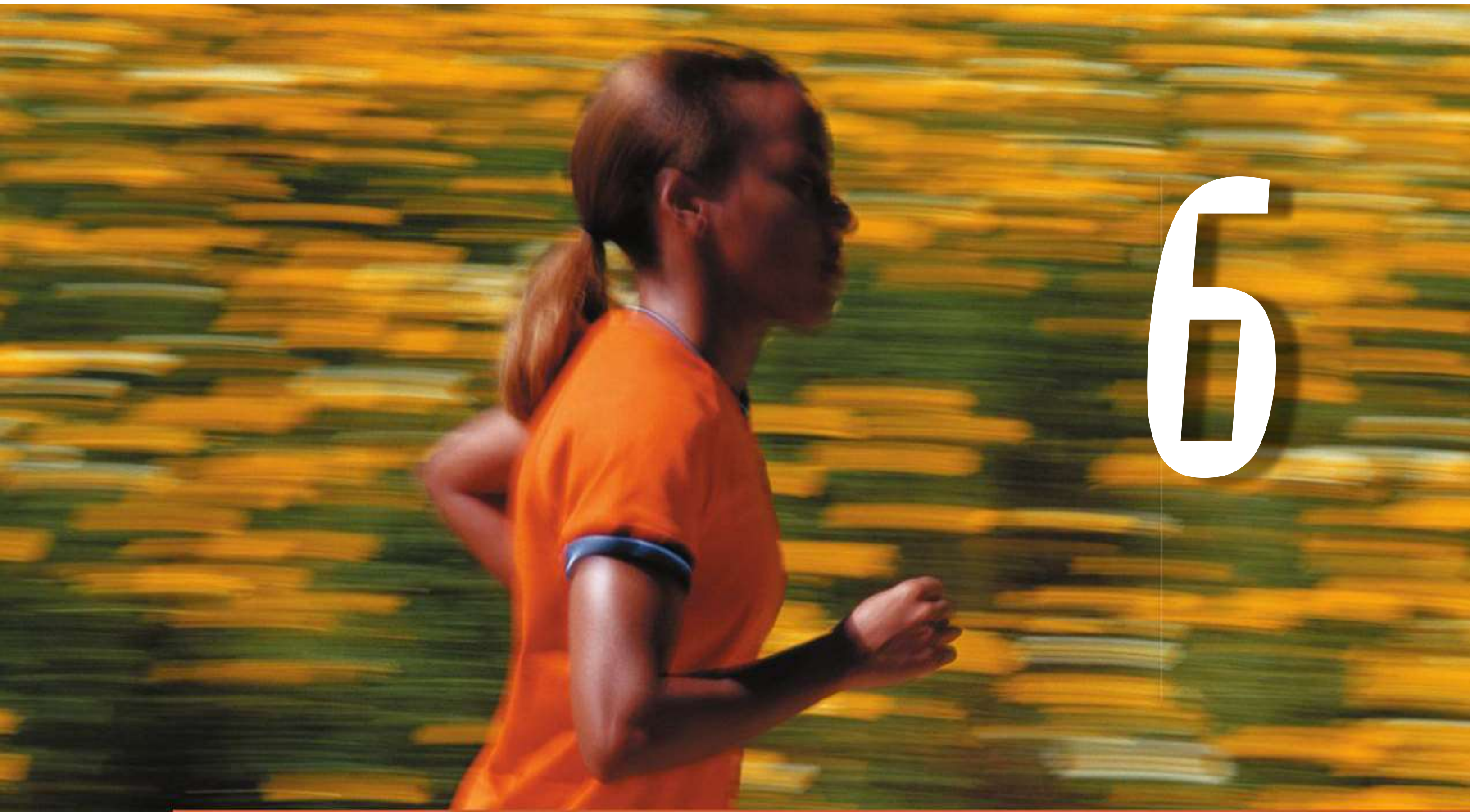


6

The Muscular System

FUNCTION PREVIEW

- The muscular system provides for movement of the body and its parts, maintains posture, generates heat, and stabilizes joints.

Because flexing muscles look like mice scurrying beneath the skin, some scientist long ago dubbed them *muscles,* from the Latin word *mus* meaning "little mouse." Indeed, the rippling muscles of professional boxers or weight lifters are often the first thing that comes to mind when someone hears the word *muscle*. But muscle is also the dominant tissue in the heart and in the walls of other hollow organs of the body. In all its forms, it makes up nearly half the body's mass.

The essential function of muscle is *contraction*, or *shortening*—a unique characteristic that sets it apart from any other body tissue. As a result of this ability, muscles are responsible for essentially all body movement and can be viewed as the "machines" of the body.

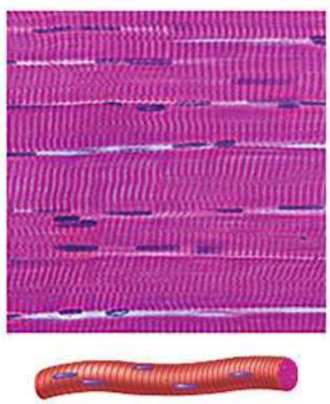
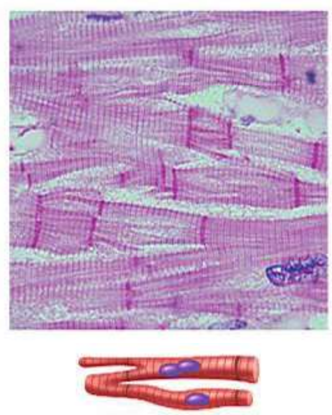
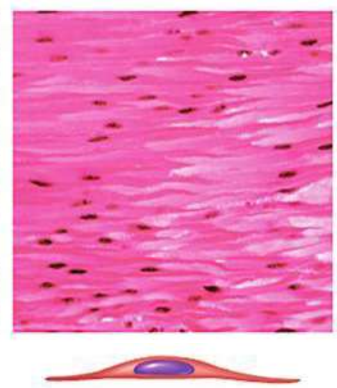
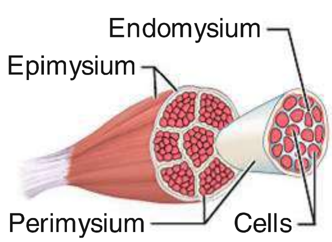
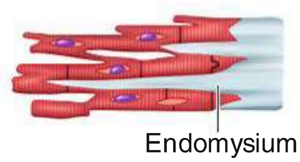
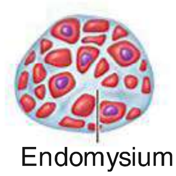
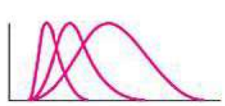
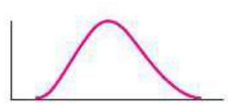
Overview of Muscle Tissues

- ✓ Describe similarities and differences in the structure and function of the three types of muscle tissue, and indicate where they are found in the body.
- ✓ Define *muscular system*.
- ✓ Define and explain the role of the following: *endomysium, perimysium, epimysium, tendon,* and *aponeurosis*.

Muscle Types

There are three types of muscle tissue—skeletal, cardiac, and smooth. As summarized in **Table 6.1**, these differ in their cell structure, body location,

Table 6.1 Comparison of Skeletal, Cardiac, and Smooth Muscles

Characteristic	Skeletal	Cardiac	Smooth
Body location	Attached to bones or, for some facial muscles, to skin	Walls of the heart	Mostly in walls of hollow visceral organs (other than the heart)
			
Cell shape and appearance	Single, very long, cylindrical, multinucleate cells with very obvious striations	Branching chains of cells; uninucleate, striations; intercalated discs	Single, fusiform, uninucleate; no striations
			
Connective tissue components	Epimysium, perimysium, and endomysium	Endomysium attached to the fibrous skeleton of the heart	Endomysium
			
Regulation of contraction	Voluntary; via nervous system controls	Involuntary; the heart has a pacemaker; also nervous system controls; hormones	Involuntary; nervous system controls; hormones, chemicals, stretch
Speed of contraction	Slow to fast	Slow	Very slow
			
Rhythmic contraction	No	Yes	Yes, in some

and how they are stimulated to contract. But before we explore their differences, let's look at some of the ways they are the same.

First, skeletal and smooth muscle cells are elongated. For this reason, these types of muscle cells (but not cardiac muscle cells) are called **muscle fibers.** Second, the ability of muscle to shorten, or contract, depends on two types of *myofilaments*, the muscle cell equivalents of the microfilaments of the cytoskeleton studied in Chapter 3. A third similarity has to do with terminology. Whenever you see the prefixes *myo-* and *mys-* ("muscle") and *sarco-* ("flesh"), you will know that muscle is being referred to. For example, in muscle cells the cytoplasm is called *sarcoplasm* (sar′ko-plaz″um).

Skeletal Muscle

Skeletal muscle fibers are packaged into the organs called *skeletal muscles* that attach to the body's skeleton. As the skeletal muscles cover our bony "underpinnings," they help form the much smoother contours of the body. Skeletal muscle fibers are huge, cigar-shaped, multinucleate cells. They are the largest of the muscle fiber types—some ranging up to 30 cm (nearly 1 foot) in length. Indeed, the fibers of large, hardworking muscles, such as the antigravity muscles of the hip, are so big and coarse that they can be seen with the naked eye.

Skeletal muscle is also known as **striated muscle** (because its fibers have obvious stripes) and as **voluntary muscle** (because it is the only muscle type subject to conscious control). However, it is important to recognize that skeletal muscles are often activated by reflexes (without our "willed command") as well. When you think of skeletal muscle tissue, the key words to remember are *skeletal, striated,* and *voluntary.* Skeletal muscle tissue can contract rapidly and with great force, but it tires easily and must rest after short periods of activity.

Skeletal muscle fibers, like most cells, are soft and surprisingly fragile. Yet skeletal muscles can exert tremendous power—indeed, the force they generate in, say lifting a weight, is often much greater than that required to lift the weight. The reason they are not ripped apart as they exert force is that thousands of their fibers are bundled together by connective tissue, which provides strength and support to the muscle as a whole (**Figure 6.1**). Each muscle fiber is enclosed in a delicate connective tissue sheath called an **endomysium** (en″do-mis′e-um). Several sheathed muscle fibers are then wrapped by a coarser fibrous membrane called a **perimysium** to form a bundle of fibers called a **fascicle** (fas′ĭ-kul). Many fascicles are bound together by an even tougher "overcoat" of connective tissue called an **epimysium,** which covers the entire muscle. The epimysia blend either into strong, cordlike **tendons** or into sheetlike **aponeuroses** (ap″o-nu-ro′sēz), which attach muscles indirectly to bones, cartilages, or connective tissue coverings.

Besides simply acting to anchor muscles, tendons perform several other functions. The most important are providing durability and conserving space. Tendons are mostly tough collagenic fibers, so they can cross rough bony projections, which would tear the more delicate muscle tissues.

Q: *What is the meaning of* epi? *Of* mys? *How do these word roots relate to the role and position of the epimysium?*

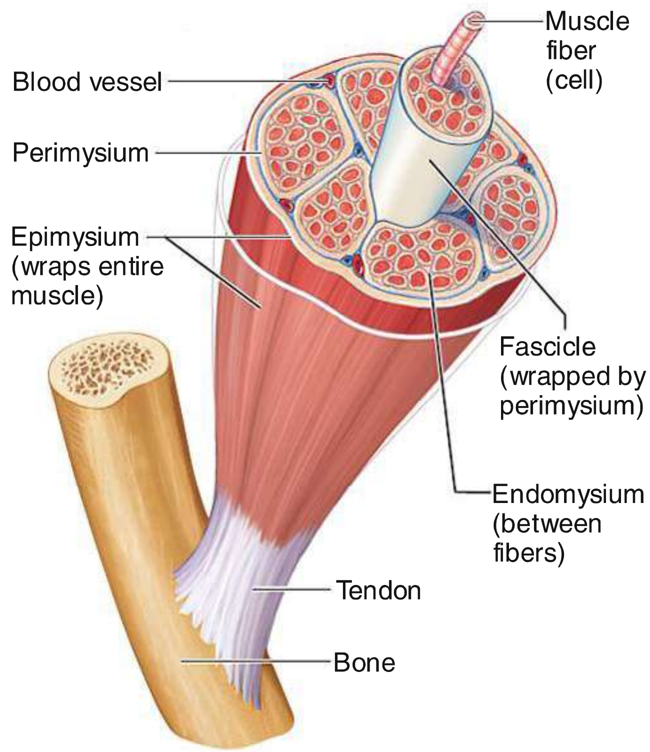


Figure 6.1 Connective tissue wrappings of skeletal muscle.

A: *Epi = upon, over, beside and mys = muscle. The epimysium is a sheath upon or over a muscle.*

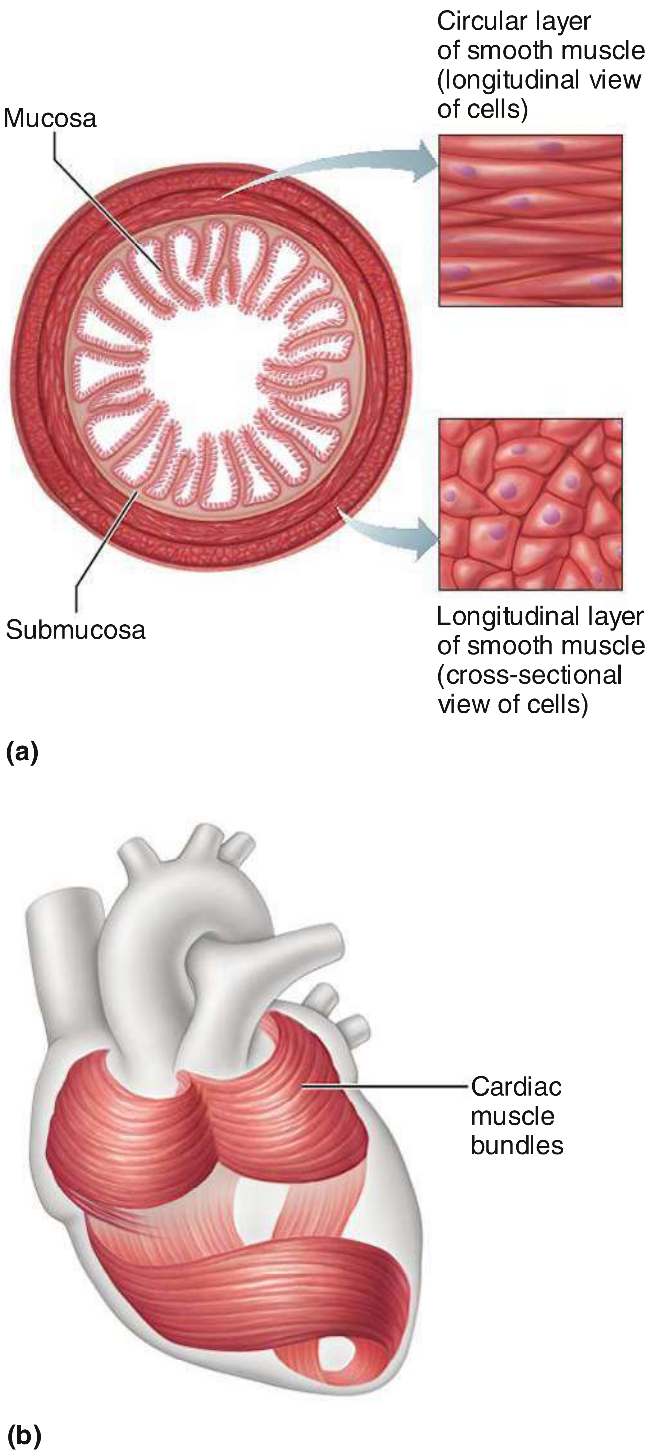


Figure 6.2 Arrangement of smooth and cardiac muscle cells. (a) Diagrammatic view of a cross section of the intestine. **(b)** Longitudinal view of the heart, showing the spiral arrangement of the cardiac muscle cells in its walls.

Because of their relatively small size, more tendons than fleshy muscles can pass over a joint.

Many people think of muscles as always having an enlarged "belly" that tapers down to a tendon at each end. However, muscles vary considerably in the way their fibers are arranged. Many are spindle-shaped as just described, but in others, the fibers are arranged in a fan shape or a circle, as described on pp. 202 and 203.

Smooth Muscle

Smooth muscle has no striations and is involuntary, which means that we cannot consciously control it. Found mainly in the walls of hollow visceral organs such as the stomach, urinary bladder, and respiratory passages, smooth muscle propels substances along a definite tract, or pathway, within the body. We can best describe smooth muscle using the terms *visceral, nonstriated,* and *involuntary.*

As described in Chapter 3, smooth muscle cells are spindle-shaped, have a single nucleus, and are surrounded by a scant endomysium (see also Table 6.1). They are arranged in layers and most often there are two such layers, one running circularly and the other longitudinally, as shown in **Figure 6.2a**. As the two layers alternately contract and relax, they change the size and shape of the organ. Moving food through the digestive tract and emptying the bowels and bladder are examples of "housekeeping" activities normally handled by smooth muscles. Smooth muscle contraction is slow and sustained. If skeletal muscle is like a speedy wind-up car that quickly runs down, then smooth muscle is like a steady, heavy-duty engine that lumbers along tirelessly.

Cardiac Muscle

Cardiac muscle is found in only one place in the body—the heart, where it forms the bulk of the heart walls. The heart serves as a pump, propelling blood into the blood vessels and to all tissues of the body. Cardiac muscle is like skeletal muscle in that it is striated, and like smooth muscle in that it is involuntary and cannot be consciously controlled by most of us. Important key words to jog your memory for this muscle type are *cardiac, striated,* and *involuntary.*

The cardiac fibers are cushioned by small amounts of soft connective tissue (endomysium) and arranged in spiral or figure 8–shaped bundles, as shown in Figure 6.2b. When the heart contracts, its internal chambers become smaller, forcing the blood into the large arteries leaving the heart. Recall that cardiac muscle fibers are branching cells joined by special junctions called *intercalated discs* (see Figure 3.20b on p. 98). These two structural features and the spiral arrangement of the muscle bundles in the heart allow heart activity to be closely coordinated. Cardiac muscle usually contracts at a fairly steady rate set by the heart's "in-house" pacemaker, but the heart can also be stimulated by the nervous system to shift into "high gear" for short periods, as when you run to catch a bus.

As you can see, each of the three muscle types has a structure and function well suited for its job in the body. But because the term *muscular system* applies specifically to skeletal muscle, we will be concentrating on this muscle type in this chapter.

Muscle Functions

Producing movement is a common function of *all* muscle types, but skeletal muscle plays three other important roles in the body as well: it *maintains posture, stabilizes joints,* and *generates heat.* Let's take a look.

Producing Movement

Just about all movements of the human body result from muscle contraction. Skeletal muscles are responsible for mobility of the body as a whole, including all locomotion (walking, swimming, and cross-country skiing, for instance) and manipulation. They enable us to respond quickly to changes in the external environment. For example, their speed and power enable us to jump out of the way of a runaway car and then follow its flight with our eyes. They also allow us to express our emotions with the silent language of smiles and frowns.

They are distinct from the smooth muscle of blood vessel walls and cardiac muscle of the heart, which work together to circulate blood and maintain blood pressure, and the smooth muscle of other hollow organs, which forces fluids (urine, bile) and other substances (food, a baby) through internal body channels.

Maintaining Posture and Body Position

We are rarely aware of the workings of the skeletal muscles that maintain body posture. Yet, they function almost continuously, making one tiny adjustment after another so that we maintain an erect or seated posture despite the never-ending downward pull of gravity.

Stabilizing Joints

As the skeletal muscles pull on bones to cause movements, they also stabilize the joints of the skeleton. Indeed, muscle tendons are extremely important in reinforcing and stabilizing joints that have poorly fitting articulating surfaces (the shoulder joint, for example).

Generating Heat

Body heat is generated as a by-product of muscle activity. As ATP is used to power muscle contraction, nearly three-quarters of its energy escapes as heat. This heat is vital in maintaining normal body temperature. Skeletal muscle accounts for at least 40 percent of body mass, so it is the muscle type most responsible for generating heat.

Additional Functions

Some other roles are usually left off lists of major muscle functions: Skeletal muscles protect fragile internal organs by enclosure. Smooth muscles form valves to regulate the passage of substances through internal body openings, dilate and constrict the pupils of our eyes, and activate the arrector pili muscles that cause our hairs to stand on end.

DID YOU GET IT?

1. How do cells of the three types of muscle tissues differ from one another anatomically?
2. Which muscle type has the most elaborate connective tissue wrappings?
3. What does *striated* mean relative to muscle cells?
4. How do the movements promoted by skeletal muscle differ from those promoted by smooth muscle?

For answers, see Appendix D.

Microscopic Anatomy of Skeletal Muscle

✓ Describe the microscopic structure of skeletal muscle, and explain the role of actin- and myosin-containing myofilaments.

As mentioned above and illustrated in **Figure 6.3a**, skeletal muscle cells are multinucleate. Many oval nuclei can be seen just beneath the plasma

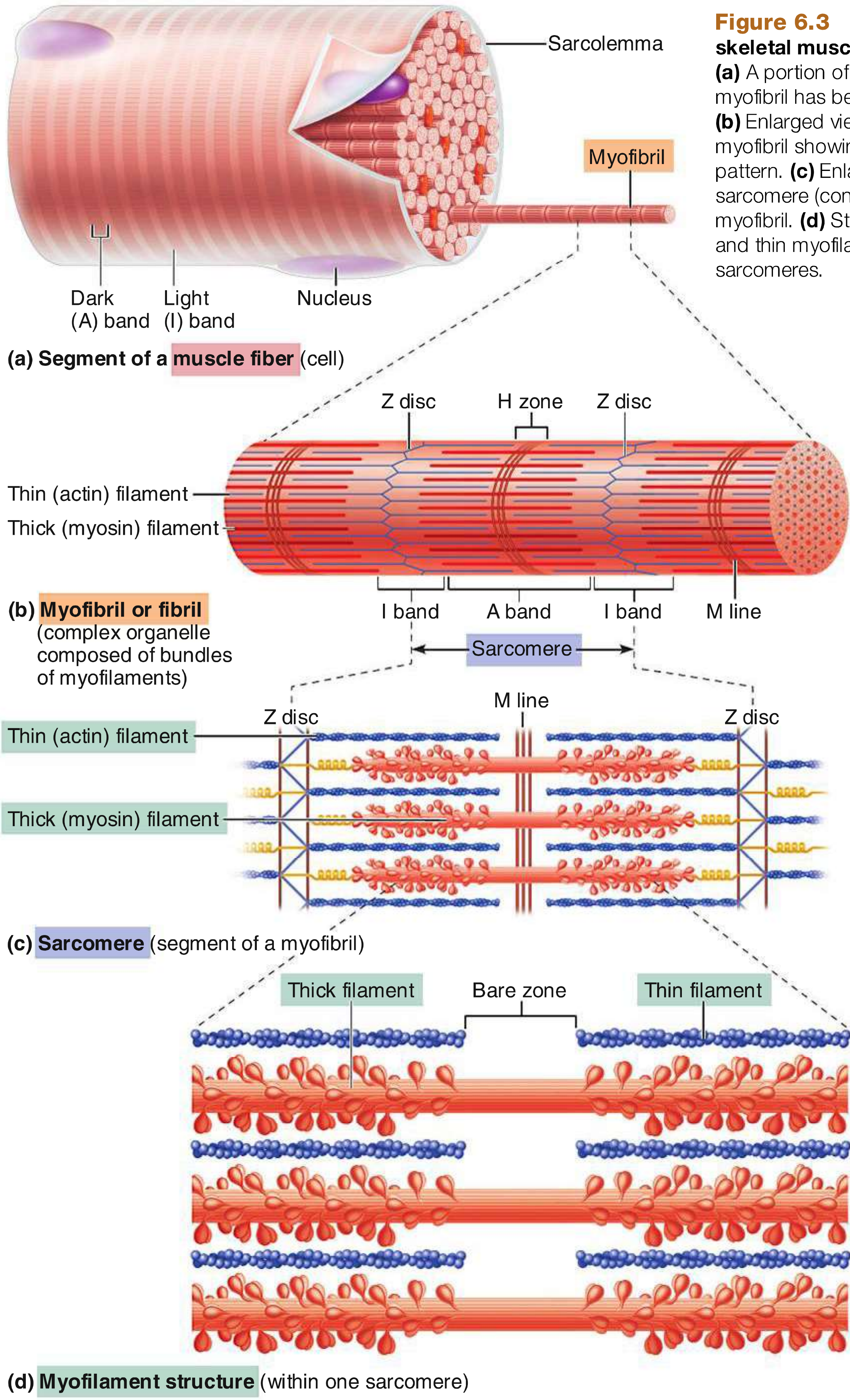


Figure 6.3 Anatomy of a skeletal muscle fiber (cell). **(a)** A portion of a muscle fiber. One myofibril has been extended. **(b)** Enlarged view of a section of a myofibril showing its banding pattern. **(c)** Enlarged view of one sarcomere (contractile unit) of a myofibril. **(d)** Structure of the thick and thin myofilaments found in the sarcomeres.

membrane, which is called the **sarcolemma** (sar″ko-lem′ah; "muscle husk") in muscle cells. The nuclei are pushed aside by long ribbonlike organelles, the **myofibrils** (mi″o-fi′brilz), which nearly fill the cytoplasm. Alternating **light (I)** and **dark (A) bands** along the length of the perfectly aligned myofibrils give the muscle cell as a whole its striped appearance. (Think of the second letter of *light,* I, and the second letter of *dark,* A, to help you remember which band is which.) A closer look at the banding pattern reveals that the light I band has a midline interruption, a darker area called the *Z disc,* and the dark A band has a lighter central area called the *H zone* (Figure 6.3b). The *M line* in the center of the H zone contains tiny protein rods that hold adjacent thick filaments together.

So why are we bothering with all these terms—dark this and light that? Because the banding pattern reveals the working structure of the myofibrils. First, we find that the myofibrils are actually chains of tiny contractile units called **sarcomeres** (sar′ko-merz), which are aligned end to end like boxcars in a train along the length of the myofibrils. Second, it is the arrangement of even smaller structures (myofilaments) *within* sarcomeres that actually produces the banding pattern.

Let's examine how the arrangement of the myofilaments leads to the banding pattern. There are two types of threadlike protein **myofilaments** within each of our "boxcar" sarcomeres (Figure 6.3c). The larger **thick filaments,** also called *myosin filaments,* are made mostly of bundled molecules of the protein **myosin,** but they also contain ATPase enzymes, which split ATP to generate the power for muscle contraction. Notice that the thick filaments extend the entire length of the dark A band. Also, notice that the midparts of the thick filaments are smooth, but their ends are studded with small projections (Figure 6.3d). These projections, or myosin *heads,* are called **cross bridges** when they link the thick and thin filaments together during contraction.

The **thin filaments** are composed of the contractile protein called **actin,** plus some regulatory proteins that play a role in allowing (or preventing) binding of myosin heads to actin. The thin filaments, also called *actin filaments,* are anchored to the Z disc (a disclike membrane). Notice that the light I band includes parts of two adjacent sarcomeres and contains *only* the thin filaments. Although they overlap the ends of the thick filaments, the thin filaments do not extend into the middle of a relaxed sarcomere, and thus the central region (the H zone, which lacks actin filaments and looks a bit lighter) is sometimes called the *bare zone.* When contraction occurs and the actin-containing filaments slide toward each other into the center of the sarcomeres, these light zones disappear because the actin and myosin filaments are completely overlapped. For now, however, just recognize that it is the precise arrangement of the myofilaments in the myofibrils that produces the banding pattern, or striations, in skeletal muscle cells.

Not shown in Figure 6.3 is another very important muscle fiber organelle—the **sarcoplasmic reticulum (SR),** a specialized smooth endoplasmic reticulum. The interconnecting tubules and sacs of the SR surround each and every myofibril just as the sleeve of a loosely crocheted sweater surrounds your arm. The major role of this elaborate system is to store calcium and to release it on demand when the muscle fiber is stimulated to contract. As you will see, calcium provides the final "go" signal for contraction.

DID YOU GET IT?

5. Specifically, what is responsible for the banding pattern in skeletal muscle cells?

For the answer, see Appendix D.

Skeletal Muscle Activity

Stimulation and Contraction of Single Skeletal Muscle Cells

✓ Describe how an action potential is initiated in a muscle cell.

Muscle cells have some special functional properties that enable them to perform their duties. The first of these is *excitability,* also termed *responsiveness,* which is the ability to receive and respond to a stimulus. The second, *contractility,* is the ability to shorten (forcibly) when adequately stimulated. This property sets muscle apart from all other tissue types. *Extensibility* is the ability of muscle cells to be stretched, whereas *elasticity* is their ability to recoil and resume their resting length after being stretched.