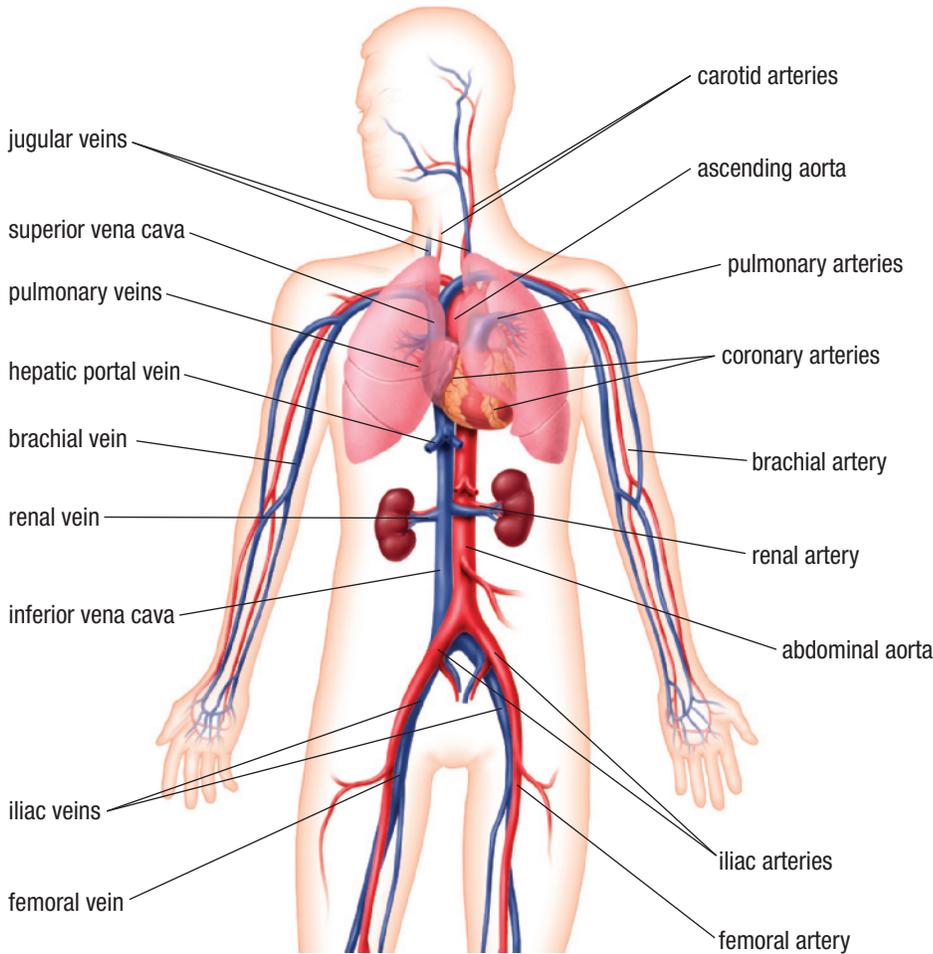


If you could join together all of the blood vessels in your body in a straight line, they would reach from St. John's, Newfoundland and Labrador, to Victoria, British Columbia, and back, twice! End to end, they would span about 19 000 km. Our blood vessels are not one long tube but a complex network of tubes that branch and rebranch. The largest blood vessel in the body is about 3 cm in diameter, slightly larger than the diameter of a regular garden hose. The smallest blood vessels are about 5  $\mu\text{m}$  to 10  $\mu\text{m}$  in diameter, just wide enough for blood cells to pass through in single file. **Figure 1** shows the major blood vessels in the human body.



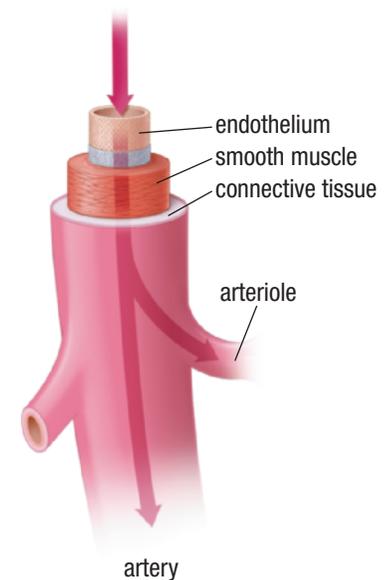
**Figure 1** The major arteries and veins of the human circulatory system

## Arteries

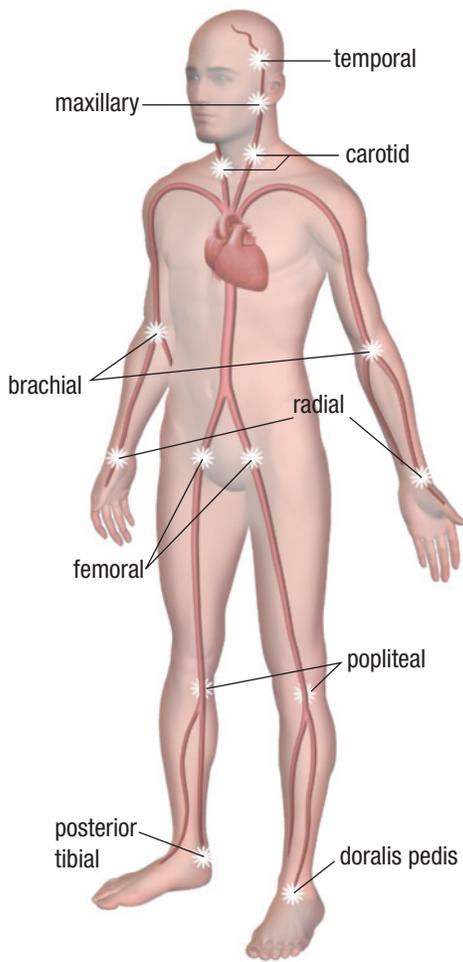
A blood vessel that carries blood away from the heart toward the body tissues is called an artery. A single large artery, called the **aorta**, leaves the heart. It branches into major arteries that carry blood around the body (refer back to Figure 1).

The walls of arteries have three layers of tissue—an outer layer of connective tissue, a middle layer of smooth muscle, and a smooth inner single layer of epithelial cells called the endothelium (**Figure 2**). When the ventricles of the heart contract to pump blood around the body, the arteries expand slightly in diameter to accommodate the increased pressure of the blood within them. The outer layer of the arteries includes elastin fibres that give the vessels elasticity. When the ventricles relax, the walls of the arteries return to their original size, pushing the blood farther into the downstream vessels. The elasticity of the artery walls ensures that there is a continuous flow of blood through the blood vessels, even when the heart is relaxed.

**aorta** the largest blood vessel in the body, connected directly to the heart; the aorta branches into arteries that carry oxygenated blood to the body tissues



**Figure 2** The three layers of tissue in the artery provide a strong but elastic tube that can withstand the pressure of the fluid it carries.



**Figure 3** Pulse points are located where an artery runs close to the surface of the body.

**arteriole** the smallest artery, with smooth muscle in its walls

**vasodilation** an increase in the diameter (dilation) of arterioles that increases the blood flow to tissues

**vasoconstriction** a decrease in the diameter of arterioles that decreases the blood flow to tissues

When blood is forced through the artery by the contraction of the heart, the artery expands. This expansion can be felt as the pulse if the artery is fairly large, close to the skin, and in front of a bone or other firm structure. Taking the pulse is a simple but very useful procedure in determining the heart rate. The pulse can be taken at a number of locations, called pulse points, on the body (**Figure 3**).

## Mini Investigation

### Taking a Pulse

**Skills:** Performing, Observing, Analyzing

SKILLS HANDBOOK  A2.1

The techniques for taking the pulse are simple and straightforward when you know the locations. The most common point is the radial artery in the wrist. The purpose of this activity is to find your pulse at several different pulse points and determine your heart rate. The main reason for taking a pulse is to measure the heart rate.

**Equipment and Materials:** stopwatch

1. Find your pulse at the radial artery. The radial artery runs along the thumb side of your wrist as shown in **Figure 4**.



**Figure 4**

2. Count the number of beats in 15 s and multiply by 4 to obtain your heart rate. Record your heart rate.
3. Refer to **Figure 3** and try to find your pulse at other accessible locations.
  - A. Why do you think the radial artery is the most commonly used pulse point? T/I A
  - B. Did you have difficulty finding other pulse points? Why do you think it was more difficult in other locations? T/I A
  - C. When police or medical personnel check for signs of life, they check the carotid pulse. Why do you think they check this pulse rather than the radial pulse? T/I A

## Arterioles

The arteries that branch from the aorta further branch and rebranch into the smallest arteries, which are called **arterioles**. Because the arterioles have smooth muscle in their walls, they can be controlled by the nervous system. Signals from the nerves can regulate the diameter of the arterioles and control the blood flow to certain parts of the body.

### CONTROLLING BLOOD FLOW IN ARTERIOLES

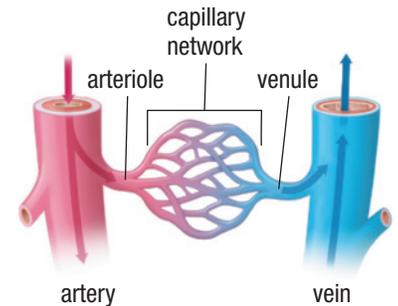
Have you ever wondered why your skin looks red or flushed when you are overheated? In certain situations (such as when the body is overheated), nerve impulses cause the smooth muscle in the arterioles in the skin to relax. This relaxation increases the diameter of the blood vessel, which allows an increased flow of blood to the skin and produces a flushed look. This is a cooling strategy: warm blood close to the surface of the skin loses thermal energy to the surrounding environment. The relaxation of the smooth muscle, which increases the diameter of blood vessels, is known as **vasodilation**. If the body is cold, the opposite happens. **Vasoconstriction** occurs when nerve impulses cause the smooth muscle in the arterioles to contract, narrowing the diameter of the blood vessel and restricting the blood flow. Restricting blood flow to the skin prevents thermal energy loss to the environment.

Vasoconstriction is an important feature of the circulatory system. Without it, you would need about 200 L of blood to fill all of the blood vessels in the body. The ability to control blood flow ensures that the 5 L of blood you have is distributed where it is needed. When you are resting, for example, your muscles do not require much blood. Constriction of the arterioles diverts blood away from the muscles to other areas of the body where blood is required. During exercise, muscles require lots of blood, so blood flow to the lungs and muscles is increased, while it is reduced to other parts of the body such as the stomach and intestines.

## Capillaries

When an arteriole reaches the tissues of the body, it branches further into smaller blood vessels called capillaries. The capillaries form networks of blood vessels that supply oxygen and nutrients to every cell throughout the body tissues. The capillaries merge in a kind of mirror image of the way they branched from the arterioles, forming larger blood vessels on the opposite (or venous) side of a capillary network (**Figure 5**).

The capillary networks are so extensive that no body cell is farther than two cells away from a capillary. The walls of the capillaries are only a single cell layer thick. Through these very thin walls, oxygen and nutrients diffuse from the blood into the tissue fluid that surrounds the cells. Likewise, carbon dioxide and other waste materials produced during aerobic cellular respiration diffuse into the tissue fluid and then into the capillaries.



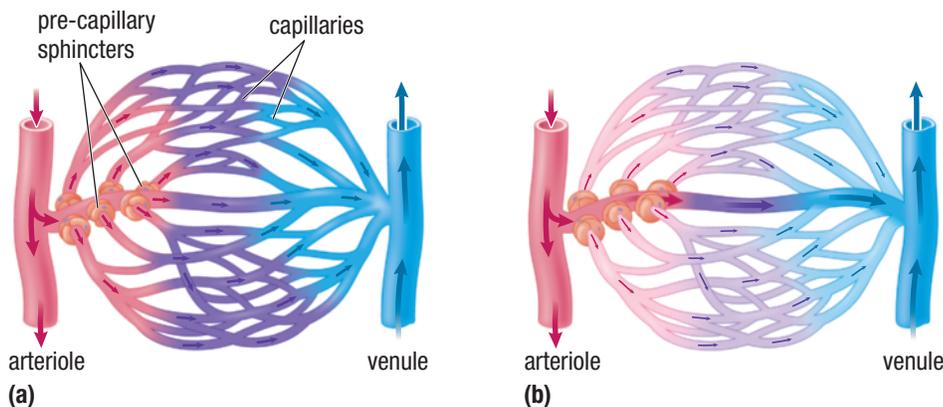
**Figure 5** Arteries branch into arterioles before branching off further, into capillary networks.

## Fluid Exchange

Differences in pressure and water concentration are responsible for the exchange of fluids in the capillary networks. Higher fluid pressure on the arterial side of a capillary network causes water to diffuse from the blood into the tissue fluid. This reduced concentration of water in the blood increases the concentration of dissolved substances and proteins in the blood as it crosses the capillary network. On the venous side of the capillary network, the concentration of water in the blood is less than the concentration of water in the tissue. This difference in concentration moves some of the water from the tissue fluid to the blood. The remainder of the water enters the lymphatic system. This exchange of fluids maintains a balance between fluids in the circulatory system and in the tissues.

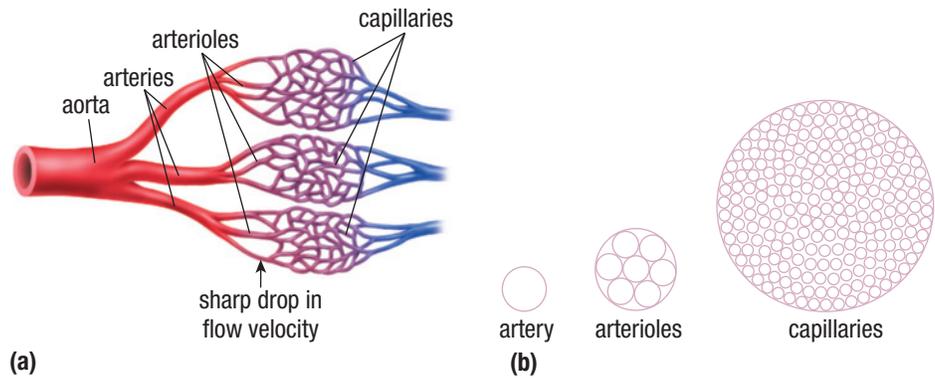
## Controlling Blood Flow in Capillaries

Since there is no smooth muscle in the walls of capillaries, the diameter of the capillaries cannot be controlled by the nervous system. However, there are pre-capillary sphincter muscles where the arteriole branches into a capillary. These sphincter muscles serve the same function as the dilation and constriction of arterioles. If blood is not needed in a particular capillary network, the pre-capillary sphincters contract and reduce blood flow (**Figure 6**). During exercise, for example, the arterioles and sphincters are fully relaxed, and the blood flow to the muscles is increased.



**Figure 6** (a) Pre-capillary sphincter muscles are relaxed and blood flow through the capillary network is at a maximum. (b) The sphincter muscles are contracted, allowing minimal blood flow through the capillary network.

Capillaries are so small in diameter that blood cells move through them in single file. You might think that this would increase the pressure and cause the blood to flow faster. However, when blood leaves an arteriole and flows into a network of capillaries there is a significant decrease in the rate at which the blood flows. This is because the millions of capillaries in a network create a total cross-sectional area that is much greater than the cross-sectional area of the arterioles and the artery from which the capillaries branch (**Figure 7**). Think of this as a fast-running stream (the artery) flowing into a much larger pool (a capillary network). As the water enters the pool, the current slows considerably. This slower flow through the capillary network is important because it provides time for the diffusion of substances into and out of the capillaries.



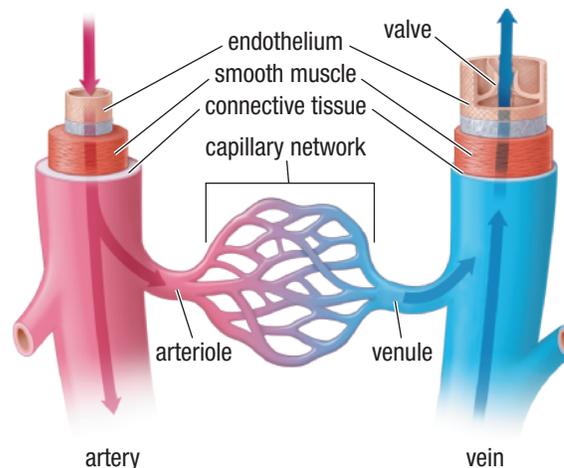
**Figure 7** (a) Capillaries are much smaller in diameter than arteries or arterioles. (b) The cumulative cross-sectional area of a capillary network is much greater than that of even the largest arteries, resulting in a decrease in flow velocity.

## Venules and Veins

The capillary networks in body tissues are a dividing region. On one side are the arteries and arterioles carrying oxygenated blood and nutrients to the tissues. On the other side, the capillaries merge into small vessels called **venules** that merge to form larger vessels called veins. Venules and veins carry deoxygenated blood containing carbon dioxide and other waste products from the body tissues. (The one exception is the capillary networks in the lungs, where the blood is oxygenated.) After passing through the capillary networks, the blood begins its journey back to the heart.

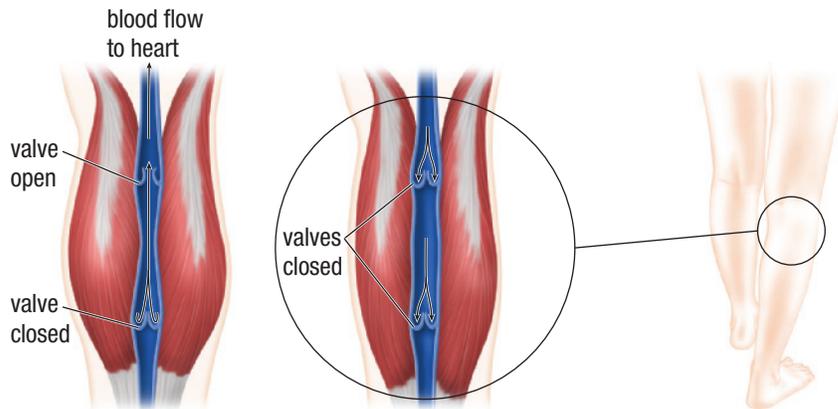
Veins have a different structure from arteries. The middle layer of smooth muscle is not as thick as in arteries, and the walls are not as elastic (**Figure 8**). As a result, the internal diameter of veins is greater than that of arteries. When a fluid moves from a smaller-diameter tube to a larger-diameter tube, the pressure is reduced. Blood pressure in veins is significantly lower than in arteries. How then does blood get back to the heart, especially from the lower parts of the body?

**venule** the smallest vein; formed by the merging of capillaries



**Figure 8** Because of the higher pressure, the walls of arteries are thicker than those of veins.

Many of the larger veins have valves that ensure the blood flows in only one direction. The skeletal muscles also help the circulation of blood. When these muscles contract, they squeeze the veins. This increases the pressure in the veins and, in conjunction with the valves, helps push the blood back toward the heart (**Figure 9**).



**Figure 9** The contraction of the muscles squeezes the veins, and the valves keep the blood flowing in the right direction.

Despite the help of valves and skeletal muscles, blood tends to pool in the lower extremities, especially after standing or sitting for a long period of time. You may have heard of military personnel fainting after standing at attention for a long period of time. In this situation, the skeletal muscles in the lower body do not move or contract enough to allow the blood to return to the heart. Most of the blood pools in the lower body, and circulation to the brain is decreased to the point where the individual faints. Blood pooling in the legs also increases the likelihood of clot formation.

As people age, their veins and other blood vessels tend to become less elastic. Individuals who have spent long periods of time standing or sitting may damage the valves in the veins of the lower legs. If the valves are not functioning properly, there is a greater accumulation of blood in the veins and the veins stretch but do not rebound, creating a bulging condition known as varicose veins (**Figure 10**).



**Figure 10** Varicose veins

## Blood Pressure

The pulse is evidence that the arteries swell when the heart contracts. Blood is under pressure in the blood vessels because of the pumping of the heart. The pressure increases when the heart contracts and decreases when the heart relaxes.

The overall volume of blood is a significant factor in determining blood pressure. Since blood is contained within the circulatory system, it exerts pressure on the walls of the circulatory system. This pressure is known as blood pressure.

A specific volume of blood can be accommodated within the confines of the circulatory system. If the amount of fluid increases, the pressure on the walls of the blood vessels will increase. Because the blood vessels are somewhat elastic, some increase in blood volume can be tolerated. The total available volume increases slightly as the blood vessels stretch. The elasticity of the blood vessel walls exerts an opposite force on the blood. This opposite force results in an increase in blood pressure. When the blood vessels are stretched to the limit, the increase in blood pressure poses more serious health risks.

Blood pressure is measured with an instrument called a sphygmomanometer. It consists of an inflatable cuff that is wrapped around the arm and a gauge or display that indicates the pressure of the blood in the brachial artery. The cuff is inflated until the blood flow in the brachial artery is stopped. As the pressure is released from the cuff, pressure sensors in the cuff detect the vibrations of the blood flowing through the artery. The first reading is the **systolic pressure**, which is the pressure in the artery when the heart contracts. Normal systolic pressure in a young adult is about 120 mm Hg. (The SI unit of pressure is the kPa, but blood pressure is still measured in millimetres of mercury, or mm Hg. One kPa is equal to 7.5 mm Hg and 1 mm Hg = 0.133 kPa.)

**systolic pressure** the blood pressure in the arteries when the heart contracts

**diastolic pressure** the blood pressure in the arteries when the heart relaxes

**Investigation 11.3.1**

**The Effect of Exercise on Heart Rate and Blood Pressure (page 513)**

Now that you have read about blood pressure, you can complete Investigation 11.3.1.

In this investigation you will design and conduct a controlled experiment to determine whether and how heart rate and blood pressure are affected by exercise.

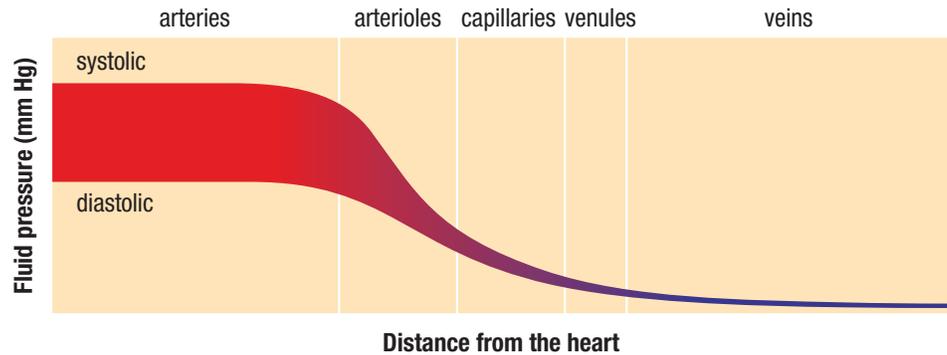
**hypertension** consistent blood pressure above the range of normal values; also called high blood pressure

<b>Nutrition Facts</b>	
Serving Size 1/4 Cup (30g)	
Servings Per Container About 38	
Amount Per Serving	
<b>Calories</b> 200	Calories from Fat 150
% Daily Value*	
<b>Total Fat</b> 17g	<b>26%</b>
Saturated Fat 2.5g	<b>13%</b>
Trans Fat 0g	
<b>Cholesterol</b> 0mg	<b>0%</b>
<b>Sodium</b> 120mg	<b>5%</b>
<b>Total Carbohydrate</b> 7g	<b>2%</b>
Dietary Fiber 2g	<b>8%</b>
Sugars 1g	
<b>Protein</b> 5g	
Vitamin A 0%	Vitamin C 0%
Calcium 4%	Iron 8%

\*Percent Daily Values are based on a 2,000 calorie diet.

**Figure 12** Nutrition labels indicate the amount of sodium and the percentage of the recommended daily allowance.

The second reading of the sphygmomanometer is taken when the heart is relaxed and blood is flowing through the artery. This is called the **diastolic pressure**. Normal diastolic pressure in a young adult is about 80 mm Hg. The blood pressure is reported as 120/80 (read as 120 over 80) and means that the individual has a systolic pressure of 120 mm Hg and a diastolic pressure of 80 mm Hg. Blood pressure is not the same throughout the circulatory system. Blood pressure decreases as blood flows away from the heart to the veins and back to the heart (**Figure 11**). The greatest drop in pressure is when the blood flows from the arteries to the arterioles and capillaries.



**Figure 11** By the time the blood gets back to the heart, it is under very low pressure.

**Hypertension**

Many factors can influence blood pressure. The diameter of the blood vessels, an individual’s level of physical activity, temperature, body position, diet, stress, age, and medications can cause variations in blood pressure.

There is an acceptable normal range of systolic and diastolic blood pressures. Blood pressures consistently above the normal levels constitute a condition called **hypertension**, commonly known as high blood pressure. Hypertension can be caused by a variety of medical or lifestyle conditions. Kidney disease, for example, can cause more fluid to be retained in the blood, causing an increase in the volume of blood and a resulting increase in blood pressure. Some medications can also cause high blood pressure. Age is a very important contributing factor. As an individual ages, the walls of blood vessels lose some of their elasticity and cannot stretch as much as they once did. Since the available volume of the circulatory system does not increase, the pressure within the system increases.

Diets that are very high in sodium (salt) create high levels of sodium in the blood because the kidneys cannot eliminate the excess. The increased sodium concentration in the blood causes water to move into the blood by osmosis. This may lead to an increase in blood volume and an elevated blood pressure. On average, Canadians consume more than twice the recommended upper level of 2300 mg of sodium per day. Nutrition labels indicate how much sodium is contained in a portion of the food and what percentage of the recommended daily value it represents (**Figure 12**).

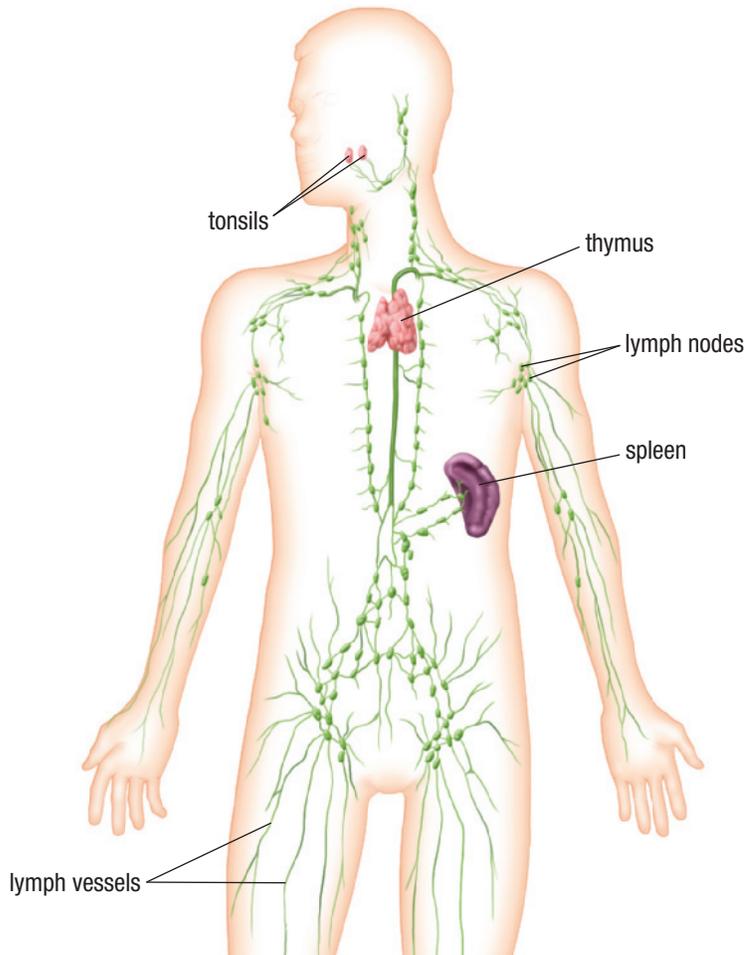
Hypertension has been labelled “the silent killer” because it usually does not show any recognizable symptoms until a serious event, such as a heart attack or stroke, occurs. Hypertension is dangerous because it forces the heart to work harder to pump blood around the body. It can also result in ruptured blood vessels in organs such as the kidneys and eyes. High blood pressure can be reduced by adjusting the individual’s lifestyle—following a more appropriate diet, losing weight, and getting regular exercise. If these approaches do not work, medications are available to reduce blood pressure through vasodilation or by reducing the amount of retained water in the blood.

**The Lymphatic System**

The lymphatic system has two major roles: one in the circulatory system and the other in the immune system. As part of the circulatory system, the lymphatic system helps ensure that the blood volume is maintained. As part of the immune system, the lymphatic system filters bacteria and other components from the blood.

As blood circulates through the capillaries, some proteins leak from the blood into the tissue fluid. This lowers the pressure of the tissue fluid, and some fluid moves from the blood into the tissue fluid by osmosis. The excess tissue fluid is collected in lymph vessels and returned to the blood in the veins. Lymph vessels are distributed throughout the body (**Figure 13**). Once the fluid is in the lymph system, it is known as **lymph**. This process is one of the mechanisms that maintains a balance of fluids in the circulatory system and ensures that the blood volume remains relatively stable. Were it not for this system, the body tissues would swell because of the extra tissue fluid.

**lymph** tissue fluid collected in lymph vessels and returned to the blood



**Figure 13** The lymph system ensures that excess tissue fluid is collected and returned to the circulatory system. The lymph nodes act as filters for the blood.

Lymph contains a variety of components—the fluid itself, bacteria and other foreign cells, dead or damaged cells, and fat molecules absorbed through the lacteals in the villi of the small intestine. These components are either delivered back into the bloodstream or filtered from the system and removed.

Removal of bacteria or other harmful cells from the blood is part of the defensive role of the lymphatic system. Scattered through the system are **lymph nodes**, where leukocytes gather to destroy disease-causing viruses, bacteria, and other microorganisms. Swollen and painful lymph nodes are a sign that the immune system is fighting a serious infection.

The **spleen** is the largest organ of the lymphatic system. It serves as a filtering station and as a reservoir of erythrocytes and leukocytes. When required, the body draws on this reservoir to fight diseases by providing additional leukocytes, or to increase oxygen delivery by providing additional erythrocytes. The tonsils also serve a similar function by filtering out bacteria, viruses, and other materials. Tonsils often become infected and inflamed, a condition known as tonsillitis. The infected tonsils become red and swollen, in order to work better to trap or stop the disease-causing bacteria. Tonsillitis begins with a sudden sore throat and painful swallowing. A serious infection of the spleen or tonsils often requires surgical removal.

**lymph node** an enlargement in the lymph vessels that acts as a filter to remove bacteria and foreign particles

**spleen** the largest organ of the lymphatic system; acts as a filter and a reservoir of erythrocytes and leukocytes

**thymus** a glandular organ of the lymphatic system; secretes hormones to promote the maturity of lymphocytes

The **thymus** is a critical organ of the immune system. The thymus secretes hormones that help lymphocytes, a type of leukocyte, develop their ability to recognize and attack specific foreign invaders. These lymphocytes are an essential line of defence against bacteria, viruses, and other disease-causing agents.

### 11.3 Summary

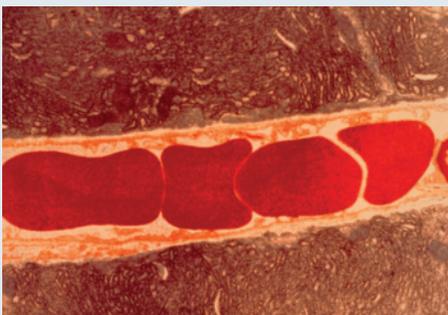
#### UNIT TASK BOOKMARK

Consider what you have learned about blood vessels and blood pressure. How can this information help you as you create a health and fitness profile in the Unit Task?

- Arteries and arterioles are blood vessels that carry blood away from the heart. Arteries have a layer of smooth muscle in their walls. Vasoconstriction reduces the diameter of arteries and decreases blood flow. Vasodilation relaxes the muscle and increases blood flow.
- The pulse is the expansion of an artery in response to the increased pressure caused by the contraction of the heart.
- Capillaries are the smallest blood vessels. The capillary networks in the tissues are the locations where the exchange of materials takes place.
- Blood pressure and flow rate decrease significantly when blood enters the capillary networks in the tissues. This provides time for the diffusion of materials into and out of the blood.
- Veins and venules are blood vessels that carry blood back to the heart after it passes through the capillary networks in the tissues. Because blood pressure is low in the veins, valves and the contraction of skeletal muscles help move the blood back to the heart.
- Blood pressure, measured with a sphygmomanometer, is reported as two values: systolic pressure (the pressure in the arteries when the heart contracts) and diastolic pressure (the pressure in the arteries when the heart relaxes).
- Hypertension, commonly known as high blood pressure, is a condition in which the blood pressure is consistently higher than normal.
- The lymphatic system has two primary functions—to return excess fluids from the tissue fluid to the bloodstream and to protect the body by filtering and destroying bacteria and other microorganisms.

### 11.3 Questions

1. Use a T-chart to identify three differences between arteries and veins. **K/U C**
2. (a) What is a pulse?  
(b) What information can you gather from taking a pulse?  
**K/U A**
3. How does gravity affect the circulation of blood? What structures in the blood vessels are designed to counteract the effect of gravity? **K/U**
4. What type of blood vessel do you think is shown in **Figure 14**? Explain your answer. **K/U T/I**
5. Explain why the rate of blood flow decreases in the capillary networks. Why is this an advantage? **K/U A**
6. Nicotine is a drug that acts as a vasoconstrictor. Would a smoker likely have high blood pressure or low blood pressure? Explain why. **K/U T/I A**
7. Analyze the available nutrition labels on the packages of the foods you ate yesterday. Estimate how much sodium you consumed. Describe the possible effects of consuming too much sodium. **T/I C A**
8. Use the Internet and other sources to research and report on the social and economic costs of hypertension. Consider loss of work hours, cost of medical treatment, loss of quality of life, etc. Prepare a presentation outlining the costs of this disorder. **T/I C**
9. Briefly describe the two primary functions of the lymphatic system. **K/U**
10. Suggest and explain two possible effects of the removal of the spleen. **K/U T/I A**



**Figure 14**



GO TO NELSON SCIENCE