.** As shown in Figure 32-8, this action decreases the distance between the Z lines, and the fiber shortens.

Then the cross-bridge detaches from actin and repeats the cycle by binding to another site on the actin filament. As thick and thin filaments slide past each other, the fiber shortens. For this reason, the process is called the sliding-filament model of muscle contraction.

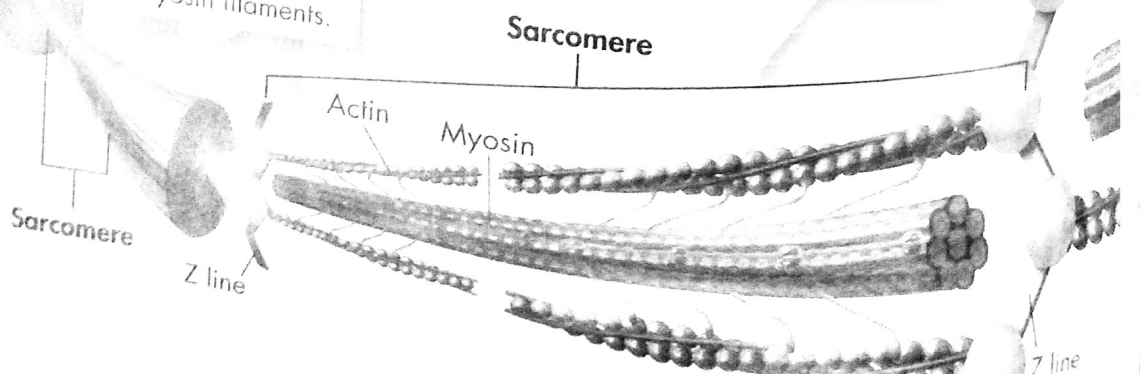
When hundreds of thousands of myosin cross-bridges repeat these actions, the muscle fiber shortens with considerable force. Contractions like this enable you to run, lift weights, or even turn a page in a book. Because one molecule of ATP supplies just enough energy for one interaction between a myosin cross-bridge and an actin filament, a muscle cell needs plenty of ATP.

A muscle consists of bundles of muscle fibers.

Each muscle fiber is a cell that contains many myofibrils.

Each myofibril contains actin and myosin filaments.

Two Z lines and the filaments between them make up a sarcomere.



- 1 When a muscle is relaxed, myosin and actin filaments are not attached.

- 2 During contraction, myosin attaches to binding sites on actin, forming cross-bridges. Using ATP, the cross-bridges pull the actin toward the center of the sarcomere.

- 3 The cross-bridges break, myosin binds to another site, and the cycle begins again until the muscle fiber is contracted.

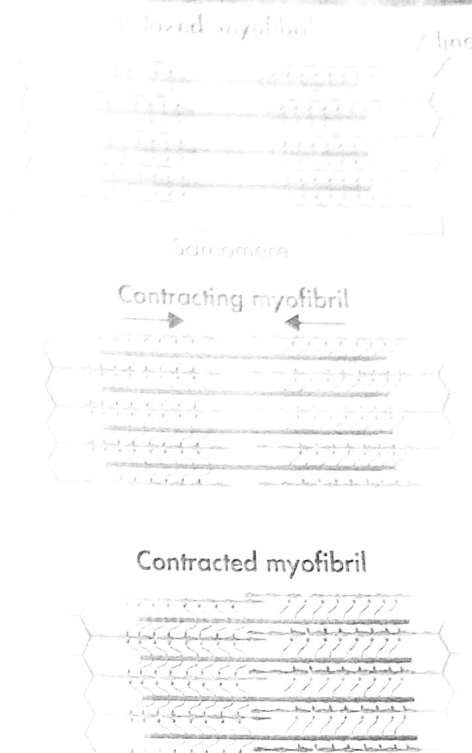
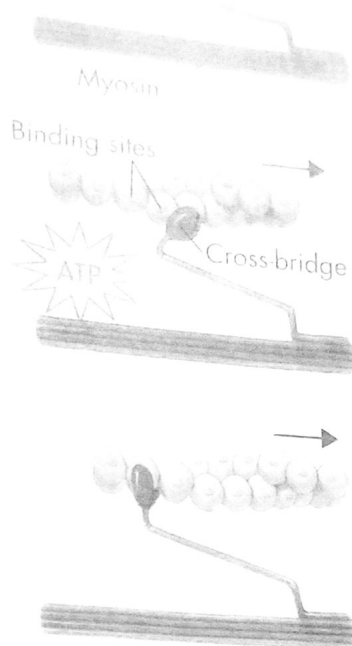


FIGURE 32-8 Sliding-Filament Model

During muscle contraction, interaction between myosin filaments and actin filaments causes a muscle fiber to contract.

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 these motor neurons control the contraction of muscle fibers.

A motor neuron and a skeletal muscle cell meet at a type of synapse known as a **neuromuscular** (noo roh MUS kyoo lur) **junction**. When a motor neuron is stimulated, its axon terminals release a neurotransmitter called **acetylcholine** (as ih til KOH leen). Acetylcholine (ACh) molecules diffuse across the synapse, producing an impulse (action potential) in the cell membrane of the muscle fiber. The impulse causes the release of calcium ions (Ca^{2+}) within the fiber. These ions affect regulatory proteins that allow myosin cross-bridges to bind to actin.

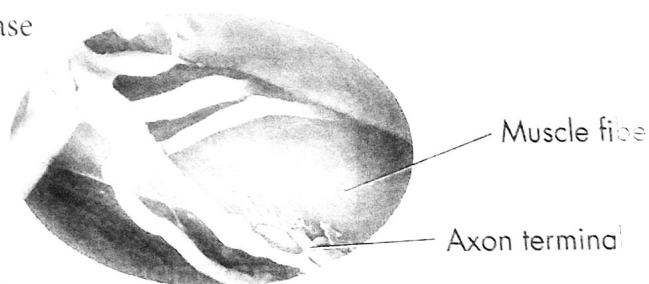


FIGURE 32-9 Neuromuscular Junction

A muscle cell contracts until the release of ACh stops and an enzyme produced at the axon terminal destroys any remaining ACh. Then, the muscle cell pumps Ca^{2+} back into storage, the cross-bridges stop forming, and the contraction ends.

What is the difference between a strong contraction and a weak contraction? When you lift something light, such as a sheet of paper, your brain stimulates only a few cells to contract. However, as you exert maximum effort, such as when lifting your book bag, almost all the muscle cells in your arm are stimulated to contract.

MYSTERY CLUE

Children with rickets may suffer from muscle spasms. What might they be lacking that could cause uncontrolled muscle movements?

What Do Tendons Do?

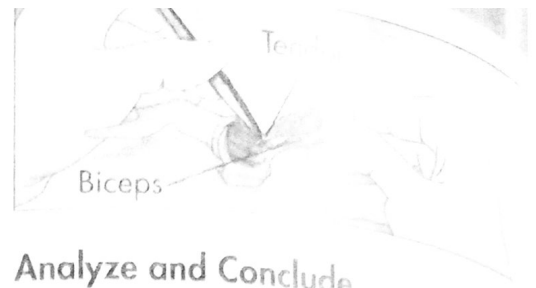


① Put on gloves and an apron. Place a chicken wing on a paper towel. Peel back or cut away the skin and fat of the largest wing segment to expose the biceps. **CAUTION:** Do not touch your face with your hands during the lab.

② Find the tendon that attaches the biceps to the bones of the middle segment of the wing.

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 per your teacher's instructions. Wash your hands.



Analyze and Conclude

1. Observe What happened when you pulled on the tendon? In a live chicken, what structure would pull on the tendon to move the wing?

2. Compare and Contrast Observe the back of your hand as you move each finger. How is the way the wing moves similar to the way your fingers move?

Muscles and Movement

How do muscle contractions produce movement?

One of the most confusing concepts to understand about muscles is that they can produce force only by contracting in one direction. Yet, you know from experience that you can use your muscles to push as well as to pull. How is this possible?

How Muscles and Bones Interact 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 the 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, several muscles that pull in different directions surround each joint. **Skeletal muscles generate force by pulling on body parts as they contract.**

We can use our muscles to push as well as to pull because most skeletal muscles work in opposing pairs. When one muscle in the pair contracts, the other muscle in the pair relaxes. The muscles of the upper arm shown in **Figure 32-10** 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 requires the involvement of both muscles. To hold a tennis racket or a violin requires a balance of forces between the biceps and the triceps.

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 involved joints move precisely.

In Your Notebook Explain in your own words the role of opposing pairs in muscle contraction.

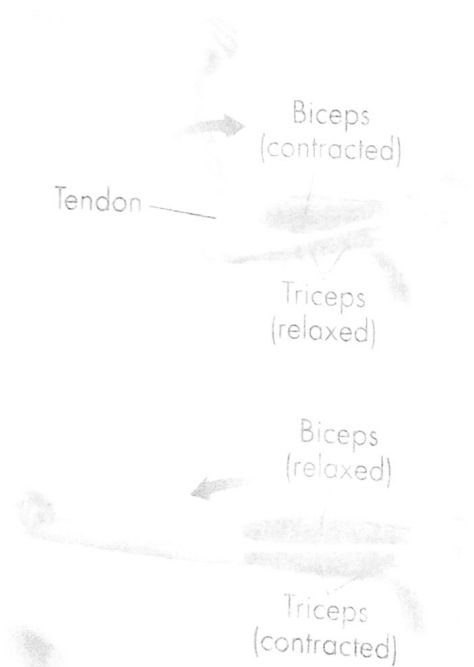


FIGURE 32-10 Opposing Muscle Pairs By contracting and relaxing, the biceps and triceps in the upper arm enable you to bend or straighten your elbow. **Apply Concepts** Which skeletal muscle must contract in order for you to straighten your elbow?

Types of Muscle Fibers There are two principal types of skeletal muscle fibers—red and white. The types of muscle fibers vary in their specific functions. Red muscle, or slow-twitch muscle, contains many mitochondria. The dark color of red muscle comes from small blood vessels that deliver a rich supply of blood and from an oxygen-storing protein called myoglobin. The abundant mitochondria and generous supply of oxygen allow these fibers to derive their energy through aerobic respiration and work for long periods of time. Red muscle is useful for endurance activities like long-distance running.

White muscle, or fast-twitch muscle, contracts more rapidly and generates more force than does red muscle, but its cells contain few mitochondria and tire quickly. White fibers are useful for activities that require great strength or quick bursts of speed, like sprinting.

Exercise and Health Regular exercise is important to maintain muscular strength and flexibility. Muscles that are exercised regularly stay firm and increase in size and strength due to added filaments. Muscles that are not used become weak and can visibly decrease in size. Regular exercise helps to maintain resting muscle tone—a state of partial contraction. Muscle tone is responsible for keeping the back and legs straight and the head upright, even when you are relaxed.

Aerobic exercises—such as running and swimming—place strong demands on the heart and lungs, helping these systems to 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. Over time, weight-training exercises will help to maintain coordination and flexibility.



FIGURE 32-11 Preventing Muscle Loss Without gravity, many muscles go unused. An astronaut in space may lose up to 5 percent of muscle mass a week. Exercise helps to maintain muscles—and bones, too.

32.2 ASSESSMENT

Review Key Concepts

- Review** List the three types of muscle tissue.
 - Compare and Contrast** Compare and contrast the structure and function of the three types of muscle tissue.
- Review** What structures make up a skeletal muscle?
 - Explain** Describe how a muscle contracts.
 - Predict** A type of poisonous gas destroys the enzyme that breaks down acetylcholine. What effect do you think this gas has on the body?

- Review** Explain the role of tendons in movement.

- Apply Concepts** In training for an Olympic weight-lifting event, which muscle fibers would be the most important to develop?

VISUAL THINKING

- 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.