

# CHAPTER 10

# The Muscular System and Homeostasis

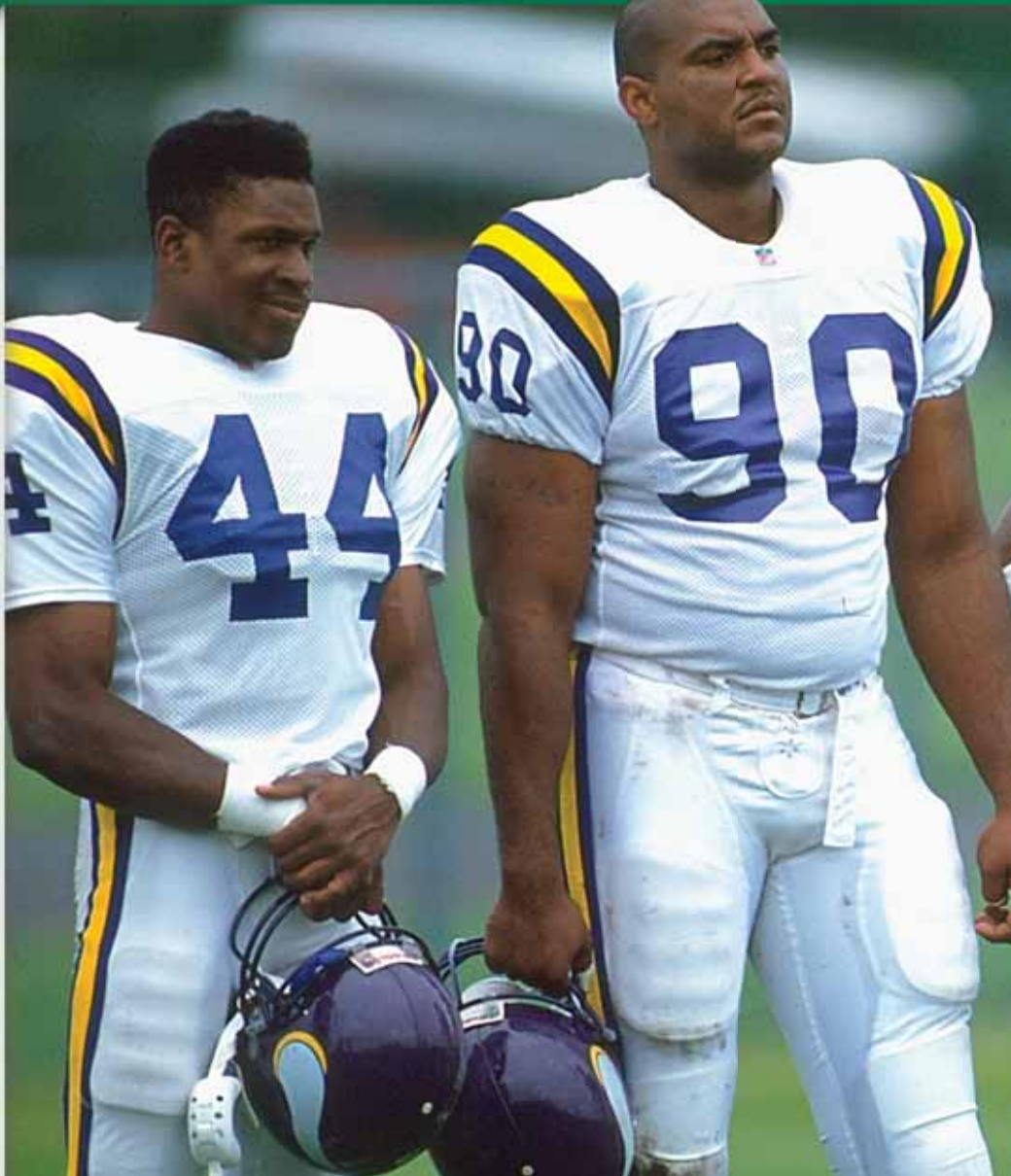
## Chapter Concepts

### 10.1 Movement and Muscle Tissue

- There are three types of muscle tissue: skeletal muscle, smooth muscle, and cardiac muscle.
- Skeletal muscle produces body movement, maintains body temperature, and provides support for the body.
- Muscle fibres are filled with myofibrils that house thin (actin) and thick (myosin) contractile protein myofilaments.
- Actin and myosin slide past each other during a muscle contraction.
- Creatine phosphate, fermentation, and aerobic cellular respiration provide energy for muscle contractions.

### 10.2 Muscles, Health, and Homeostasis

- Three types of skeletal muscle—slow-twitch, fast-twitch, and an intermediate type—are found in different parts of the body.
- Muscles atrophy with inadequate stimulation and can hypertrophy with appropriate repeated stimulation.
- The muscular system works with other body systems to maintain homeostasis.



**M**uch of the heat that maintains the core body temperature of 37 °C is generated by muscle activity. The muscles of high-performance athletes, such as the members of the Minnesota Vikings shown here, generate an enormous amount of heat—so much so that a hard workout on a hot day can take a player's core body temperature into the danger zone. In 2001, the Vikings lost a teammate to heat stroke after a tough July workout.

In this chapter you will find out how muscles work to move you, heat your body, and support other body systems. You will also look at the benefits of maintaining healthy muscle structure and function throughout your life.

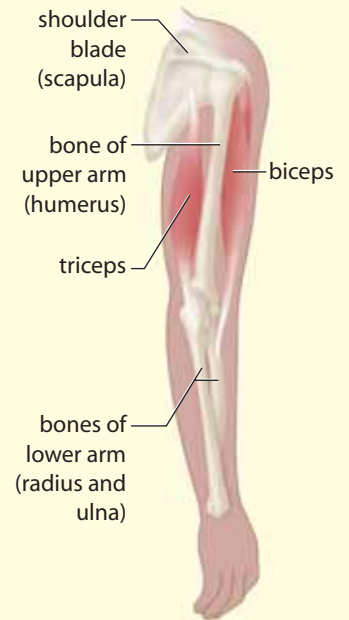
## Launch Lab



Today, many coaches are using technology developed by NASA—an ingestible temperature-measuring device and a hand-held sensor—to safeguard the core body temperature of their players.

### Working in Pairs

The muscles that enable you to move your body are attached to the bones of the skeleton. The contractions of these muscles cause the movements of the bones at a joint (a place where two or more bones meet). Because muscles shorten when they contract, they can only pull; they cannot push. Therefore, muscles work in pairs. One muscle of the pair causes a bone to move in one direction, and the contraction of the other muscle of the pair causes the same bone to move in the opposite direction. In this activity, you will flex your muscles in the name of science!



### Procedure

1. With a partner, try out different states of relaxation and contraction of the biceps and triceps—two paired muscles in your arm. While one of you does the flexing, the other should observe by sight and by touch how these two muscles change.
2. Switch roles with your partner.

### Analysis

1. Sketch and label the arm to show the relationship between the biceps and triceps when the arm is relaxed (hanging down at your side).
2. Sketch and label the arm to show the two muscles when the arm is flexed.
3. Were you able to observe, through touch, any temperature increase in the biceps or triceps? If so, can you be sure that the heat you felt was the result of the activity of these muscles, rather than heat radiating from blood vessels in the skin? What would you need to do to help you decide?



# Movement and Muscle Tissue

## Section Outcomes

- In this section, you will
- **observe** and **compare** the three types of muscle tissue
  - **describe**, in general, the action of actin and myosin in muscle contraction and heat production
  - **identify** the sources of energy for muscle contraction

## Key Terms

smooth muscle  
cardiac muscle  
skeletal muscle  
muscle fibres  
myofibrils  
myofilaments  
actin myofilament  
myosin myofilament  
sliding filament model

Muscle tissue is highly specialized to convert chemical energy into kinetic energy—the energy of movement. The intricate, precise movements of a dancer, a basketball player, and an artist occur through the coordinated contracting and relaxing of many muscles. All muscles, regardless of their type, can contract (shorten). When muscles contract, some part of the body, or the entire body, moves.

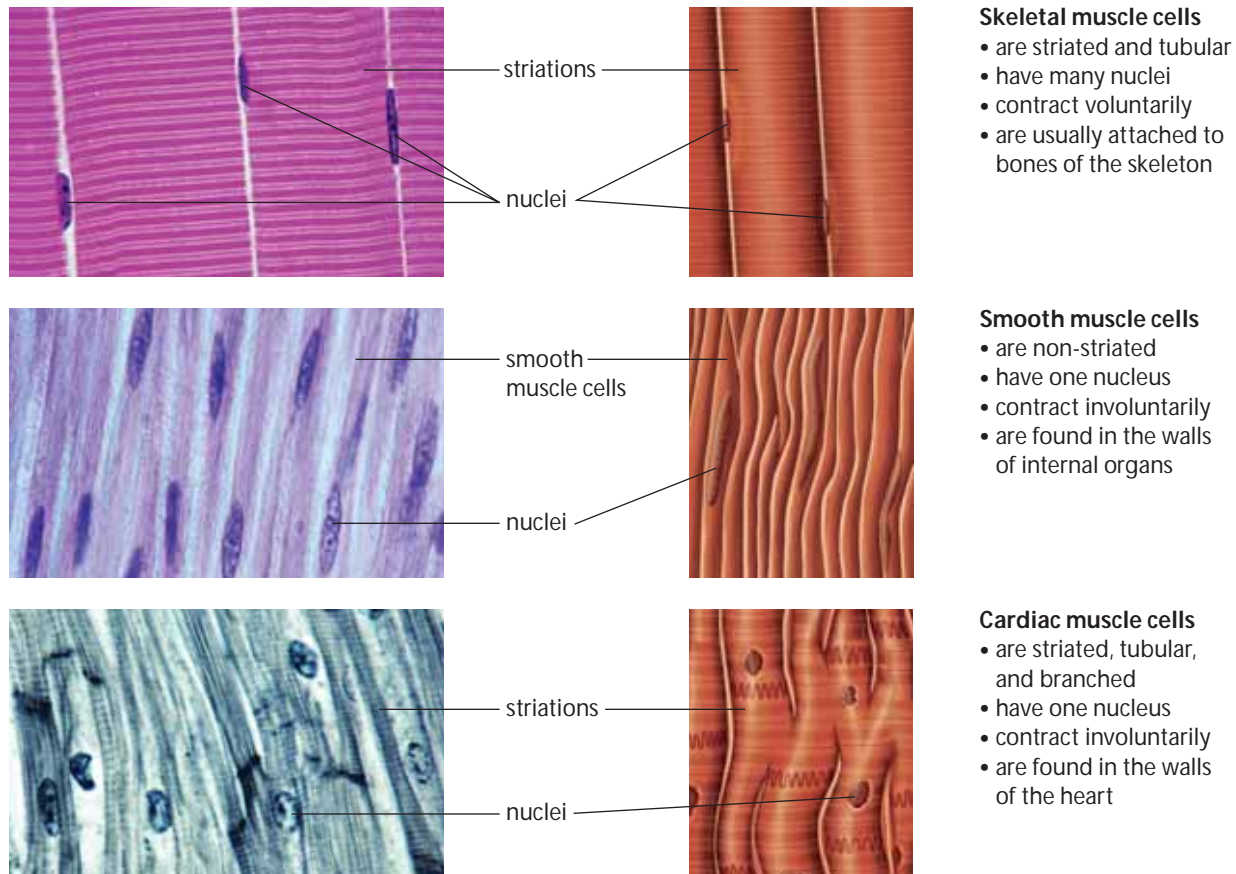
There are three types of muscle cells, as illustrated in Figure 10.1. Food moves through the intestines because of the contractions of smooth muscle. The heart accomplishes its unceasing movement because of cardiac muscle. The body is able to move because skeletal muscle pulls on the bones of the skeleton.

The cells of **smooth muscle** tissue are long and tapered at each end and

have one nucleus. They are usually arranged in parallel lines, forming sheets. You can find smooth muscle in many parts of the body. In the walls of certain blood vessels, for example, smooth muscle contracts, helping to regulate blood pressure and direct blood flow. In the iris of the eye, smooth muscle controls the size of the eye's opening to light. As well, smooth muscle is located in the walls of hollow internal organs, and it causes these walls to contract. Contraction of smooth muscle is involuntary—it occurs without conscious control. Although smooth muscle is slower to contract than skeletal muscle, it can sustain prolonged contractions and does not fatigue easily.

**Cardiac muscle** is unique to the heart and forms the wall of the heart.

**Figure 10.1** Comparing and contrasting skeletal, smooth, and cardiac muscle cells.



The cells are tubular and striated (have bands of light and dark) and have one nucleus. Cardiac muscle cells are branched, creating a netlike structure. Like smooth muscle, cardiac muscle contraction is involuntary.

**Skeletal muscle** cells, like cardiac muscle cells, are tubular and striated. The “meat” (flesh) of animal bodies is skeletal muscle. Skeletal muscle contraction is voluntary, because its contraction is consciously controlled by the nervous system. The great range and types of movement in the human body are due to over 600 skeletal muscles. These muscles have numerous functions, as outlined in the box below.

Unlike smooth and cardiac muscle cells, skeletal muscle cells are very long and have many nuclei. Because of the length of a skeletal muscle cell, its needs for energy and materials are too much to be coordinated by a single nucleus. Multiple nuclei maintain the normal functions of these cells. Because of their structural organization and the presence of many nuclei, skeletal muscle cells are usually referred to as *fibres*, rather than cells.

### The Functions of Skeletal Muscle

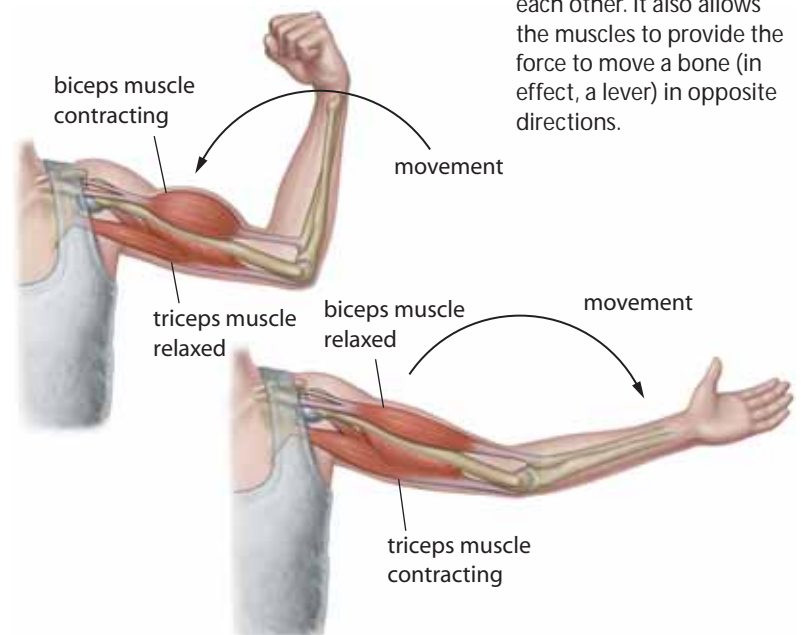
- *Skeletal muscle supports the body.* The contraction of skeletal muscle opposes the force of gravity and enables us to stand and remain upright.
- *Skeletal muscle makes the bones move.* Muscle contraction accounts not only for the movements of the arms and legs but also for the movements of the eyes and for facial expressions and breathing.
- *Skeletal muscle helps to maintain a constant body temperature.* Skeletal muscle contraction causes ATP to break down, releasing a considerable amount of heat, which is distributed throughout the body.
- *Skeletal muscle helps to protect the internal organs and stabilize the joints.* Skeletal muscle pads the bones that protect the organs. As well, it has tendons that help to hold the bones together at the joints.

1 Briefly describe the main differences among smooth, cardiac, and skeletal muscle.

## The Cooperation of Skeletal Muscles

When muscles contract, they shorten. This means that muscles can only pull; they *cannot* push. The work of any muscle is done during its contraction. Relaxation is the passive state of the muscle. There must always be a force available to stretch a muscle after it has stopped contracting and relaxes. Therefore, the muscles that permit movements of the skeleton are present in pairs (see Figure 10.2). For the action of each muscle, there is another muscle that has the opposite action. For example, the biceps muscle causes the arm to flex (bend) as the muscle shortens. The contraction of its “opposite,” the triceps muscle, causes the arm to extend (straighten) and, at the same time, stretches the relaxed biceps muscle.

2 Why do muscles that cause bones to move function as opposing pairs?



## BiologyFile

### FYI

The movement of the jaw to chew food requires the action of four pairs of skeletal muscles. Moving a foot involves eight pairs.

**Figure 10.2** To lengthen, a muscle must relax so that an opposing force can pull the muscle back to its full length. The arrangement of opposing pairs of muscles around a joint (in effect, a fulcrum) allows the muscles to act together to stretch each other. It also allows the muscles to provide the force to move a bone (in effect, a lever) in opposite directions.

Target Skills

**Observing** different types of muscle with a microscope

**Recording** observations through the use of labelled sketches

**Obtaining and interpreting** experimental evidence to account for muscle fibre contraction

## Observing Muscle Tissue

The three types of muscle tissue—skeletal, smooth, and cardiac—have characteristics that distinguish them from each other. In this investigation, you will observe the three types of muscle tissue and compare them to each other.

### Questions

How do the three types of muscle tissue differ under microscopic examination? What conditions are necessary for a muscle fibre to contract?



### Safety Precautions

Make sure that your hands are dry when handling electrical equipment. Handle microscope slides carefully, since they can break easily and cause cuts.

### Materials

- petri dish with glycerol and skeletal muscle tissue
- light microscope
- small forceps or tweezers
- teasing needle
- prepared slides of different muscle tissues
- dropper pipette
- 2 microscope slides
- 2 cover slips

### Procedure

#### Part 1

- Design a data table, like the one shown here, to record your observations.

Data Table for Part 1

Type of muscle	Organization of fibres	Description of fibres	Description of nuclei
skeletal			
smooth			
cardiac			

- Place the slide of the skeletal muscle tissue on the microscope stage, and focus using the low-power lens.
- Scan the slide to find an area where you can observe individual muscle fibres.
- Observe the fibres, using Figure 10.1 for reference. In your table, record your observations of the fibres, including their organization, the presence or absence

of striations, and the presence (and number) or absence of nuclei in each fibre.

- Make your own drawing of skeletal muscle tissue. Label your drawing as completely as you can, and estimate the size of the cells.
- Repeat steps 2 to 5 until you have observed all three types of muscle tissue.
- Answer Analysis questions 1 to 3 and Conclusion question 5.

#### Part 2

- Make a copy of the data table for Part 2.

Data Table for Part 2

Solution	Length (mm)	
	Slide 1	Slide 2
glycerol alone		
potassium-magnesium salt solution alone		
ATP alone		
both salt solution and ATP		

- Label two slides 1 and 2. On each slide, mount a strand of glycerinated muscle fibres in a drop of glycerol. Place each slide on a ruler, and measure the length of the strand. Record the length of each strand in the first row of your data table.
- If there is more than a small drop of glycerol on each slide, soak up the excess with a piece of lens paper held at the edge of the glycerol, farthest from the fibre strand.
- To slide 1, add a few drops of the salt solution that contains potassium ions and magnesium ions. Measure any change in the length of the strand, and record your results.
- To slide 2, add a few drops of ATP solution. Measure and record any change in the length of the strand.
- Now add ATP solution to slide 1. Measure and record any change in the length of the strand.

7. To slide 2, add a few drops of the potassium-magnesium solution. Measure and record any change in the length of the strand.

8. Answer Analysis question 4 and Conclusion questions 6 and 7.

### Analysis

1. Describe each type of muscle tissue.
2. Explain the difference between voluntary and involuntary muscle. Is it possible to tell from your observations whether muscle tissue is voluntary or involuntary? Explain.
3. Cardiac muscle is only found in the heart. Suggest a reason why the heart needs a unique type of muscle.

4. Summarize your observations of the strand of muscle fibres in Part 2, noting which variables were controlled and which were manipulated.

### Conclusions

5. Make a statement that correlates the observed structure of each type of muscle fibre to its function in the body.
6. Based on your observations, identify the factors required for a muscle fibre to contract.
7. Based on your observations, and given that a whole muscle is comprised of numerous muscle fibres, suggest a plausible mechanism for the contraction of skeletal muscle in the body.

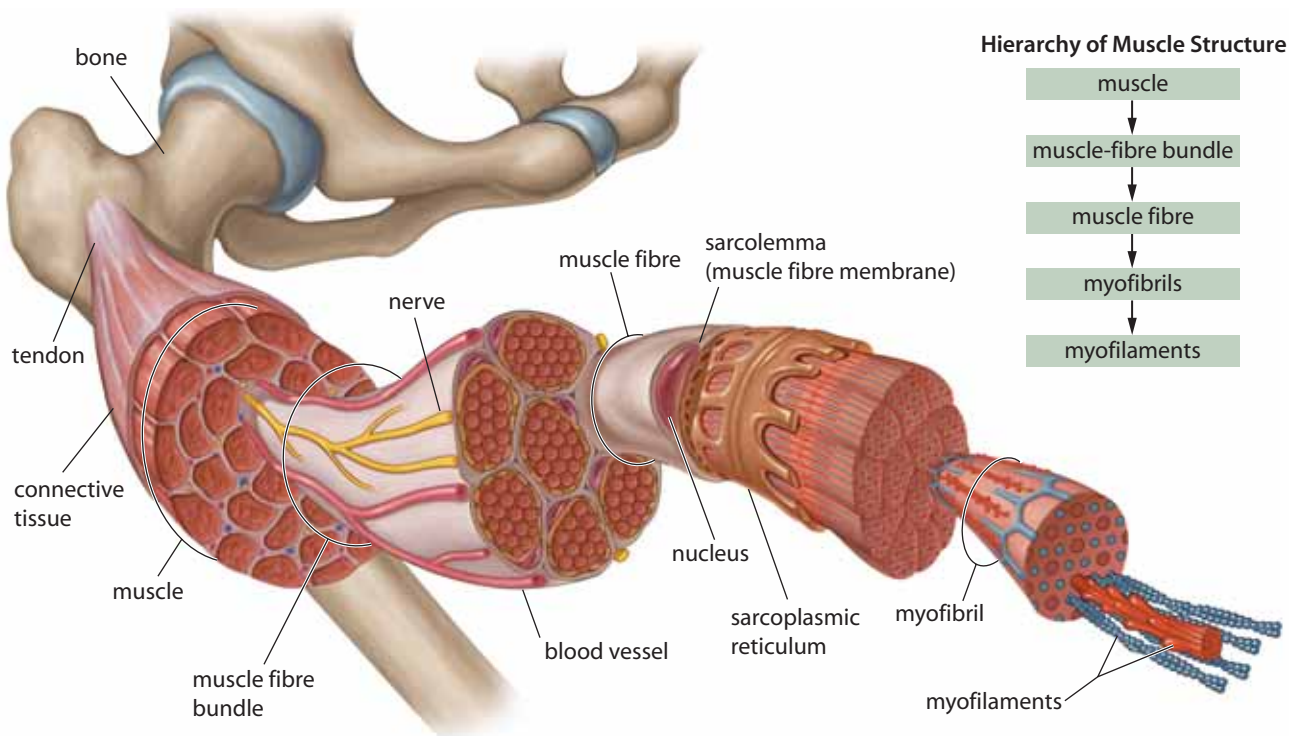
## Skeletal Muscle Consists of Bundles of Fibres

Figure 10.3 shows the levels of organization of skeletal muscle. Each muscle in the body lies along the length of a bone. A tough, heavy band of tissue, called a tendon, attaches each end of a muscle to a different bone. The long skeletal muscle fibres can be up to 20 cm in length. **Muscle fibres** are organized into many larger bundles. A muscle, then,

consists of clusters of such bundles of muscle fibres. A layer of connective tissue wraps around each fibre. Another layer wraps around each bundle of fibres, and another around the whole muscle itself.

Blood vessels and nerves run between the bundles of muscle fibres. The rich blood supply provides muscle fibres with nutrients and oxygen to power contractions, and it removes cellular wastes. The nerves trigger and control muscle contractions.

**Figure 10.3** A muscle is composed of many muscle fibres. The muscle fibres are made up of myofibrils, which are composed of two kinds of myofilaments.





## BiologyFile

### Try This

Unlike the hollow organs of the body, which are made up of smooth muscle tissue, the diaphragm of the respiratory system is made up of skeletal muscle tissue. What do you know about the function of the diaphragm that would enable you to infer that the diaphragm is composed of skeletal, rather than smooth, muscle tissue?

Most of the volume of a muscle fibre consists of hundreds of thousands of cylindrical subunits called **myofibrils**. Each myofibril is made of even finer **myofilaments**, which contain protein structures that are responsible for muscle contractions. The rest of the volume of a muscle fibre consists of numerous mitochondria (about 300 per muscle fibre) and other organelles common to most cells. Table 10.1 outlines some of the main components of a muscle fibre. Note that some of the names of the components are different from the names used for these components in other types of cells. For example, the cell membrane of a muscle fibre is called the sarcolemma (from two Greek words that mean “flesh husk”), and the cytoplasm is called the sarcoplasm.

3 Describe how skeletal muscle fibres are organized.

## The Mechanism of Muscle Fibre Contractions

Muscle contractions involve the coordinated action of the two types

of myofilaments: actin and myosin. A thin **actin myofilament** consists of two strands of protein (actin) molecules that are wrapped around each other, somewhat like two strands of beads loosely wound together. A thick **myosin myofilament** also consists of two strands of protein molecules wound around each other, but it is about 10 times longer than an actin filament and has a different shape. One end of a myosin myofilament consists of a long rod, while the other end consists of a double-headed globular region, often called the “head.” Figure 10.4 compares the structures of actin and myosin.

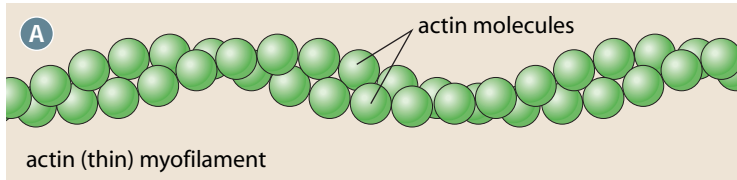
4 How is myosin different from actin?

### How Myofilaments Contract

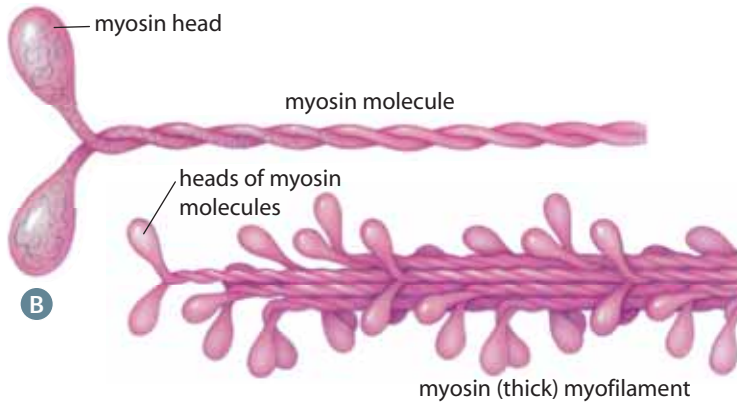
Examine the diagram of myosin and actin (Figure 10.5), and focus on the myosin heads. When a myofilament contracts, the heads of the myosin move first. Like flexing your hand at the wrist, the heads bend backward and inward. This moves them closer to their rod-like “backbone” and a few nanometers in the

**Table 10.1** Some Components of Skeletal Muscle Fibres

Component	Description	Function
Muscle fibre	single muscle cell	is responsible for muscle contractions
myoglobin	oxygen-binding pigment (similar to hemoglobin) in a skeletal muscle fibre	stores oxygen for use during muscle contractions
sarcolemma	membrane of a muscle fibre	surrounds the muscle fibre and regulates the entry and exit of materials
sarcoplasm	cytoplasm of a muscle fibre	is the site of metabolic processes for normal cell activities; contains myoglobin and glycogen (which stores energy for muscle contractions)
sarcoplasmic reticulum	smooth endoplasmic reticulum in a muscle fibre (refer to Unit 3 Preparation to review the structure and function of cell organelles)	stores calcium ions needed for muscle contractions
Myofibrils	organized bundles of myofilaments; cylindrical structures, as long as the muscle fibre itself	contain myofilaments that are responsible for muscle contractions
thick filament	fine myofilament composed of bundles of protein called myosin (about 11 nm in diameter)	binds to actin and causes muscle contractions
thin filament	fine myofilament composed of strands of protein called actin (about 5 nm in diameter)	binds to myosin and causes muscle contractions



**A** Actin myofilaments are composed of globular actin proteins. Other proteins (discussed on the next page) are also associated with strands of actin.



**B** Myosin myofilaments are composed of myosin molecules. Each myosin molecule consists of two polypeptide chains wrapped around each other. The end of each chain has a distinctive globular region, known as the head. Since the thick myofilaments are composed of bundles of myosin molecules, the heads protrude at regular intervals.

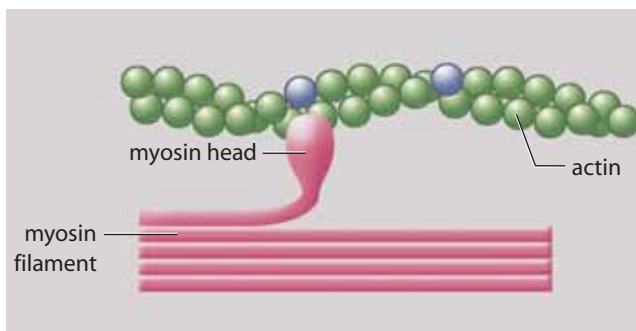
**Figure 10.4** The structures of actin and myosin.

direction of the flex. Because the heads are attached (chemically bound) at this time to an actin myofilament, the actin is pulled along with the myosin heads as they flex. As a result, the actin myofilament slides past the myosin myofilament in the direction of the flex. As one after another myosin head flexes, the myosin, in effect, walks step by step along the actin. Each step requires a molecule of ATP to

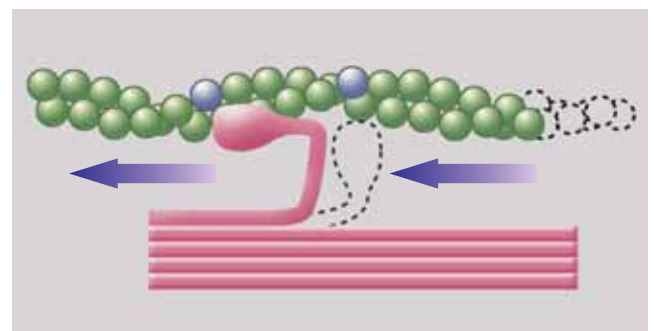
provide the energy that repositions the myosin head before each flex.

The sliding of actin past myosin is part of the **sliding filament model** of muscle contraction. As shown in Figure 10.6 on the next page, the actin is anchored at one end of each myofilament, at a position in striated muscle tissue called the Z line. Because the actin is anchored like this, its movement pulls its “anchor”

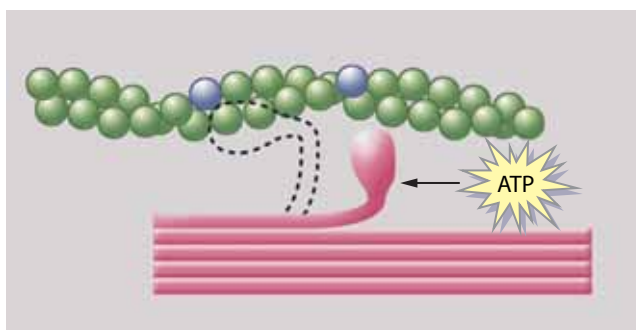
**Figure 10.5** The movement of actin and myosin.



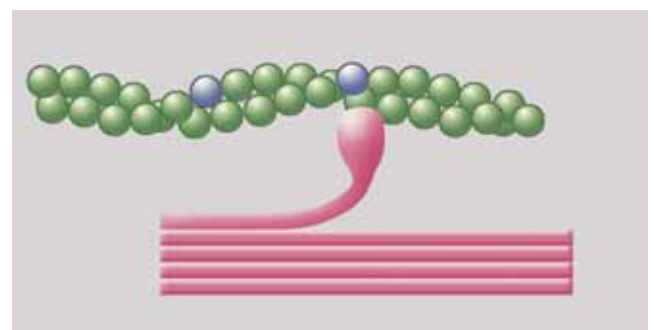
**A** The myosin head is attached to actin.



**B** The myosin head flexes, advancing the actin filament.



**C** The myosin head releases and unflexes, powered by ATP.



**D** The myosin reattaches to actin farther along the fibre.



## BiologyFile

### FYI

The year 1996 brought a surprising announcement from two American dentists, Gary Hack and Gwendolyn Dunn, at the University of Maryland. To study the muscles involved in chewing, they were performing a dissection from an atypical angle—entering from the front of the head, rather than from the side as is usual. To their astonishment, the scientists discovered muscle that had never been identified and described before. They named it the sphenomandibularis.

(the Z line) along with it. As actin moves past myosin, it drags the Z line toward the myosin. The mechanism of muscle contraction depends on the structural arrangement of myosin myofilaments in relation to pairs of actin myofilaments. With one actin myofilament being pulled inward in one direction and the other actin myofilament being pulled inward in the opposite direction, the two pairs of actin molecules drag the Z lines toward each other as they slide past the myosin core. As the Z lines are pulled closer together, the plasma membranes to which they are attached move toward one another, causing the entire muscle fibre to contract.

5 Explain how muscle fibres contract.

6 What is the sliding filament model?

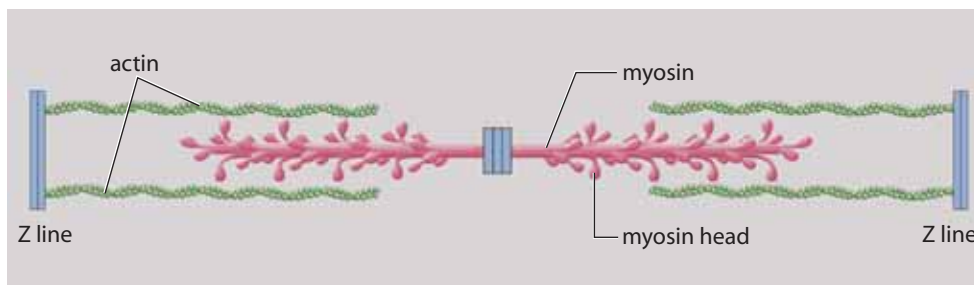
## The Role of Calcium Ions in Contraction

When a muscle is relaxed, its myosin heads are raised and ready, through the splitting of ATP. They are, however, unable to bind to actin. This is because the attachment sites for the myosin heads on the actin are physically blocked by another protein called tropomyosin. Therefore the myosin heads cannot bind to actin in the relaxed muscle, and the filaments cannot slide.

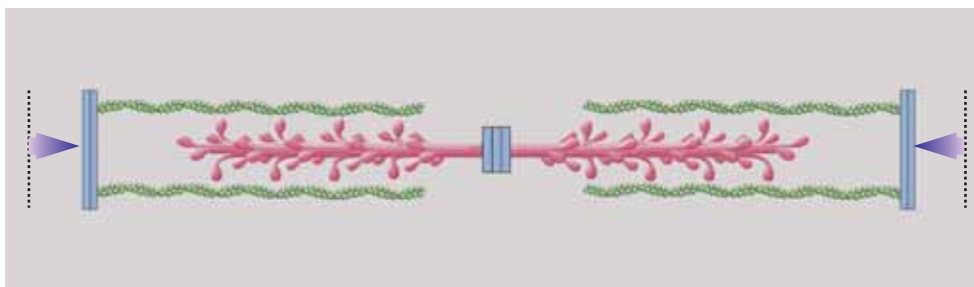
For a muscle to contract, the tropomyosin must be moved out of the way. This requires another protein called troponin, which binds to the tropomyosin. The troponin and tropomyosin form a complex that is regulated by the calcium ion ( $\text{Ca}^{++}$ ) concentration of the sarcoplasm (muscle fibre cytoplasm).

When the calcium ion concentration in the sarcoplasm is low, tropomyosin inhibits myosin binding, and the muscle is relaxed (see Figure 10.7A). When the

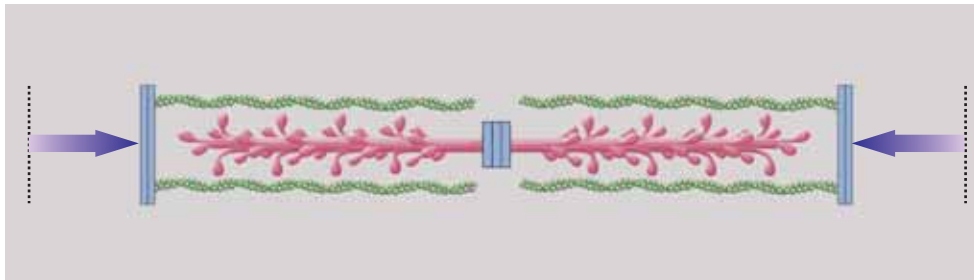
A The heads on the two ends of the myosin filament are oriented in opposite directions. When the heads attach to the actin, they bend toward the centre of the myosin.



B As one end of the myosin filament draws the actin filament and its attached Z line toward the centre, the other end of the myosin filament does the same.



C Both Z lines move toward the centre, and contraction occurs.



**Figure 10.6** The sliding filament model of muscle contraction

## Thought Lab 10.1 Designing a Muscle Fibre Model

### Target Skills

Designing a functional model of a skeletal muscle fibre

Working cooperatively with team members to design a muscle fibre model

In this Thought Lab, you will design a working model of a skeletal muscle fibre. If time permits, your teacher may have you construct and test your model.

#### Procedure

1. In a group, review your understanding of the mechanics of muscle fibre contraction. Brainstorm ideas for designing a model to demonstrate how a skeletal muscle fibre works.
2. Choose one design, and sketch and label its components. Identify all the materials you would need to construct the model.
3. Prepare a summary sheet to outline how you expect your model to work.

4. With your teacher's permission, construct your model.

#### Analysis

1. Compare your model with the models of other groups. How does your model differ from the others? How is it the same?
2. How would the muscle fibre you modelled fit together with other muscle fibres to form muscle tissue?

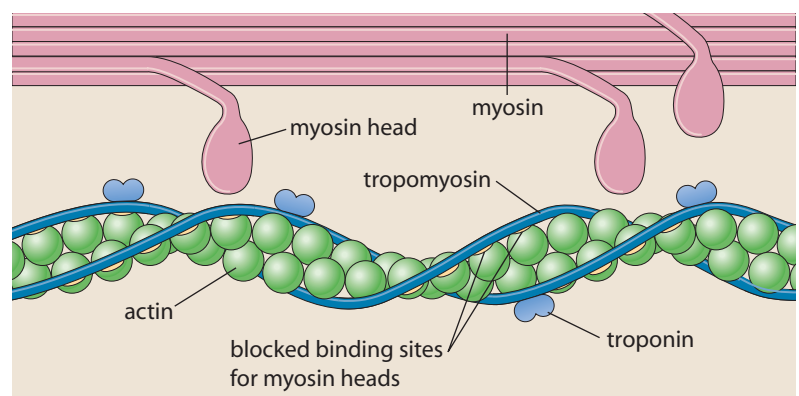
calcium ion concentration is raised,  $\text{Ca}^{++}$  binds to troponin (see Figure 10.7B). This causes the troponin-tropomyosin complex to be shifted away from the attachment sites for the myosin heads on the actin. When the repositioning has occurred, the myosin heads attach to actin and, using ATP energy, move the actin filament to shorten the myofibril.

The source of calcium ions for this process is the sarcoplasmic reticulum. When a muscle fibre is stimulated to contract,  $\text{Ca}^{++}$  is released from the sarcoplasmic reticulum and diffuses into the myofibrils. When the nerve impulses that initiate muscle contractions stop and the contractions stop, the calcium ions are returned to the sarcoplasmic reticulum through active transport.

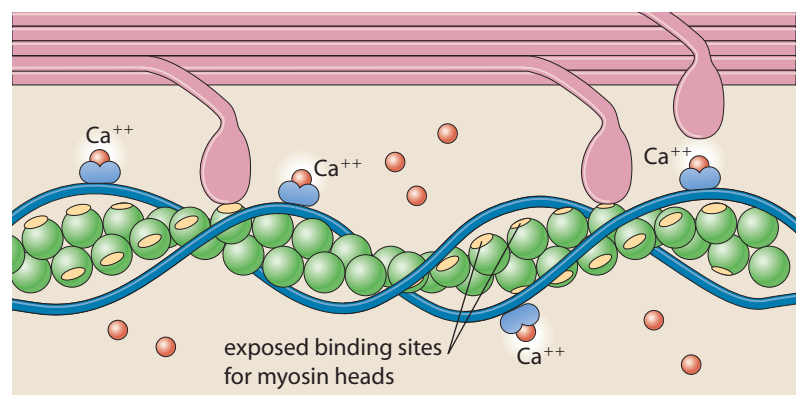
7 Can muscles in the body contract without calcium? Explain why or why not.

### Energy for Muscle Contraction

The ATP that is produced before strenuous exercise lasts only a few seconds. The muscles then acquire new ATP in three different ways, depending on the availability of oxygen: the breakdown of a molecule called creatine phosphate, aerobic cellular respiration, and



**A** The muscle is at rest. A long filament, composed of the protein molecule tropomyosin, blocks the myosin binding sites of the actin molecule. Without actin's ability to bind with myosin at these sites, muscle contraction cannot occur.



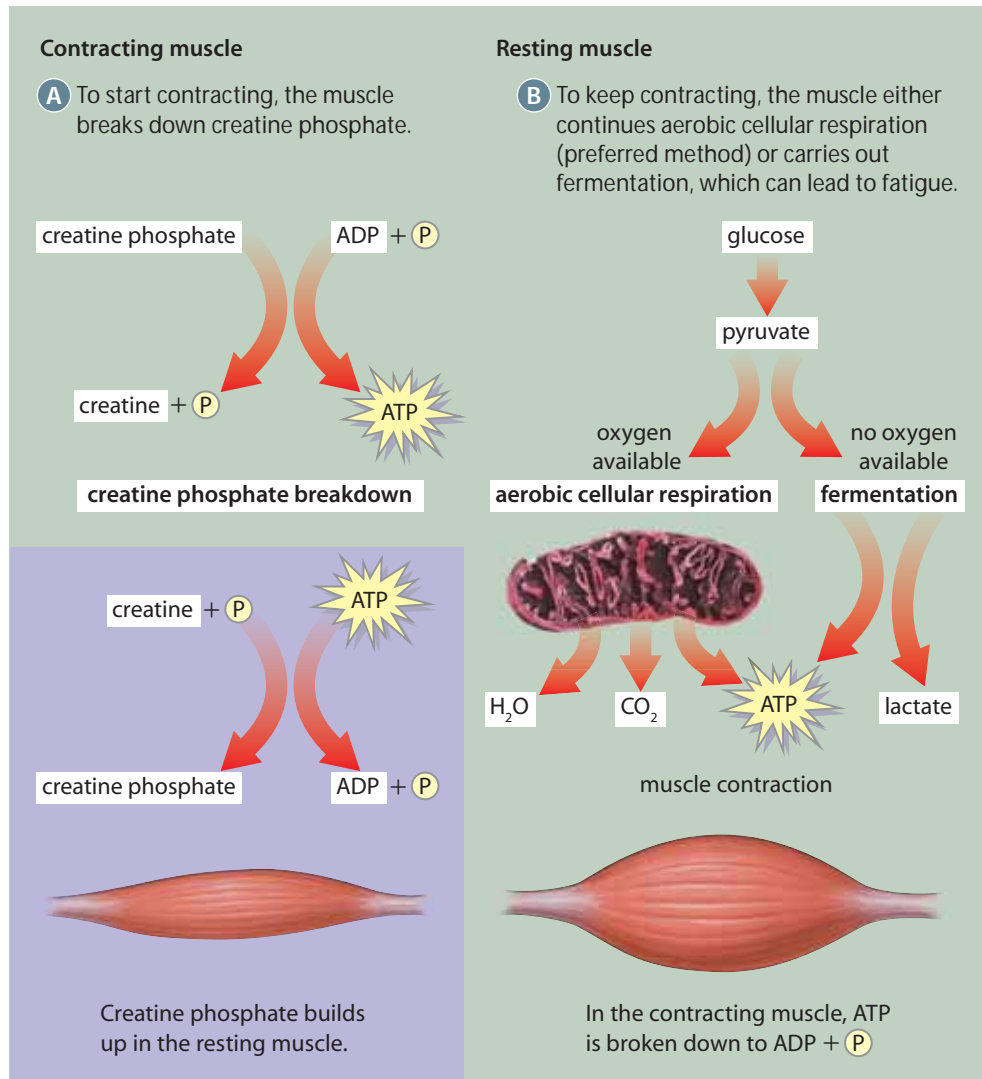
**B** Calcium ions have bonded to another protein molecule, troponin, which is part of the actin myofibril. The resulting complex repositions the tropomyosin, exposing the myosin binding sites of actin. The myosin heads can bind to the actin, and contraction occurs.

**Figure 10.7** How calcium controls muscle contractions

**Figure 10.8** Creatine phosphate builds up and is stored in a resting muscle (purple background). For the muscle to contract (green background), it needs to acquire ATP.

**(A)** When the muscle starts contracting, it breaks down stored creatine phosphate. This generates some ATP that is used immediately.

**(B)** To continue contracting, the muscle carries out aerobic cellular respiration as long as oxygen is available. When the oxygen has been used up, the muscle can carry out fermentation for a limited period of time. As you know from Chapter 5, fermentation results in only a small amount of ATP, compared with the amount produced by aerobic cellular respiration, and lactate builds up. Once the muscle resumes resting (purple background), creatine phosphate builds up again.

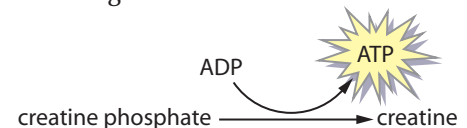


fermentation (see Figure 10.8). Creatine phosphate breakdown and fermentation are anaerobic, so they do not require oxygen. Creatine phosphate breakdown is used first. It is a way to acquire ATP before oxygen starts to enter the mitochondria. Aerobic cellular respiration can only occur if oxygen is available. If exercise is so vigorous that oxygen cannot be delivered fast enough to the working muscles, then fermentation occurs. Fermentation causes an oxygen deficit (or oxygen debt, as it is also called).

### Creatine Phosphate Breakdown

Creatine phosphate is a high-energy compound that builds up when a muscle is resting. This compound cannot participate directly in muscle contraction.

Instead, it regenerates ATP by the following reaction:



This reaction occurs in the midst of sliding filaments. Therefore, it is the speediest way to make ATP available to muscles. Creatine phosphate provides enough energy for only about eight seconds of intense activity, and then it is spent. It is rebuilt when a muscle is resting, through the transfer of a phosphate group from ATP to creatine.

### Aerobic Cellular Respiration

Aerobic cellular respiration, which takes place in the mitochondria, usually provides most of a muscle's ATP.

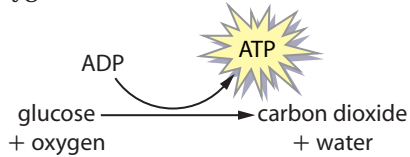
## BiologyFile

### Try This

When an animal dies, its cells can no longer produce ATP, so the linkages between the myosin heads and actin cannot be broken. This is what causes the death-related muscle rigidity called *rigor mortis* (Latin for "stiffness of death"). *Rigor mortis* is not permanent. After about 36 h, the body loses its stiffness. Infer a reason for this. Also infer factors that could affect the rate at which *rigor mortis* sets in when death occurs.



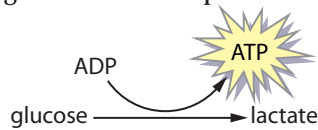
Glycogen and fat are stored in muscle cells. Therefore, a muscle fibre can use glucose from glycogen and fatty acids from fats as fuel to produce ATP when oxygen is available:



Myoglobin—an oxygen-carrying molecule that is similar to hemoglobin—is synthesized in muscle cells. Its presence accounts for the reddish-brown colour of skeletal muscle fibres. Myoglobin has a higher affinity for oxygen than hemoglobin does. Therefore, it can temporarily store oxygen and make it available to the mitochondria when cellular respiration begins. The resulting carbon dioxide leaves the body at the lungs, and the water simply diffuses into the extracellular space. The third byproduct of this reaction, heat, helps to warm the entire body. Roughly two thirds to three quarters of the heat that maintains a constant body temperature comes from the aerobic cellular respiration of skeletal muscle throughout the body.

### Fermentation

Fermentation, like creatine phosphate breakdown, supplies ATP without consuming oxygen. As you may recall from Chapter 5, glucose is broken down during fermentation to produce lactate:



The accumulation of lactate in a muscle fibre makes the sarcoplasm more acidic and, eventually, enzymes cease to function well. If fermentation continues longer than two or three minutes, cramping and fatigue set in. Biologists hypothesize that cramping results (in part, at least) from the lack of ATP needed to pump calcium ions back into the sarcoplasmic reticulum and to break the linkages between actin and myosin so that the muscle fibres can relax.

- 8 Describe the role of creatine phosphate in muscle contraction.
- 9 What is the benefit of fermentation in muscle contraction?
- 10 Identify the source of energy that usually provides most of a muscle's ATP.

### Oxygen Deficit

When a muscle uses fermentation to supply its energy needs, it incurs an oxygen deficit (see Figure 10.9). The ability to run up an oxygen deficit is one of muscle tissue's greatest assets. Brain tissue, by contrast, cannot function nearly as long without oxygen as muscle tissue can.

In athletes and other people who train, the number of mitochondria in muscle tissue increases. Thus, fermentation is not needed to produce ATP. The mitochondria can start consuming oxygen as soon as the ADP concentration starts to rise during muscle contraction. Because the mitochondria can break down fatty acid instead of glucose, blood glucose is spared for the activities of the brain. (The brain, unlike other organs, can only use glucose to produce ATP.) Because less lactate is produced in people who train, the pH of the blood remains more steady, and there is less of an oxygen deficit.



### BiologyFile

#### Try This

Use a computer interface and temperature probe to demonstrate the link between muscle activity and heat production. Select a dumbbell that you can *just* use to do 10 biceps curls with one arm. Obtain a base temperature reading for your muscle by holding the probe firmly against your rested biceps (no dumbbell) for 60 s. With the probe still firmly pressed against your biceps, do 10 curls with the dumbbell. Repeat this procedure using different types of thermometers. Repeat using fewer and greater numbers of curls. What can you conclude about heat generation and temperature-measuring technologies from your observations?



**Figure 10.9** Oxygen deficit is obvious when a person continues to breathe heavily after exercising.

## BiologyFile

### Web Link

Creatine, a component of the creatine phosphate molecule, is produced by the liver and kidneys. As well, a small amount can be obtained by eating meat and fish. Some people use over-the-counter supplements of creatine (creatine monohydrate) to increase the concentration of creatine phosphate in their muscles. Do these supplements work? What evidence supports this practice? What health-related concerns are associated with it?

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WWW

Replenishing an oxygen deficit requires replenishing creatine phosphate supplies and disposing of lactate. Lactate can be changed back to pyruvate and metabolized completely in the mitochondria. As well, it can be sent to the liver to synthesize glycogen. The exhaustion of a marathon runner at the end of a race is often not due to an oxygen deficit. Instead, the runner has used up all the muscles' (and perhaps the liver's) supply of glycogen. The body takes about two days, on a high-carbohydrate diet, to replace its glycogen stores.

11 Explain why an oxygen deficit occurs and how it is overcome.

### Section 10.1 Summary

- There are three types of muscle tissue: smooth, cardiac, and skeletal. Skeletal muscle contractions are voluntary, while smooth and cardiac muscle contractions are involuntary. Skeletal muscle has several functions, such as providing movement, producing heat, and maintaining posture.

- A skeletal muscle contains bundles of muscle fibres, which contain myofibrils. The myofibrils contain actin and myosin myofilaments.
- When calcium ions are released into muscle fibres, actin myofilaments slide past myosin myofilaments, resulting in contraction of the muscle fibres.
- Calcium ions bind to troponin, causing the tropomyosin threads that wind around actin to shift their position. This reveals sites that myosin can bind to.
- ATP energy enables myosin to detach from actin, ready to link to another binding site farther along the actin.
- A muscle fibre has three ways to acquire ATP for muscle contraction: (1) Creatine phosphate, built up when a muscle is resting, can rebuild ADP, quickly forming ATP. (2) Fermentation also forms ATP quickly, but it results in an oxygen deficit because oxygen is needed to complete the metabolism of the lactate that is produced and accumulates. (3) Aerobic cellular respiration takes longer because oxygen must be transported to the mitochondria in the muscle fibres.

## Section 10.1 Review

1. Use a word processor or spreadsheet program to make a table that lists the three types of muscle fibres (cells) and compares them based on the following criteria: shape, number of nuclei per fibre, presence of striations, voluntary or involuntary contractions, examples of locations in the body, and function in the body. **ICT**
2. Explain why muscles can pull but cannot push.
3. Outline, using a labelled sketch, the structural organization of skeletal muscle.
4. Explain why you expect to find a rich supply of blood vessels and mitochondria in skeletal muscle tissue.
5. Distinguish, both in sentence form and pictorially, actin from myosin filaments.
6. Use a word processor or spreadsheet program to make a table that describes the structure and function of the following components of skeletal muscle fibres: muscle fibre, myoglobin, sarcolemma, sarcoplasm, sarcoplasmic reticulum, myofibrils, actin myofilament, myosin myofilament. **ICT**
7. Use graphics software to sketch a diagram or series of diagrams illustrating the movement of actin and myosin filaments in the sliding filament model of a skeletal muscle contraction. Include a caption with each diagram that describes the events in this model. **ICT**
8. Justify the following statement: "Muscle contraction in the body cannot occur without calcium."
9. Identify three sources of energy for muscle contraction. Briefly describe the contribution of each source.
10. Explain why lactate forms in skeletal muscle tissue and explain how it is removed.

## How Much Does It Cost To Be the Best?

Dr. Vivienne Nathanson, Head of Ethics at the British Medical Association, made this statement in a BBC Radio Broadcast in January 2004: “There are some very frightening bits of research which show that if you talk to people aspiring to be elite athletes and you say to them ‘If we could give you a drug which would guarantee that you’d win a gold medal at the Olympics but you might be dead within five years, would you do it?’, the majority would say yes.”

### Winners or Losers?

How would you respond to this question? How would your peers respond? In a recent study of more than 10 000 adolescents living throughout the United States, researchers found that 8 percent of females and 12 percent of males aged 12 to 18 reported using products to improve appearance, muscle mass, or strength. Approximately 4.7 percent of the males and 1.6 percent of the females used supplements such as protein powder or shakes, creatine, growth hormone, or anabolic/injectable steroids at least weekly to improve appearance or strength.

Where does the idea of success at any cost come from? The researchers found that adolescents involved in sports, particularly weight lifting and football, are more inclined to use substances that may be performance-enhancing. As the ongoing progress of sport through record breaking and higher achievement puts increasing demands on athletes, they are taking advantage of the scientific advances and technologies that are now available. Should their bodies be included in the equipment required to produce new records?

The researchers also found that males who read fashion, health/fitness, or men’s magazines, and females who were trying to look like women in the media, were significantly more likely than their peers to use products to improve appearance or strength. What role do the media play in creating and perpetuating certain kinds of body types and images? What responsibilities do the media have in their portrayal of society?

### What Now?

Long-term studies of teenagers’ use of nutritional supplements have not been done, and for ethical reasons they probably never will be. No one can state with reasonable confidence, however, that prolonged use of supplements is safe until more data is compiled. But is the safety of supplements the issue we should be investigating?

...

1. Survey students at your school using the question in the first paragraph of this feature. Ask for reasons for their responses. Compile and discuss the statistical and anecdotal responses.
2. Debate the following statement: “Scientists already help athletes win through specially manufactured equipment. Performance-enhancing substances have been used for centuries and should not be viewed any differently.”





# Muscles, Health, and Homeostasis

## Section Outcomes

In this section, you will

- **explain** how the skeletal muscles of the motor system support other body systems to maintain homeostasis
- **identify** conditions that impair the healthy functioning of muscles and technologies that are used to treat or prevent these conditions
- **describe** the benefits of exercise for maintaining the healthy structure and functioning of muscles

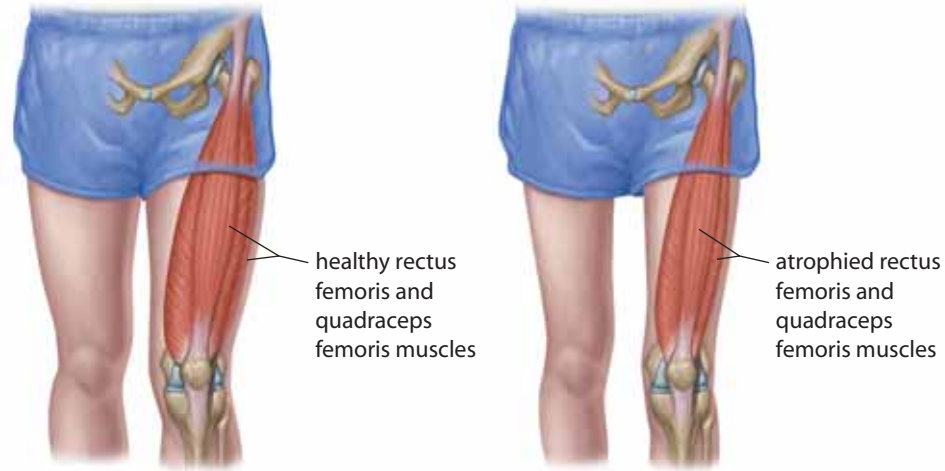
## Key Terms

atrophy  
hypertrophy  
muscle twitch  
slow-twitch fibres  
fast-twitch fibres

## BiologyFile

### FYI

In people who are bedridden or have a leg immobilized by a cast for two to three weeks, researchers have observed declines in the size and strength of calf and leg muscles that are comparable to those observed during space missions. In fact, immobilization of a leg in a cast results in more rapid declines in muscle size and performance than those observed for similar periods of time in bed rest or microgravity.



**Figure 10.10** Muscle atrophy is a concern for people not only on Earth, but also in the microgravity environment of space. During the early 1970s, experiments with the astronauts onboard the NASA *Skylab* missions led to modifications in diet and exercise programs that were able to compensate for some atrophy due to microgravity. Active research in this area continues today.

During active use, some muscle fibres are contracting and others are relaxing. Therefore, muscles rarely fatigue completely. Even when muscles appear to be at rest, some of their fibres are always contracting. This continuous, “low-level” activity of the muscles results in what is referred to as tone. Muscle tone is important for maintaining posture. If all the fibres within the muscles of the neck, torso, and lower limbs were to relax completely, the body would collapse.

## Complications of the Muscular System

In general, the skeletal muscles of the motor system are subject to fewer disorders than other organ systems are. Muscles, however, are especially vulnerable to injuries that result from sudden and intense stress placed on them and on tendons. Table 10.2 lists some of the more common disorders of the muscular system.

Muscles also may be impaired simply from lack of use. This condition is referred to as atrophy (from two Greek words that mean “without nourishment”).

**Atrophy** is a reduction in the size, tone,

and power of a muscle. If a skeletal muscle experiences reduced stimulation, its fibres decrease in size and become weaker. Even a temporary reduction in muscle use can lead to muscular atrophy. People who experience damage to the nervous system, or who become paralyzed by a spinal cord injury, gradually lose muscle tone and size in the areas that are affected. Initially, the atrophy is reversible, but dead or dying muscle fibres are not replaced. If extreme atrophy occurs, the loss of muscle function is permanent. This is why physical therapy is so important for people who have a temporary loss of mobility as a result of an injury or surgery (see Figure 10.10, as well as the Career Focus at the end of this unit).

12 Explain how muscle atrophy can occur.

## Exercise and Muscle Contraction

Regular, moderate exercise strengthens the muscular system and enables the

**Table 10.2** Some Common Disorders and Ailments of the Skeletal Muscles

Condition	Description
muscular dystrophy	a collective term for several hereditary conditions in which the skeletal muscles degenerate, lose strength, and are gradually replaced by fatty and fibrous tissue that impedes blood circulation; this, in turn, accelerates muscle degeneration in a fatal spiral of positive feedback
botulism	a potentially fatal muscular paralysis caused by a toxin produced by the bacterium <i>Clostridium botulinum</i> ; the toxin prevents the release of a muscle-stimulating compound (acetylcholine) released by muscle-related cells of the nervous system, thus leading to paralysis
cramps	painful muscle spasms triggered by strenuous exercise, extreme cold, dehydration, salt (electrolyte) imbalance, low blood glucose, or reduced blood flow
contracture	abnormal muscle shortening not caused by nerve stimulation; can result from inability to remove calcium ions from the sarcoplasm or from the contraction of scar tissue (as in people who have experienced severe burns)
fibromyalgia	chronic muscular pain and tenderness often associated with fatigue and sleep disturbances; can be caused by infectious diseases, physical or emotional trauma, or medications
crush syndrome	a shock-like state following massive crushing of the muscles (as in, for example, the aftermath of an earthquake, the collapse of a building following an explosion, or a traffic accident); associated with high fever, heart irregularities caused by potassium ions released from the muscles, and kidney failure caused by blockage of the renal tubules with myoglobin released by the traumatized muscles
delayed onset muscle soreness	pain, stiffness, and tenderness felt from several hours to a day after strenuous exercise; associated with trauma to the muscles, disruptions in the myofibrils and sarcolemma, and increased levels of myoglobin and muscle-fibre enzymes in the blood
myositis	muscle inflammation and weakness resulting from infection or an autoimmune disease

muscles to use energy more efficiently. During the first few months after a person (for example, a runner) starts training, gradually increasing distance, the leg muscles noticeably enlarge. This exercise-induced increase in muscle mass is called **hypertrophy**. It is due to an

increase in the size of individual skeletal muscle fibres, not an increase in their number.

Becoming physically fit through exercise causes other changes to muscles as well. The enzymes within a trained runner's muscle fibres are more active

## Thought Lab 10.2 Injuries Related to Athletics

Each year, tens of thousands of athletes—professionals, amateurs, and high-school students—sustain some kind of injury to their muscles, as do increasing numbers of people who have taken up running and other forms of physical exercise. Improper or inadequate warming up and conditioning are often the cause of these injuries.

### Procedure

- Select one of the athletics-related injuries listed below.
  - baseball finger
  - blocker's arm
  - charley horse
  - compactment syndrome
  - pitcher's arm
  - pulled groin
  - pulled hamstrings
  - rider's bones
  - rotator cuff injury
  - shin splints
  - tennis elbow
  - tennis leg
- Research the injury you selected, as well as ways that this injury and most other common muscle injuries can be

prevented. (Start with index and search-engine keywords related to exercise, warming up, and conditioning.)

### Analysis

- Using a suitable medium and format, outline the nature, cause, treatment, and prevention of the injury you selected. **ICT**
- The phrase "no pain, no gain" is sometimes used in fitness and bodybuilding classes. Evaluate the use of the phrase and the potential effects on the health of the people who follow this advice.

### Target Skills

**Analyzing** the effects of exercise on skeletal muscle and muscle fibre

**Evaluating** assumptions and behaviour related to athletics and physical conditioning

**Consulting** a wide variety of sources, and **assessing** the authority, reliability, and validity of the information gathered

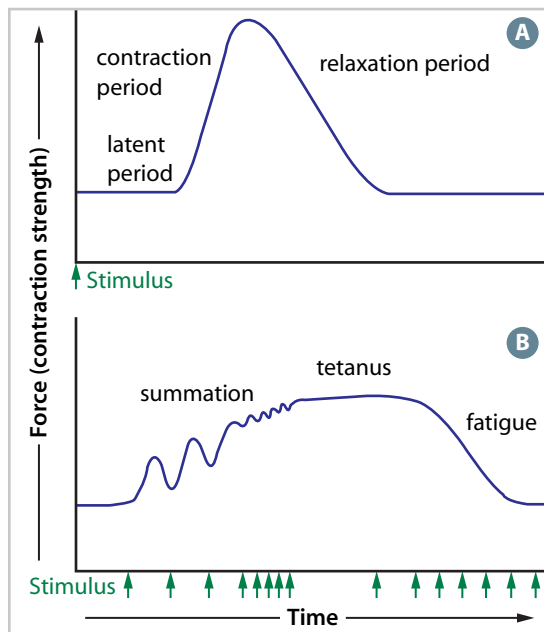
and numerous, and the mitochondria are more abundant, than they are in the skeletal muscles of a person who engages in little or no exercise. Thus, a runner's muscles can withstand far more exertion than the muscles of an untrained person before fermentation begins. A runner's muscles also receive more blood (through the development of additional blood vessels) and store more glycogen than those of an untrained person.

13 Explain how hypertrophy is different from atrophy.

### Muscle Twitch

Isolated skeletal muscles have been studied by stimulating them artificially with electrodes. By attaching a muscle to a movable lever and stimulating it, the contraction can be recorded as a visual pattern, such as the one shown in Figure 10.11 (A).

At first, the stimulus may be too weak to cause a contraction. As soon as



**Figure 10.11** These graphs of the force of muscle contraction with time are called myograms. (A) A simple muscle twitch has three periods: latent, contraction, and relaxation. (B) When a muscle is not allowed to relax completely between stimuli, the contraction gradually increases in intensity until it reaches a maximum, which is sustained until the muscle fatigues.

the strength of the stimulus reaches a certain threshold, however, the muscle contracts and then relaxes. This action—a single contraction that lasts a mere fraction of a second—is called a **muscle twitch**. Figure 10.11A shows that a twitch can be divided into three periods: a latent period (the period of time between stimulation and initiation of contraction), a contraction period (when the muscle shortens), and a relaxation period (when the muscle returns to its former length).

Stimulation of an individual muscle fibre within a muscle usually results in a maximal, all-or-none contraction. The contraction of a whole muscle, however, can vary in strength depending on the number of muscle fibres contracting.

If a muscle is given a rapid series of threshold stimuli, it can respond to the next stimulus without relaxing completely. In this way, successive twitches partially “ride piggyback” on each other in a cumulative response called summation, as shown in Figure 10.11B. Eventually maximal sustained contraction, called tetanus, is achieved. (Do not confuse this term with the disorder that shares the same name, which is accompanied by a painful state of muscle contracture.) As you can see in Figure 10.11B, once tetanus occurs, the graph no longer shows individual twitches. The twitches are, instead, fused and blended completely into a straight line. Tetanus continues until the muscle fatigues due to depletion of energy reserves. Fatigue is apparent when a muscle relaxes even though stimulation continues.

14 Why does a muscle eventually fatigue?

### Slow-Twitch and Fast-Twitch Fibres

You have seen that all muscle fibres metabolize both aerobically and anaerobically. Some muscle fibres, however, use one method more than

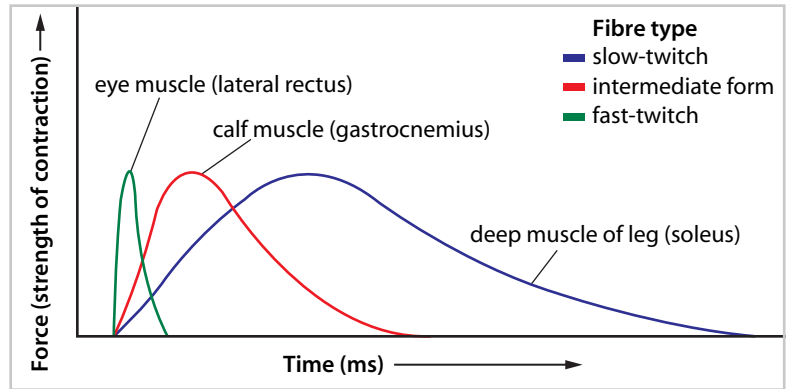


the other to provide myofibrils with ATP. Slow-twitch fibres (also called Type I fibres) tend to be aerobic, and fast-twitch fibres (also called Type II fibres) tend to be anaerobic.

**Slow-twitch fibres** contract slowly but resist fatigue (that is, they have more endurance). These muscle fibres are most helpful in activities such as biking, jogging, swimming, and long-distance running. Because they produce most of their energy aerobically, they tire only when their fuel supply is gone. Slow-twitch fibres have many mitochondria. They are dark in colour because they contain myoglobin, the respiratory pigment found in muscles. They are surrounded by dense capillary beds and draw more blood and oxygen than fast-twitch fibres. Because slow-twitch fibres have a substantial reserve of glycogen and fat, their abundant mitochondria can maintain a steady, prolonged production of ATP when oxygen is available.

**Fast-twitch fibres** are adapted for the rapid generation of power. They are most helpful in activities such as sprinting, weight lifting, and swinging a hockey stick or tennis racket. These fibres are rich in glycogen. They are light in colour because they have little or no myoglobin. They also have fewer mitochondria and fewer blood vessels than slow-twitch fibres do. The dependence of fast-twitch fibres on anaerobically produced energy, however, leaves them vulnerable to an accumulation of lactate that causes them to fatigue quickly.

Human muscles have a third, intermediate form of fibres. These fibres are fast-twitch, but they also have a high oxidative capacity. Thus, they are more resistant to fatigue. Endurance training increases the proportion of these fibres in muscles. Note, however, that heredity also plays a role in the proportion of fast-twitch and slow-twitch fibres in the bodies of individuals. Figure 10.12 compares the twitch of three muscles of the body.



**Figure 10.12** Skeletal muscles have different proportions of fast-twitch and slow-twitch fibres. Thus, the force and response times of their contractions differ.

15 The muscles that move the eyes reach maximal contraction (tetanus) in about 7 ms (milliseconds). The soleus muscle (in the lower leg) reaches tetanus in about 100 ms. Which muscle is composed of fast-twitch fibres, and which is composed of slow-twitch fibres?

### The Value of Exercise

The depletion of muscle glycogen and the buildup of lactate place a limit on exercise. Therefore, any adaptation that spares muscle glycogen and/or efficiently removes lactate improves physical endurance. Because the aerobic capacity of endurance-trained athletes is higher than that of untrained people, athletes can perform more exercise before lactate production and glycogen depletion cause muscle fatigue.

Endurance training does *not*, however, increase the size of muscles. Muscle enlargement is produced only by frequent periods of high-intensity exercise in which the muscles work against high resistance, as in weight lifting. As a result of resistance training, fast-twitch muscle fibres become thicker, so the muscle grows by hypertrophy—an increase in the size of the muscle fibres. This happens because the myofibrils within a muscle fibre thicken due to the

synthesis of actin and myosin, and the addition of new material to the fibre. Then, after a myofibril has attained a certain thickness, it may split into two myofibrils, each of which may also become thicker. Thus, muscle hypertrophy is caused by an increase in the size of the myofibrils and then an increase in the number of myofibrils within the muscle fibres.

The decline in the physical strength of people as they age is associated with reduced muscle mass, which is due to a loss of muscle fibres and a decrease in the size of fast-twitch muscle fibres. Aging is also associated with a reduced density of the blood capillaries that surround the muscle fibres, leading to a decrease in oxidative capacity. Resistance training can cause the surviving muscle fibres to hypertrophy and become stronger, thus partly compensating for the decreased number of muscle fibres in older people. As well, endurance training can increase the density of the blood capillaries in the muscles, improving the ability of the blood to deliver oxygen to the muscles. The muscle glycogen of seniors also can be increased by endurance training, but not to the levels present earlier in life.

16 Why is the aerobic capacity of endurance athletes higher than the aerobic capacity of untrained people?

17 Describe how a muscle can increase in size.

### Homeostasis, Muscles, and Other Body Systems

Movement, which involves the muscular system in conjunction with the skeletal system, is essential for maintaining health and homeostasis throughout the life cycle (see Figure 10.13). This is evident in a simple way, when you move to respond to certain types of changes in the environment. For instance, if you are sitting in the Sun and start to feel too hot

after a period of time, you can move to a shady location or indoors. If you were unable to move to a cooler location, you would run the risk of developing heat stroke—an inability of the body to cope with elevated body temperature due to very high air temperature.

At a more physiological level, many body systems, including the muscular system, help to maintain a constant body temperature. When you are cold, smooth muscle in the blood vessels that supply the skin constrict, reducing the amount of blood that is close to the surface of the body. This helps to conserve heat in the body's core, where the vital organs lie. If you are cold enough, you might start to experience involuntary skeletal muscle contractions, commonly known as shivering. This action is initiated by temperature-sensitive cells in the hypothalamus of the brain. As you know, skeletal muscle contraction requires ATP, and using ATP generates much of the body's heat.

If you think about the body systems you have investigated in this unit, you can appreciate other ways in which the muscular system is involved in homeostasis, too. Contraction of the skeletal muscles associated with the jaw and tongue allow you to grind food with your teeth. The rhythmic smooth-muscle contractions of peristalsis move ingested materials through the digestive tract. These processes are necessary for supplying the body cells with nutrients. Skeletal muscles attached to the bones of the rib cage, along with the action of the diaphragm (which is comprised of skeletal muscles), permit the mechanics of breathing, which brings oxygen to the body cells and rids them of carbon dioxide waste. The ceaseless beating of the heart, which propels blood into the arteries, is the contraction of cardiac muscle. Contractions of skeletal muscles in the body, especially the skeletal muscles associated with breathing and leg movements, help to return venous blood to the heart by pushing the blood



**Figure 10.13** The benefits of physical activity start early in life, and they extend throughout one's entire lifecycle. These benefits include the development and maintenance of flexibility, endurance, and strength of all the muscle tissues—smooth and cardiac, as well as skeletal—in the body. What roles do play, recreational physical activity, or formal exercise training occupy in your life? What are their whole-body benefits now and in the future?

back toward the heart. (This is why people are cautioned not to lock their knees when standing for long periods of time. The reduction in venous blood return causes a drop in blood pressure that can lead to fainting.) The pressure exerted by skeletal muscle contractions also helps to squeeze tissue fluid (lymph) into the lymphatic vessels. Finally, the smooth muscle tissue of the urinary bladder permits the storage and, through its sphincters, release of the nitrogenous waste materials that would otherwise poison the human body and its essential systems.

### Section 10.2 Summary

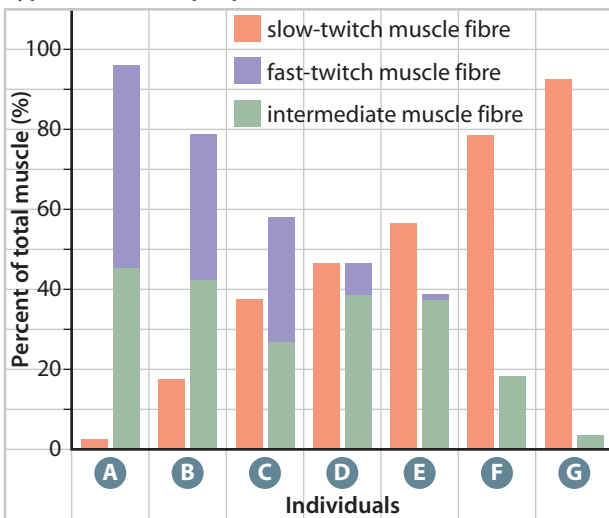
- Muscle contractions can be described in terms of muscle twitch. Muscle twitch can be used to classify muscle fibres according to the speed at which they contract.
- Slow-twitch fibres are smaller than fast-twitch fibres, contract fairly slowly, and are more resistant to fatigue than fast-twitch fibres.
- Fast-twitch fibres are large in diameter compared with slow-twitch fibres, use a lot of ATP, and fatigue easily.
- Intermediate fibres are similar to fast-twitch fibres but are more resistant to fatigue.
- Muscles atrophy if stimulation is inadequate.
- Muscle hypertrophy is an increase in the size of muscle fibres. Repetitive stimulation causes more myofibrils to develop.
- The muscular system interacts with all the other systems of the human body in ways that promote and maintain homeostasis.



1. a) Describe the general cause of muscle atrophy.  
b) Describe what happens to a muscle as it atrophies, and explain why extreme atrophy would lead to permanent loss of muscle function.
2. Explain how hypertrophy is different from atrophy.
3. Describe the term “muscle twitch.”
4. Use a graphics software program to sketch a labelled myogram for a single skeletal muscle twitch. Describe the terms latent period, contraction period, and relaxation period. **ICT**
5. Use a graphics software program to sketch a labelled myogram for a skeletal muscle that is not allowed to completely relax between stimuli. Describe the terms summation, tetanus, and fatigue. **ICT**
6. Identify three beneficial changes to skeletal muscles that result from regular exercise.
7. Use word processing or spreadsheet software to design a table that compares fast-twitch muscle fibres to slow-twitch muscle fibres. **ICT**

Use the following information to answer the next question.

The relative abundance of different muscle fibre types in different people



The bar graph above compares the relative abundance of different muscle fibre types in different people. These people are:

- a world-class sprinter
- an extreme endurance racer
- a world-class marathon runner
- a person with a spinal injury
- a sedentary person (“couch potato”)
- a middle distance runner
- an average active person

8. Infer which individuals are represented by A through G, and explain your reasoning.
9. How does resistance training, such as weight lifting, cause muscle fibres to change?

Use the following information to answer the next two questions.

### Hypothermia and Shivering

Shivering is one of the symptoms used to diagnose hypothermia. If the person is able to stop shivering voluntarily, then the hypothermia is only mild. But if it can't be stopped voluntarily, the person has moderate to severe hypothermia.

10. Define shivering and explain why an individual going into hyperthermia starts to shiver.
11. Explain why a person going into hyperthermia can only shiver for a few hours?
12. Muscles support the functions of other body systems in many ways to maintain homeostasis. Give one example of this for each of the following systems:
  - a) the circulatory system
  - b) the respiratory system
  - c) the digestive system
  - d) the excretory system

Use the following information to answer the next question.

### Muscle Strain Injuries

Muscle strains are overuse injuries that result when the muscle is stretched without being properly warmed up. It's like pulling a rubber band too long. Eventually, the rubber band will either lose its shape or tear apart. The same options apply to muscles. Should you suffer a strain or other muscle or joint injury, treat it with the RICE method—Rest, Ice, Compression, and Elevation. RICE can relieve pain, limit swelling, and protect the injured tissue, all of which help to speed healing. After an injury occurs, the damaged area will bleed (externally or internally) and become inflamed. Healing occurs as the damaged tissue is replaced by collagen, perhaps better known as scar tissue. Ideally, the scar tissue needs complete repair before a full return to sport is recommended.

13. Explain why the RICE method is used to treat most muscle strain injuries.

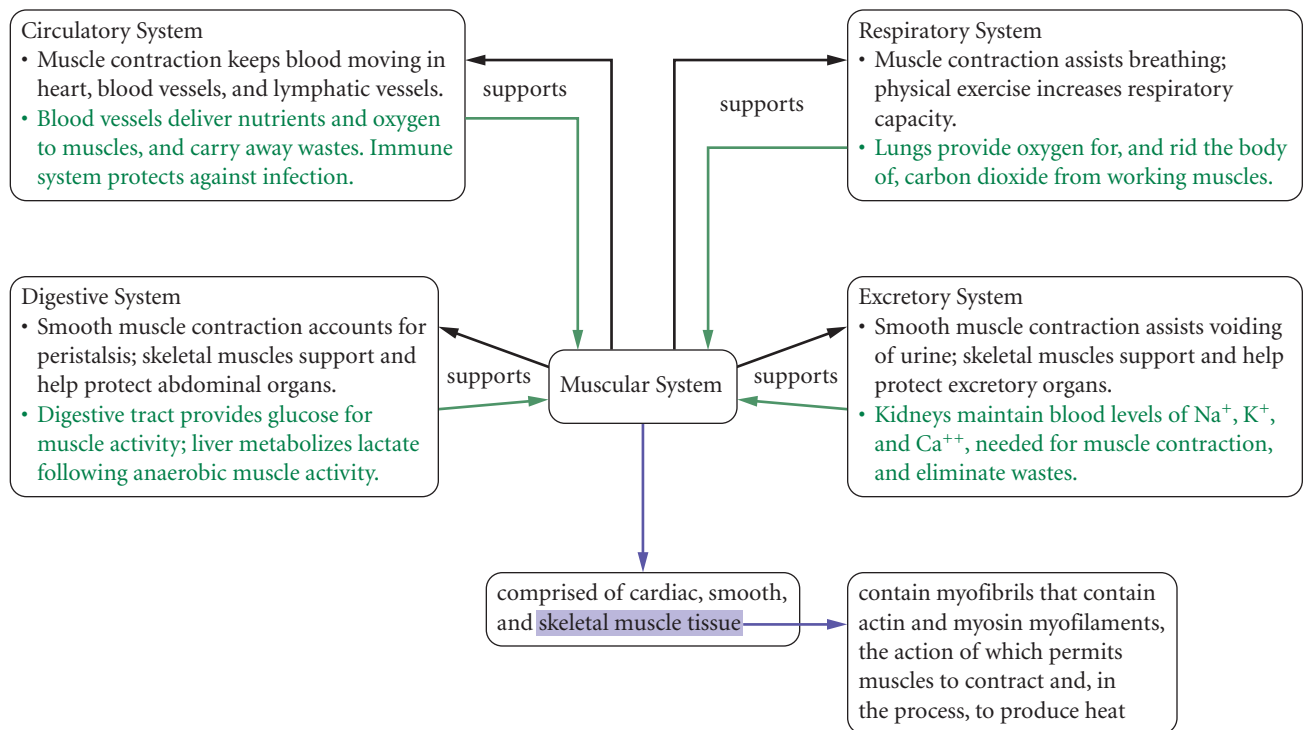
All muscles do their work by contracting (shortening). Relaxation is the passive state of a muscle. There are three types of muscle cells: skeletal, smooth, and cardiac. Skeletal muscle cells are attached to the bones of the skeleton, have many nuclei, are striated and tubular, and contract voluntarily. Smooth muscle cells are found in the walls of internal organs, have one nucleus, are not striated, and contract involuntarily. Cardiac muscle cells form the walls of the heart; have one nucleus, are striated, tubular, and branched; and contract involuntarily.

The fact that skeletal muscles can only either contract or relax means they can pull but not push. Therefore, they must work in pairs in order to move any part of the body—a relaxed muscle is only lengthened when the opposing muscle contracts to stretch it. Skeletal muscle contractions are explained by the sliding filament model.

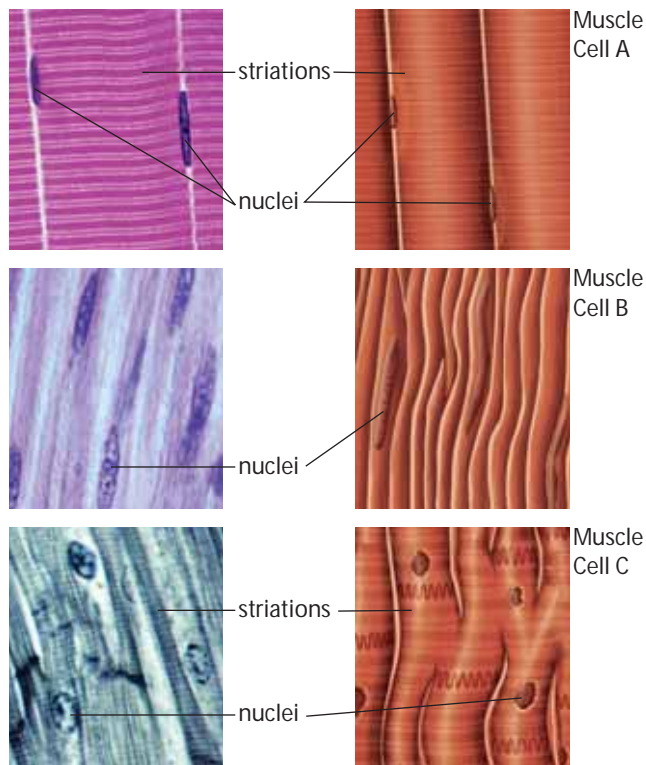
Skeletal muscle produces heat as well as movement and also supports and pads the body. Each muscle is made up of clusters of bundles of muscle fibres, which enclose bundles of myofibrils containing thin myofilaments of actin and thick myofilaments of myosin. Blood vessels supply nutrients and oxygen to the fibre bundles and remove wastes. The oxygen fuels the cellular respiration that supplies most of the energy muscles use.

Nerves trigger and control muscle contractions, which last for only a fraction of second in each muscle fibre. It is the wave of successive contractions, or twitches, that result in a muscle contraction. Skeletal muscles have both slow- and fast-twitch fibres that are good for either endurance (slow-twitch) or intense (fast-twitch) activities. Using the skeletal muscles is the only way to maintain and build their function.

## Chapter 10 Graphic Organizer

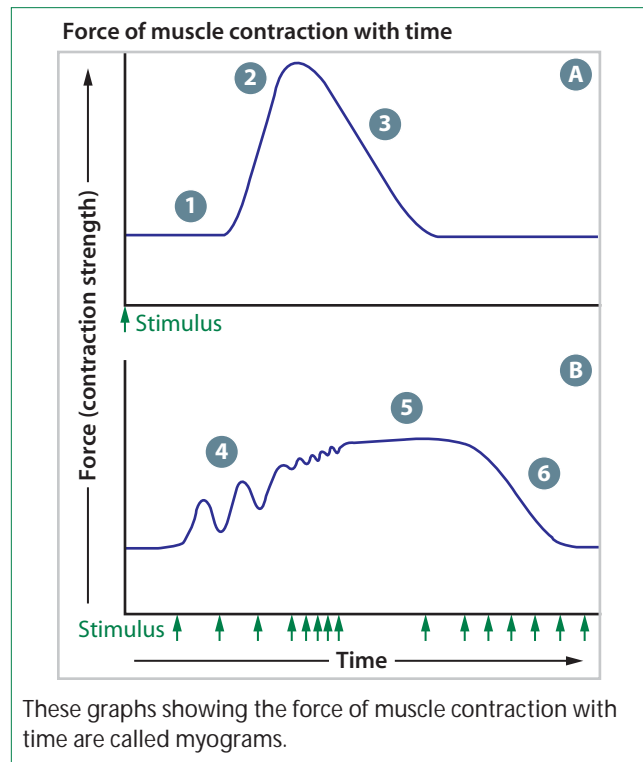


## Understanding Concepts



1. Identify and describe the three types of muscle tissue shown in the diagram above.
2. List three functions of skeletal muscle.
3. Use graphics software to draw a sketch explaining how myofilaments, muscle fibre, and myofibrils are related. **ICT**
4. Describe the major events that occur when a muscle fibre contracts.
5. Explain how ATP and creatine phosphate function in muscle contraction.
6. Describe how oxygen is supplied to muscle tissue.
7. Describe how an oxygen deficit may develop.
8. Explain how muscle fibres can become fatigued and how a person's physical condition can affect tolerance to fatigue.
9. Explain how the actions of skeletal muscles affect the maintenance of body temperature.
10. Give three examples of how the muscular system helps to maintain homeostasis.
11. Describe the role that myoglobin plays in muscle tissue.
12. Describe the three ways that energy is supplied for skeletal muscle contraction during strenuous exercise.

Use the following information to answer the next two questions.



13. Identify the regions shown on Graph A, and describe what is happening to the muscle fibre at each region.
14. Identify the region shown on Graph B, and describe what is happening to the muscle fibre at each region.

## Applying Concepts

15. In terms of contraction speed, infer the type of muscle fibre that comprises muscle tissue in the esophagus and in the heart. Justify your answer.
16. A muscle contracts and shortens because its myofibrils contract and shorten. When this happens, however, the myofilaments inside the myofibrils do not shorten. Explain why.
17. The events that occur in the sliding filament model follow a cyclical pathway.
  - a) Use graphics software to sketch this pathway, and use this sketch to explain the cyclical nature of this pathway. **ICT**
  - b) Identify two factors that can modify the activity of this cycle.
18. People who engage in physical activity generally perform better if they warm up by exercising lightly first. Suggest one possible reason for this.
19. As lactate and other substances accumulate in an active muscle, they stimulate pain-sensing nerves, and the



muscle may feel sore. How might the application of heat help to relieve such soreness?

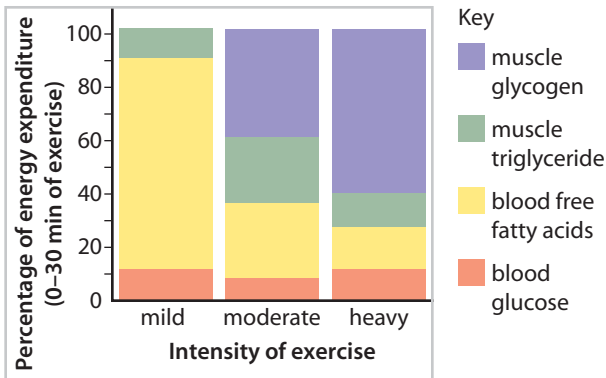
20. A skeletal muscle can often maintain a moderate level of active tension for long periods of time, even though many of its fibres become fatigued. Explain how this occurs.
21. Compare hypertrophy of muscles to atrophy. Include potential causes of both and the impact that each has on the overall health of the individual.

### Making Connections

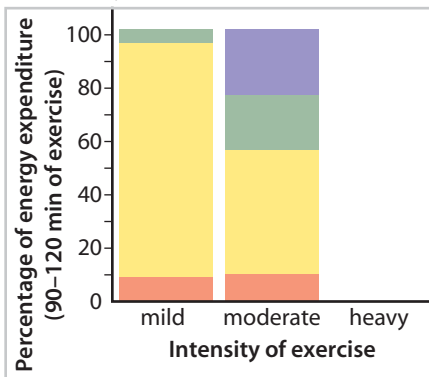
Use the following information to answer the next question.

In the following bar graphs, the relative concentrations of blood glucose, blood free fatty acids, muscle triglyceride, and muscle glycogen are plotted against the energy consumption of exercising muscles. Data for heavy exercise performed at 90 to 120 min were not collected.

The energy expenditure of exercising muscles



The energy expenditure of exercising muscles



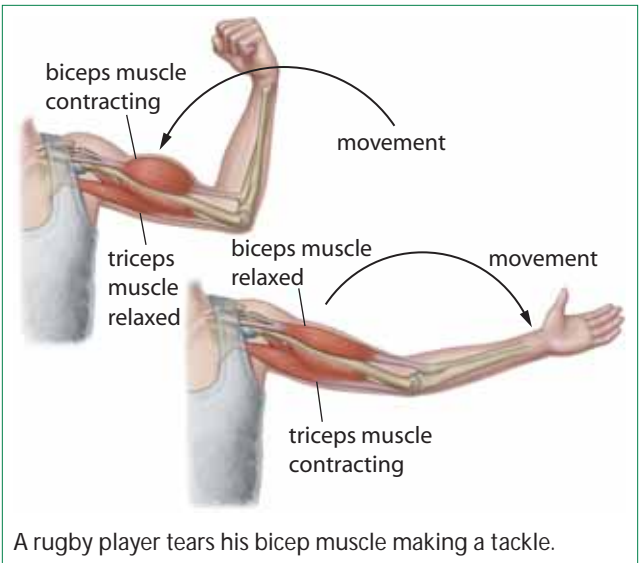
22. Use graphics or spreadsheet software to sketch a bar graph that you predict would reflect the data for heavy exercise performed at 90 to 120 minutes. Explain your reasoning. **ICT**

Use the following information to answer the next question.

A researcher is investigating the composition of muscle tissue in the calf muscles of several athletes. Samples of muscle tissue from each athlete are taken and examined. In this procedure, a needle is inserted into the muscle. A small “plug” of tissue remains in the needle when it is removed from the muscle.

23. Describe the main differences that this researcher would see when comparing the muscle tissues of athletes who perform in the following events:
  - a) 100-m dash
  - b) weight lifting
  - c) 10 000-m run

Use the following information to answer the next question.



24. Explain, in terms of skeletal muscle action, how this injury would affect his ability to flex his arm properly.

Use the following information to answer the next question.

Myosin, actin, tropomyosin, and troponin make up over three quarters of the protein in muscle fibres. Approximately two dozen other proteins make up the rest. These proteins serve such functions as attaching and organizing the filaments and connecting the filaments to the plasma membrane and the extracellular matrix.

Mutations in the genes encoding these proteins may produce defective proteins and resulting defects in the muscles. The muscular dystrophies (MD) are a group of more than 30 genetic diseases characterized by progressive weakness and degeneration of the skeletal muscles.

25. Based on your knowledge of skeletal muscles, explain why some individuals with MD would require the assistance of a respirator to breathe.

# Career Focus: Ask an Athletic Therapist



Robyn Bagley has been a Certified Athletic Therapist for 6 years. She has a Bachelor of Kinesiology from the University of Calgary and a Diploma in Physical Education—Athletic Therapy from Mount Royal College. In addition to work with private clients, Robyn works as Assistant Athletic Therapist at the University of Calgary. She is also a registered massage therapist.

**Q Athletes train to challenge the limits of the human body. What are the most common kinds of injuries you see?**

Injuries vary with the sports, but generally injuries to the joints—ankles, knees, shoulders—are quite common because the joints are a point of weakness. Joints are where two bones come together, held by ligaments, and acted upon by muscles and tendons. They are susceptible to both acute and chronic, repetitive injuries.

**Q What do you do in a typical session with a client?**

An assessment would be completed first to determine the injury, and then, depending on the injury, rehabilitation could include heat, ultrasound, laser, manual therapy, electrical modalities, strengthening exercises, stretching, and cold.

**Q Have advances in technology and equipment changed the stresses on the body? How?**

Definitely. Advances in technology and equipment will always add new dimensions, both positive and negative, to a sport. In some aspects, advances have improved a sport so we see fewer injuries than we once did; for example, visors in hockey reduce the incidence of eye injuries. Unforeseen aspects that advances bring include athletes' ability to hit each other harder, which increases the severity of injury and the occurrence of spinal and head injuries; newfound ability to push themselves farther in training, which increases the risk of repetitive injuries; the ability to perform tasks they could not do without the new equipment; the creation of a longer season, which also increases the risk of repetitive injuries; and the creation of new sports, to name just a few.

**Q Research into the human body is ongoing. How do you keep up with the new findings?**

I belong to a professional association—the Canadian Athletic Therapists Association. Every member

receives publications updating them on current research and is able to download information from the Internet. It is also helpful that many of our members are involved in new medical research and able to pass their findings on to the rest of the membership. As a part of our continued certification, all members of the association must continue to educate themselves regarding new techniques, research, and information.

**Q How does the work of an athletic therapist differ from that of a physiotherapist?**

Athletic therapists share a similar skill set with physiotherapists, however, athletic therapists specialize in musculoskeletal conditions. We traditionally follow the cyclical nature of sport from the field of play, to the clinic, and back to the field of play. Physiotherapists also work with patients with neurological, cardio, and respiratory conditions and traditionally work primarily in a clinical setting.

**Q Do serious athletes inevitably suffer injuries? What do you advise them to do to protect themselves?**

Balance in training and life is always important to help the body keep up with the demands we place on it. For high level athletes it is all the more important. Rest and recovery, along with proper training, including core strengthening and sport-specific drills, proper nutrition and hydration, all provide a strong base for all athletic pursuits. Core training—the strengthening of the postural and support muscles located primarily in the trunk of the body—is important for all people, regardless of their level of activity. The abdominal muscles, scapular muscles, and deep neck flexor muscles, for a start, provide the body with a good foundation to perform daily activities, let alone a high level of sport.

## Other Careers Related to Athletic Therapy

**Physiotherapist** Physiotherapists help their clients manage physical damage and injury through a variety of physical methods. Musculoskeletal physiotherapy helps the body heal from soft-tissue injuries. Neurological physiotherapy helps the body regain functions lost due to stroke, brain injury, or neurological disease. Cardiorespiratory physiotherapy helps the body improve breathing.

**Occupational Therapist** Occupational therapists help people with disabilities, long-term injuries and illnesses, or other conditions find ways to perform daily activities. Occupational therapists work in their clients' homes and workplaces, and in hospitals, schools, and universities.

**Massage Therapist** Massage therapists specialize in soft tissue manipulation, relaxation, and stretching techniques. They are often part of a team of physiotherapists, doctors, and other health-care professionals.

**Kinesiologist** Kinesiologists study factors that affect physical movement and look for ways to improve the efficiency of the body. They look at the psychological, physiological, biomechanical, historical, and social aspects of human movement. Kinesiologists design exercise equipment, do research, manage recreational facilities, coach, and teach physical education.

### Go Further...

1. Is possible for the average athlete to achieve excellence without understanding the physiological function of the human body? Why or why not?
2. How can an understanding of how the human systems function and interact improve the life of the average person? Does the average person have a responsibility to society to use this knowledge to keep him- or herself healthy? Why or why not?
3. Research the latest technology related to one of the following and explain how recent design improvements draw on our knowledge of how the body works:
  - a. Helmets
  - b. Running shoes
  - c. Rehydration drinks

