Outline

Objectives

AFTER YOU HAVE COMPLETED THIS CHAPTER, YOU SHOULD BE ABLE TO:

1. List, locate in the body, and compare the structure and function of the three major types of muscle tissue.
2. Discuss the microscopic structure of a skeletal muscle sarcomere and motor unit.
3. Discuss how a muscle is stimulated and compare the major types of skeletal muscle contractions.
4. Name, identify on a model or diagram, and give the function of the major muscles of the body discussed in this chapter.
5. List and explain the most common types of movement produced by skeletal muscles.

A*lthough we will* initially review the three types of muscle tissue introduced earlier (see Chapter 3), the plan for this chapter is to focus on skeletal or voluntary muscle—those muscle masses that attach to bones and actually move them about when contraction or shortening of muscle cells, or muscle fibers, occurs. If you weigh 120 pounds, about 50 pounds of your weight comes from your skeletal muscles, the "red meat" of the body that is attached to your bones.

Movements caused by skeletal muscle contraction vary in complexity from blinking an eye to the coordinated and fluid movements of a gifted athlete. Not many of our body structures can claim as great an importance for happy, useful living as can our voluntary muscles, and only a few can boast of greater importance for life itself. Our ability to survive often depends on our ability to adjust to the changing conditions of our environment. Movements frequently constitute a major part of this adjustment.

Muscle Tissue

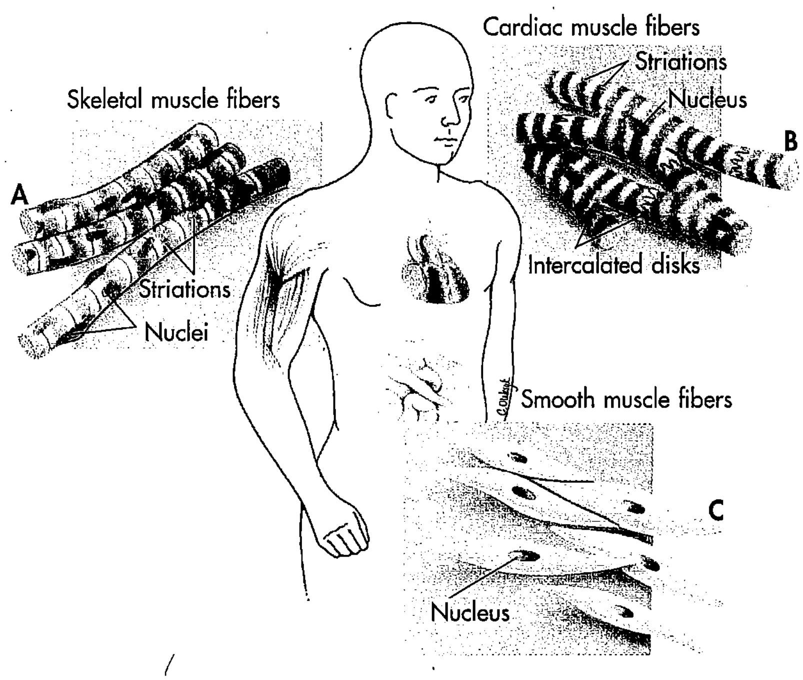
Under the microscope, threadlike and cylindrical skeletal muscle cells appear in bundles. They are characterized by many crosswise stripes and multiple nuclei (Figure 6-1, *A*). Each fine thread is a muscle cell or, as it is usually called, a *muscle fiber.* This type of muscle tissue has three names: *skeletal muscle,* because it attaches to bone; *striated muscle,* because of its cross stripes or striations; and *voluntary muscle,* because its contractions can be controlled voluntarily.

In addition to **skeletal muscle,** the body also contains two other kinds of muscle tissue: cardiac muscle and nonstriated, smooth, or involuntary muscle. **Cardiac muscle** composes the bulk of the heart. Cells in this type of muscle are also cylindrical, branch frequently, (Figure 6-1, *B*) and then recombine into a continuous mass of interconnected tissue. Like skeletal muscle cells, they have cross striations. They also have unique dark bands called *intercalated disks* where the plasma membranes of adjacent cardiac fibers come in contact with each other. Cardiac muscle tissue demonstrates the principle that "form follows function." The interconnected nature of cardiac muscle fibers helps the tissue to contract as a unit and increases the efficiency of the heart muscle in pumping blood.

Nonstriated or **smooth muscle** cells are tapered at each end, have a single nucleus, and lack the cross stripes or striations of skeletal muscle cells (Figure 6-1, C). They have a smooth, even appearance when viewed through a microscope. They are called *involuntary* because we normally do not have control over their contractions. Smooth or involuntary muscle forms an important part of blood vessel walls and of many hollow internal organs (viscera) such as the gut, urethra, and ureters. Because of its location in many visceral structures, it is sometimes called *visceral muscle.* Although we cannot willfully control the action of

FIGURE 6-1

Muscle tissue. A, Skeletal muscle. **B,** Cardiac muscle. **C,** Smooth muscle.



smooth muscle, its contractions are highly regulated so that, for example, food is passed through the digestive tract or urine is pushed through the ureters into the bladder.

Muscle cells specialize in contraction, or shortening. Every movement we make is produced by contractions of skeletal muscle cells. Contractions of cardiac muscle cells keep the blood circulating, and smooth muscle contractions do many things; for instance, they move food into and through the stomach and intestines and make a major contribution to the maintenance of normal blood pressure.

STRUCTURE OF SKELETAL MUSCLE

A skeletal muscle is an organ composed mainly of striated muscle cells and connective tissue. Most skeletal muscles attach to two bones that have a movable joint between them. In other words, most muscles extend from one bone across a joint to another bone. Also, one of the two bones is usually more stationary in a given movement than the other. The muscle's attachment to this more stationary bone is called its **origin.** Its attachment to the more movable bone is called the muscle's **insertion.** The rest of the muscle (all of it except its two ends) is called the *body* of the muscle (Figure 6-2).

Tendons anchor muscles firmly to bones. Made of dense fibrous connective tissue in the shape of heavy cords, tendons have great strength. They do not tear or pull away from bone easily. Yet any emergency room nurse or physician sees many tendon injuries—severed tendons and tendons torn loose from bones.

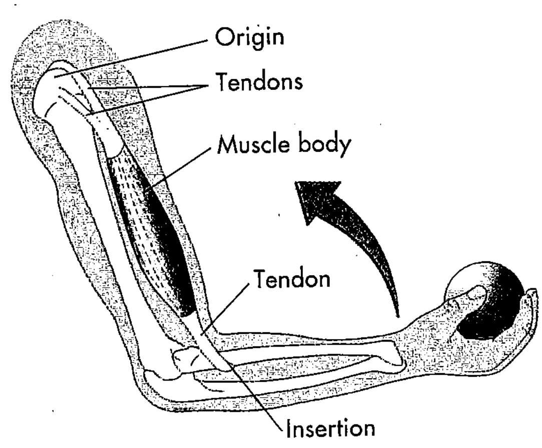
Small fluid-filled sacs called **bursae** lie between some tendons and the bones beneath them (see Figure 5-20). These small sacs are made of connective tissue and are lined with **synovial membrane.** The synovial membrane secretes a slippery lubricating fluid (synovial fluid) that fills the bursa. Like a small, flexible cushion, a bursa makes it easier for a tendon to slide over a bone when the tendon's muscle shortens. **Tendon sheaths** enclose some tendons. Because these tube-shaped structures are also lined with synovial membrane and are moistened with synovial fluid, they, like the bursae, facilitate body movement.

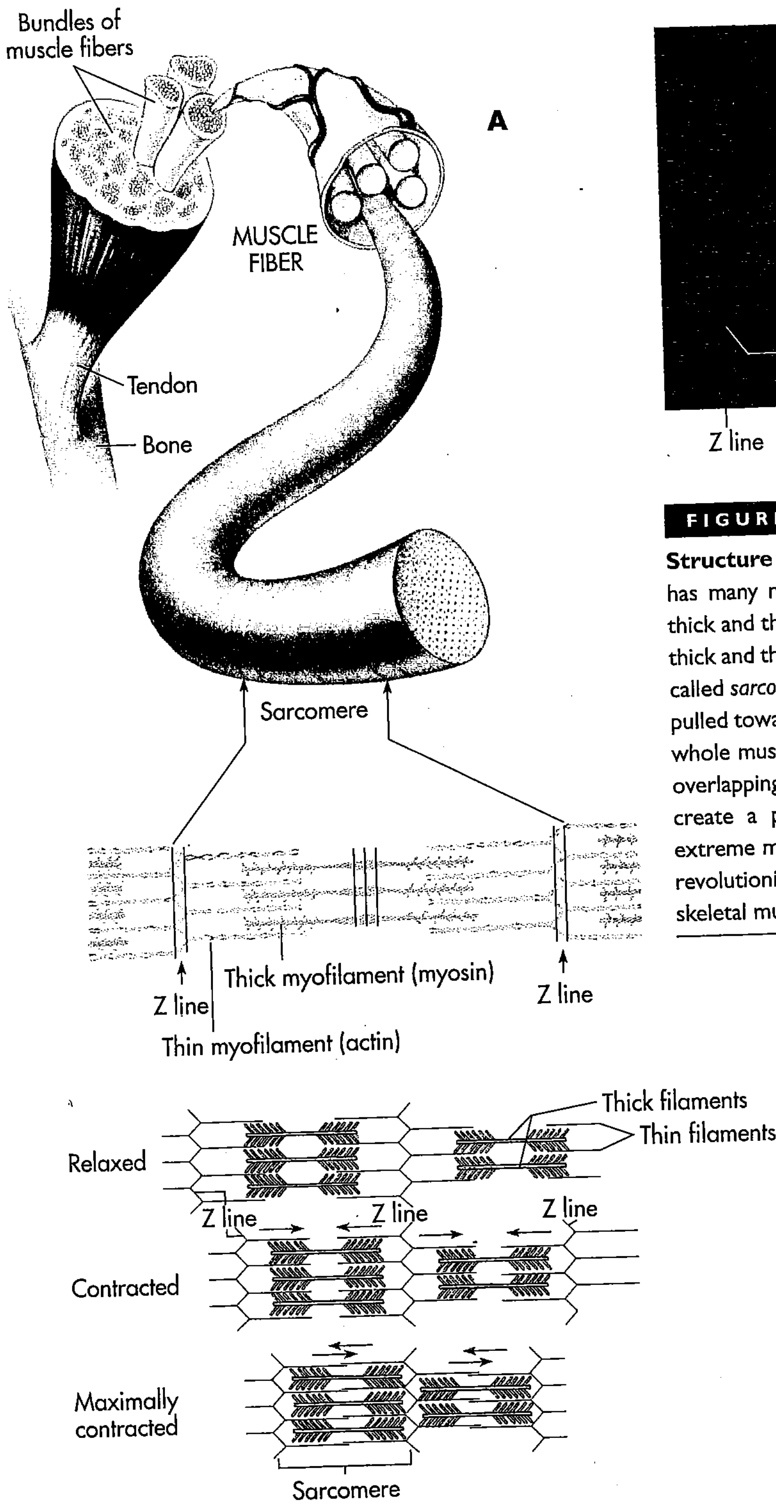
Microscopic Structure

Muscle tissue consists of specialized contractile cells or **muscle fibers** that are grouped together and arranged in a highly organized way. Each skeletal muscle fiber is itself filled with two kinds of very fine and threadlike structures called **thick** and **thin myofilaments** (my-o-FIL-a-ments). The thick myofilaments are formed from a protein called **myosin,** and the thin myofilaments are composed mostly of the protein **actin.** Find the label **sarcomere** (SAR-ko-meer) in Figure 6-3. Think of the sarcomere as the basic functional or *contractile unit* of skeletal muscle. Recall that the osteon (Haversian system) serves as the basic building block of compact bone; the sarcomere serves that function in skeletal muscle. The submicroscopic structure of a sarcomere consists of numerous actin and myosin myofilaments arranged so that, when viewed under a microscope, dark and light stripes or cross striations are seen. The

FIGURE 6-2

Attachments of a skeletal muscle. A muscle originates at a relatively stable part of the skeleton (origin) and inserts at the skeletal part that is moved when the muscle contracts (insertion).





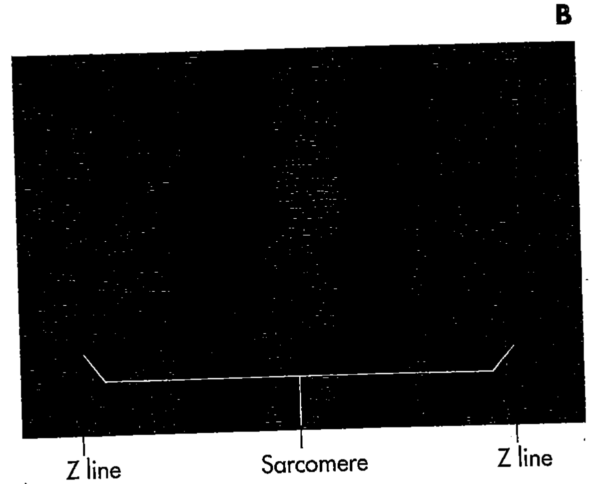


FIGURE 6-3

Structure of skeletal muscle. A, Each muscle organ has many muscle fibers, each containing many bundles of thick and thin filaments. The diagrams show the overlapping thick and thin filaments arranged to form adjacent segments called *sarcomeres*. During contraction, the thin filaments are pulled toward the center of each sarcomere, shortening the whole muscle. **B,** This electron micrograph shows that the overlapping thick and thin filaments within each sarcomere create a pattern of dark striations in the muscle. The extreme magnification allowed by electron microscopy has revolutionized our concept of the structure and function of skeletal muscle and other tissues.

repeating units or sarcomeres are separated from each other by dark bands called *Z lines.*

Although the sarcomeres in the upper portion (Figure 6-3, *A*) and in the electron photomicrograph (EM) of Figure 6-3, *B*, are in a relaxed state, the thick and thin myofilaments, which are lying parallel to each other, still overlap. Now look at the diagrams in the lower portion of Figure 6-3, *A*. Note that contraction of the muscle causes the two types of myofilaments to slide toward each other and shorten the sarcomere and thus the entire muscle. When the muscle relaxes, the sarcomeres can return to resting length, and the filaments resume their resting positions.

An explanation of how a skeletal muscle contracts is provided by the **sliding filament model.** According to this model, during contraction, the thick and thin myofilaments in a muscle fiber first attach to one another by forming "bridges" that then act as levers to ratchet or pull the myofilaments past each other. The connecting bridges between the myofilaments form properly only if calcium is present. During the relaxed state, calcium is within the endoplasmic reticulum (see Chapter 2) in the muscle cell. It is released into the cytoplasm when the muscle is stimulated by a nerve to contract. The shortening of a muscle cell also requires energy. This is supplied by the breakdown of adenosine triphosphate (ATP) molecules, the energy storage molecules of the cell.

Functions of Skeletal Muscle

The three primary functions of the muscular system are:

1. Movement
2. Posture or muscle tone
3. Heat production

Movement

Muscles move bones by pulling on them. Because the length of a skeletal muscle becomes shorter as its fibers contract, the bones to which the muscle attaches move closer together. As a rule, only the insertion bone moves. Look again at Figure 6-2. As the ball is lifted, the shortening of the muscle body pulls the insertion bone toward the origin bone. The origin bone stays put, holding firm, while the insertion bone moves toward it. One tremendously important function of skeletal muscle contractions therefore is to produce body movements. Remember this simple rule: a muscle's insertion bone moves toward its origin bone. It can help you understand muscle actions.

Voluntary muscular movement is normally smooth and free of jerks and tremors because skeletal muscles generally work in coordinated teams, not singly. Several muscles contract while others relax to produce almost any movement that you can imagine. Of all the muscles contracting simultaneously, the one that is mainly responsible for producing a particular movement is called the **prime mover** for that movement. The other muscles that help in producing the movement are called **synergists** (SIN-er-jists). As prime movers and synergist muscles at a joint contract, other muscles, called **antagonists** (an-TAG-o-nists), relax. When antagonist muscles contract, they produce a movement opposite to that of the prime movers and their synergist muscles.

Locate the biceps brachii, brachialis, and triceps brachii muscles in Figure 6-6. All the muscles in these figures are involved in bending and straightening the forearm at the elbow joint. The biceps brachii is the prime mover during bending, and the brachialis is its helper or synergist muscle. When the biceps brachii and brachialis muscles bend the forearm, the triceps brachii relaxes. Therefore while the forearm bends, the triceps brachii is the antagonistic muscle. While the forearm straightens, these three muscles continue to work as a team. However, during straightening, the triceps brachii becomes the prime mover and the biceps brachii and brachialis become the antagonistic muscles. This combined and coordinated activity is what makes our muscular movements smooth and graceful.

Posture

We are able to maintain our body position because of a specialized type of skeletal muscle contraction called **tonic contraction.** Because relatively few of a muscle's fibers shorten at one time in a tonic contraction, the muscle as a whole does not shorten, and no movement occurs. Consequently, tonic contractions do not move any body parts. They do hold muscles in position, however. In other words, muscle tone maintains **posture.** Good posture means that body parts are held in the positions that favor best function. These positions balance the distribution of weight and therefore put the least strain on muscles, tendons, ligaments, and bones.

Skeletal muscle tone maintains posture by counteracting the pull of gravity. Gravity tends to pull the head and trunk down and forward, but the tone in certain back and neck muscles pulls just hard enough in the opposite direction to overcome the force of gravity and hold the head and trunk erect.

Heat Production

Healthy survival depends on our ability to maintain a constant body temperature. A fever or elevation in body temperature of only a degree or two above 37° C (98.6° F) is almost always a sign of illness. Just as serious is a fall in body temperature. Any decrease below normal, a condition called **hypothermia** (hy-po-THER-mee-ah), drastically affects cellular activity and normal body function. The contraction of muscle fibers produces most of the heat required to maintain body temperature. Energy required to produce a muscle contraction is obtained from ATP. Most of the energy released during the breakdown of ATP during a muscular contraction is used to shorten the muscle fibers; however, some of the energy is lost as heat during the reaction. This heat helps us to maintain our body temperature at a constant level.

FATIGUE

If muscle cells are stimulated repeatedly without adequate periods of rest, the strength of the muscle contraction decreases, resulting in **fatigue.** If repeated stimulation occurs, the strength of the contraction continues to decrease, and eventually the muscle loses its ability to contract.

During exercise, the stored ATP required for muscle contraction becomes depleted. Formation of more ATP results in a rapid consumption of oxygen and nutrients, often outstripping the ability of the muscle's blood supply to replenish them. When oxygen supplies run low, the muscle cells switch to a type of energy conversion that does not require oxygen. This process produces lactic acid that may result in muscle soreness after exercise. The term ***oxygen debt*** describes the continued increased metabolism that must occur in a cell to remove excess lactic acid that accumulates during prolonged exercise. Thus the depleted energy reserves are replaced. Labored breathing after the cessation of exercise is required to "pay the debt" of oxygen required for the metabolic effort. This mechanism is a good example of homeostasis at work. The body returns the cells' energy and oxygen reserves to normal, resting levels.

ROLE OF OTHER BODY SYSTEMS IN MOVEMENT

Remember that muscles do not function alone. Other structures such as bones and joints must function with them. Most skeletal muscles cause movements by pulling on bones across movable joints.

The respiratory, circulatory, nervous, muscular, and skeletal systems play essential roles in producing normal movements. This fact has great practical importance. For example, a person might have perfectly normal muscles and still not be able to move normally. He might have a nervous system disorder that shuts off impulses to certain skeletal muscles and thereby results in **paralysis.** Multiple sclerosis acts in this way, but so do some other conditions such as a brain hemorrhage, a brain tumor, or a spinal cord injury. Skeletal system disorders, especially arthritis, have disabling effects on body movement. Muscle func-