20D—The Muscular System

The two key words that describe the muscular system are *contraction* and *movement.* Contraction refers to the ability of a muscle tissue to shorten and thereby cause movement. Some muscles, like those used to get out of bed in the morning, are consciously controlled. However, the muscles of the stomach and intestines that help digest food operate without mental commands. Muscles that cause breathing are consciously controlled when one is talking, singing, or taking a deep breath; at other times breathing is automatic. The muscle of the heart, under certain conditions, not only contracts but also tells itself when to contract.

Muscle tissue also possesses three other important characteristics. *Irritability* is the muscle's ability to respond to impulses from the nervous system. After the muscle responds by contracting, it rebounds to its original length. This ability to return to its previous shape is *elasticity.* Muscle tissue also possesses *extensibility*: it can be stretched when it is relaxed. Extensibility is very important because when one group of muscles contracts, often another muscle group must passively stretch to allow for movement.

20D-1 Objectives

- Compare the three types of human muscle
- Describe the structures of a typical skeletal muscle fiber

20D-1 Muscle Anatomy

Muscle tissue, composed of a great number of cells called **muscle fibers**, is supported by layers of connective tissues. In any description of muscle tissue, the words *fiber* and *cell* are synonymous, but in other body tissues the word *fiber* refers to either a part of the cell (nerve fiber) or a nonliving strand of matrix in connective tissues.

Types of Muscle Tissue

There are three types of muscle tissue in the human body. Each type has properties that fit it for particular functions. These muscle types are distinguished by their location, microscopic appearance, and type of nervous control.

The first type, named for its location, is **skeletal muscle** tissue. It is usually attached to bones. It is also called *striated* (STRY ay tid) *muscle* because there are dark and light stripes in its cells when viewed with a microscope. These striations are actually filaments of protein in the muscle cells. Skeletal muscle is also known as *voluntary* muscle tissue because it is primarily controlled by conscious thought. However, the term *voluntary* does not always apply (for example, when a person moves while sleeping).

The diaphragm (the primary muscle of breathing) functions under voluntary control when a person speaks or sings, but at other times it functions involuntarily. Therefore, it is difficult to classify the diaphragm, even though it is skeletal by its location and appears striated. The muscular tissues in the walls of the pharynx (throat) are also classified as striated because of their appearance, but they are neither voluntary nor attached to a bone.

The second type is **visceral muscle** tissue. The term *visceral* refers to internal organs. The name fits well because visceral muscle is located in the walls of internal organs such as the stomach, intestines, blood vessels, and urinary bladder. Visceral muscle is also located in the iris of the eye and causes the diameter of the pupil to increase or decrease, depending on the brightness of the environment.

Most of the *sphincters** (SFINGK turz), circular bundles of muscles that regulate the diameter of various tubular organs and openings, are visceral muscles. The muscular valves at both ends of the stomach are examples of sphincters.

Visceral muscle is also called *nonstriated* or *smooth* because it does not have dark and light stripes. All visceral muscle tissue is termed *involuntary* because it is *not* directly controlled by conscious thought. In other words, visceral muscle tissue can function (and, in fact, functions most regularly) when a person is asleep.

Cardiac* muscle, the third type of muscle, is located only in the heart. Cardiac muscle tissue is *striated* and *involuntary.* The striations, however, are not as regular and distinct as in skeletal muscle. Cardiac muscle fibers branch and join together. This network of interwoven fibers allows nerve impulses to spread quickly through the muscular walls of the heart and produces effective pumping of the blood.

Visceral and cardiac muscle tissues are discussed in greater detail in connection with other body systems (see Chaps. 21–25). The remainder of this chapter deals with skeletal muscle tissue.

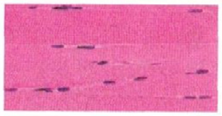
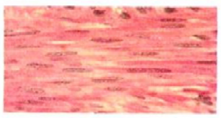
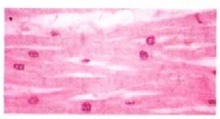
sphincters: (Gk. SPHINGEIN, to bind tight)

cardiac: (heart)

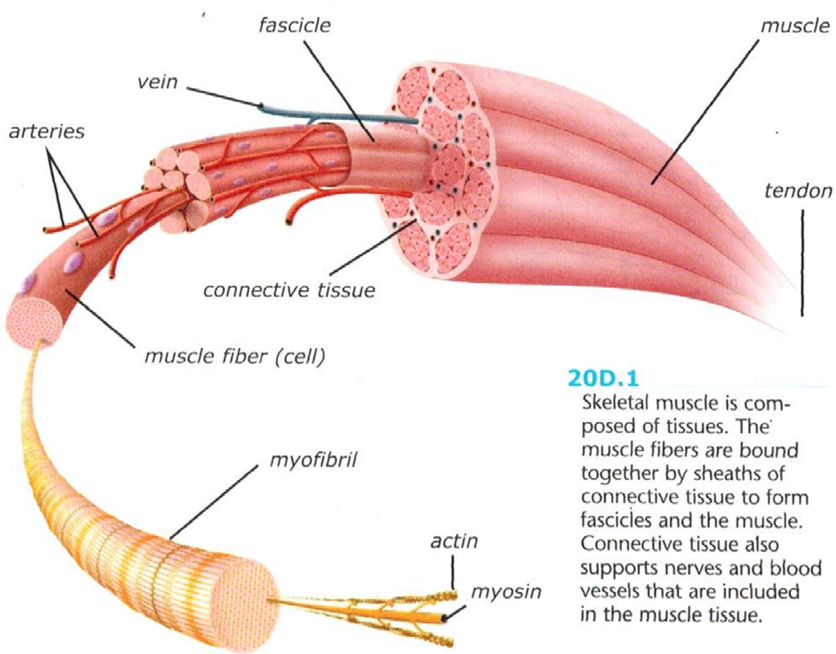
Muscle Structure

A skeletal muscle fiber (cell) is barely visible to the unaided eye. Each fiber is a multinucleate cylinder wrapped in a thin sheath of connective tissue. Groups of ten to a hundred fibers are bound together with other layers of connective tissue to form a **fascicle**. A thicker connective tissue layer encloses groups of fascicles to form the muscle itself. At the ends of the muscle, the connective tissue merges to form the tendons that attach the muscle to bones. The connective tissues not only hold the muscle fibers together but also support blood vessels and nerves that supply the fibers.

Table 20D-1 Muscle Classification

Kind of muscle		Location of muscle	Function of muscle	Kind of fibers	Voluntary or involuntary
Skeletal		Primarily attached to bones and other movable structures	Move parts of the body	Striated	Voluntary
Visceral		Walls of internal organs and blood vessels	Move organ or substance within the organ	Smooth	Involuntary
Cardiac		Heart	Contract heart to pump blood	Striated	Involuntary

The cytoplasm within each muscle fiber contains numerous tiny threadlike **myofibrils*** (MYE uh FYE bruhlz). These myofibrils parallel each other and extend the length of the fiber. There are two kinds of protein filaments in each myofibril—thick filaments made of the *myosin* (MYE uh sin) and thin filaments made of the *actin*. The overlapping arrangement of these filaments is repeated to produce the striated appearance. The actin filaments are anchored at their midline to a structure called the **Z line**. The distance from one Z line to another is called a **sarcomere**—the functional unit of muscle contraction.

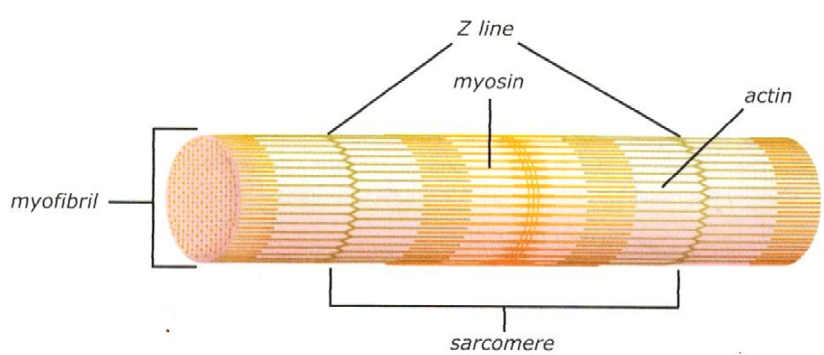


20D.1
Skeletal muscle is composed of tissues. The muscle fibers are bound together by sheaths of connective tissue to form fascicles and the muscle. Connective tissue also supports nerves and blood vessels that are included in the muscle tissue.

Muscle Cell Terminology

Because a skeletal muscle fiber is actually a fusion of several cells into one, its parts have special names. The prefix *sarco-* comes from the Greek word *sarko*, meaning flesh.

- sarcolemma—plasma membrane
- sarcoplasm—cytoplasm
- sarcoplasmic reticulum—endoplasmic reticulum
- sarcosome—mitochondrion



20D.2
Sarcomere: the functional unit of a muscle

myofibril: myo- (Gk. MUS, muscle) + -fibril (fiber)

20D-2 Objectives

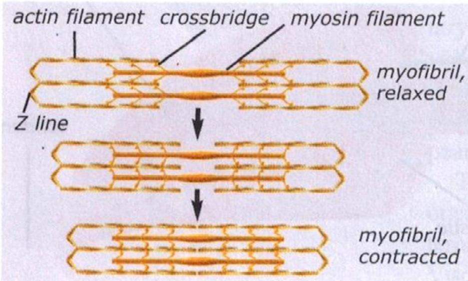
- Describe the muscle contraction process
- Explain muscle fatigue

20D-2 Muscle Physiology

Muscles move. To move, they need ATP as an energy source; as they move, energy is released as heat. How muscles accomplish these functions is the science of *muscle physiology*.

Muscle Contractions

The contraction process begins when impulses from nerve cells stimulate the actin and myosin filaments to interact and shorten the sarcomere. The myosin filaments have little extensions called crossbridges that are shaped like golf club heads. Actin filaments look like a strand of twisted beads. Calcium ions and energy cause the crossbridges of the myosin filaments to attach to the actin filaments. The crossbridges flex and pull the actin filaments, drawing the muscle ends together and shortening the sarcomere.



20D.3
Interaction between actin and myosin during muscular contraction

During a single contraction, the actin and myosin attach, disengage, and reattach multiple times, making a coordinated movement of the muscle. Muscle contraction requires the energy derived from ATP molecules; therefore, a continuous supply is needed. Normally, cellular ATP is derived from the breakdown of glucose to pyruvic acid and then to carbon dioxide and water. The amount of ATP in a muscle cell is enough for only a few contractions; therefore, it must be continually replenished by the numerous sarcosomes that are located in the muscle fibers.

Muscle contraction is an all-or-none response—the fibers either contract or remain relaxed. How does one reduce the force of a contraction of the muscles in

a Closer Look

Muscle Contraction and the Sliding Filament Model

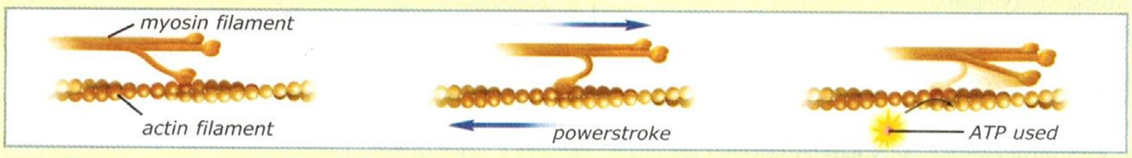
The sliding filament model is the process researchers have devised to explain God's plan for muscular movement at the molecular level.

In the relaxed state, the heads of the myosin filaments are uncocked. The influx of calcium ions unblocks the binding site on the actin filament. The myosin head binds to the actin and pulls it. This is called the *powerstroke*. At the end of the powerstroke, the myosin head releases the actin filament.

The contraction of a sarcomere (and subsequently the entire muscle) is a result of millions of powerstrokes occurring simultaneously. What keeps the fibers from slipping back? Each myosin is surrounded by six actin fibers, and the action is similar to pulling a rope hand over hand. While one hand is pulling, the other hand is resting and preparing to pull again. In this way there is a continuous pull on the rope.

ATP is used in the following phases of the process:

1. When the attachment between the head of the myosin and the actin receptor site is formed
2. When the detachment of the crossbridge and the recocking of the myosin head take place



Sliding filament model at the molecular level his hand when he is gently holding an infant's hand and then increase the force when holding onto the leash of a large dog? The number of muscle fibers stimulated determines the force of the contraction. When the number of fibers stimulated is increased, the force of the contraction is increased.

Muscle Fatigue and Physical Condition

When a person is resting or moderately active, the skeletal muscles usually have enough glucose and oxygen for energy production. However, after he exercises skeletal muscles strenuously for a few minutes, his respiratory and circulatory systems cannot supply enough oxygen to the muscles. Glucose then breaks down to *pyruvic acid* and releases a small amount of energy to make ATP. The pyruvic acid is then converted to lactic acid.

Eventually, if exercise continues, the demand exceeds the supply. The decrease of both ATP and oxygen results in the buildup of lactic acid inside the muscle fibers. Since the lactic acid cannot be used, it must be transported by the blood to the liver cells, where it can be converted into glucose through the expenditure of ATP energy. The blood, however, can transport only a fixed amount of lactic acid at a time. The excess lactic acid in muscle cells decreases the pH, resulting in an inability of the muscle fibers to respond (contract) to the nerve stimulation. This inability of the fibers to contract is called **muscle fatigue**.

The lack of oxygen that causes the accumulation of lactic acid in the muscles and liver is known as the **oxygen debt**. The amount of oxygen debt equals the amount of oxygen needed by these cells to convert the accumulated lactic acid into glucose.

It is common to feel "out of breath" and to continue to breathe deeply following vigorous exercise. During this time of deep breathing, oxygen is supplied to the muscles. When sufficient oxygen has reached the muscles and ATP production proceeds as usual, normal breathing resumes. However, some lactic acid remains in the muscles and liver. It may take several hours or days to relieve this oxygen debt completely.

A person is in good physical condition ("in shape") when he can engage in moderately strenuous physical activity without developing fatigued muscles. The conditioned athlete can run several miles without significant oxygen debt or soreness, but the unconditioned athlete cannot. The conditioned athlete's muscles have more filaments and hold more oxygen. His circulatory and respiratory systems function efficiently to transport oxygen to the muscles.

The "out of shape" person does not have these benefits and soon begins to pant (which does not supply as much oxygen to the lungs as smooth deep breathing) and to waste energy on excess movements. The person in poor physical condition builds up an oxygen debt much sooner and with much less physical activity than the person in good physical condition.

The body builds the muscle fibers and oxygen-holding capacity it needs for its normal activities. Daily exercise will soon prepare it for a more strenuous workout.

Big Muscles, Little Muscles

In a body-building program a person may perform numerous muscle contractions to increase the size and strength of his muscles. This increase is an enlargement of individual muscle fibers, not an increase in the number of fibers. The mitochondria within the fibers reproduce, and the number of actin and myosin filaments increases.

Because the strength of a contraction is directly related to the diameter of the muscle fibers, large muscles are strong muscles. Running and other aerobic exercises, however, usually produce only slight increases in the size and strength of the muscles involved. Running benefits the heart, blood vessels, and lungs more than it does the skeletal muscles. The runner may not have the strength or the bulging muscles of the weightlifter, but his endurance is probably greater. Today, most fitness trainers recommend an exercise program that includes both aerobic and strength training. Of course, the final results depend on the individual and his genetic makeup.

The proper motive for participating in any exercise program is to develop and maintain the body's health and strength in order to serve the Lord regularly and efficiently. The desire for bulging biceps to impress people is sinful pride.

A muscle that is not used or is used only to produce weak contractions usually decreases in size and strength. Mitochondria in the fibers and blood capillaries decrease in number. The amount of muscle protein (actin and myosin) also decreases. This is called *muscular atrophy** (AT ruh fee) and occurs when a muscle is in a cast or when an active person becomes inactive.

atrophy: a- (without) + -trophy (nourishment)

Unit 4: The Muscular System

1. What are the five characteristics of a muscle?
2. What are the three basic types of muscle tissue? Describe the appearance of each tissue and tell where it is located in the body.
3. Draw a sketch of a muscle fiber (like the one on page 647) and label its parts.
4. What molecule do muscles burn for energy?
5. What causes you to breathe deeply after running?
6. Why can someone who is physically fit exercise moderately without getting tired?
7. Why do muscle cells get bigger when you exercise them over and over?
8. What is muscular atrophy?