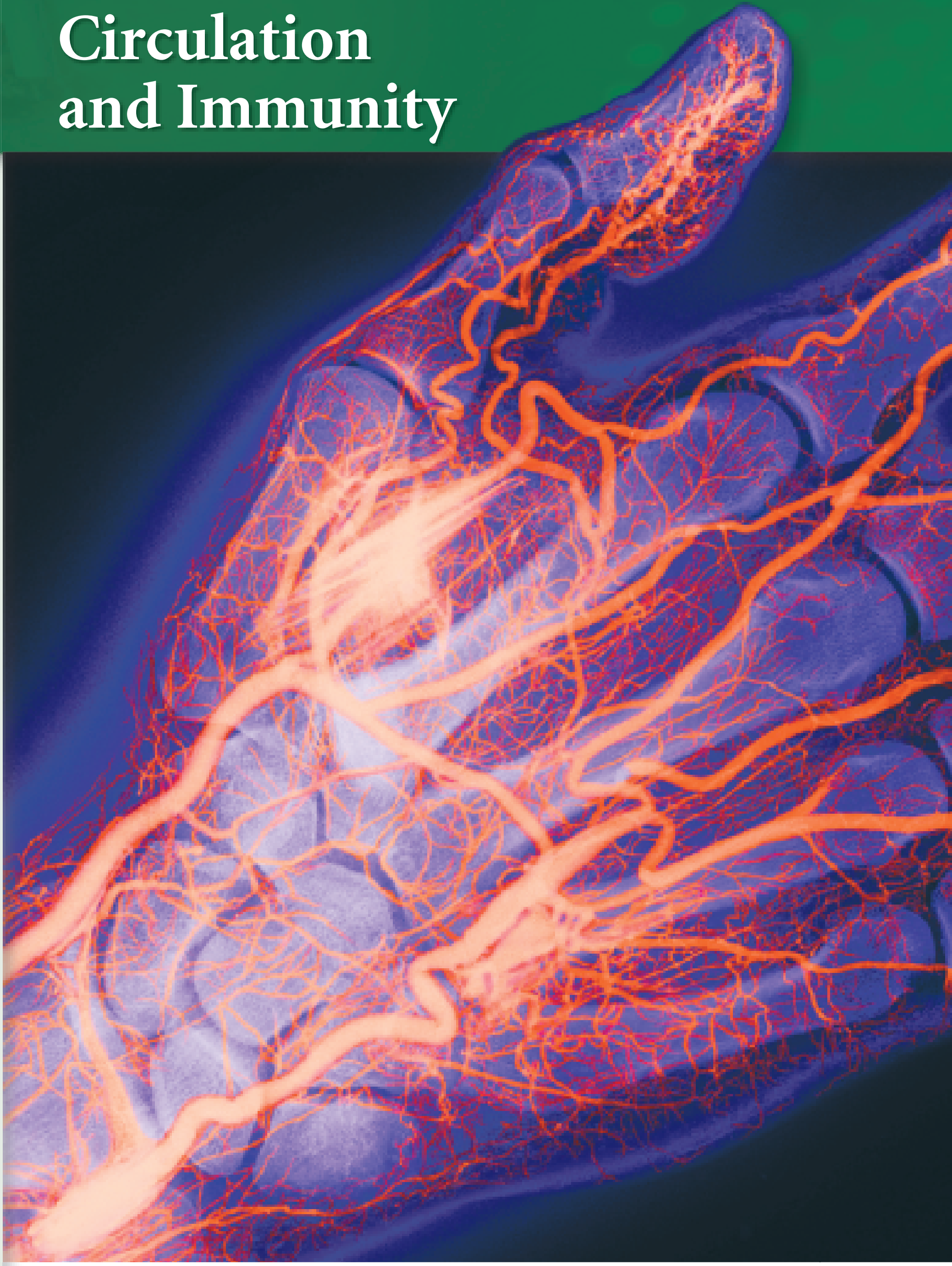
CHAPTER

8

Circulation and Immunity



Chapter Concepts

8.1 Structures of the Circulatory System

- The heart and blood vessels are collectively called the cardiovascular system.
- The mammalian heart is a muscular organ that contains four chambers and acts as a double pump.
- There are three circulatory pathways through the body: the pulmonary pathway, the systemic pathway, and the coronary pathway.

8.2 Blood and Circulation

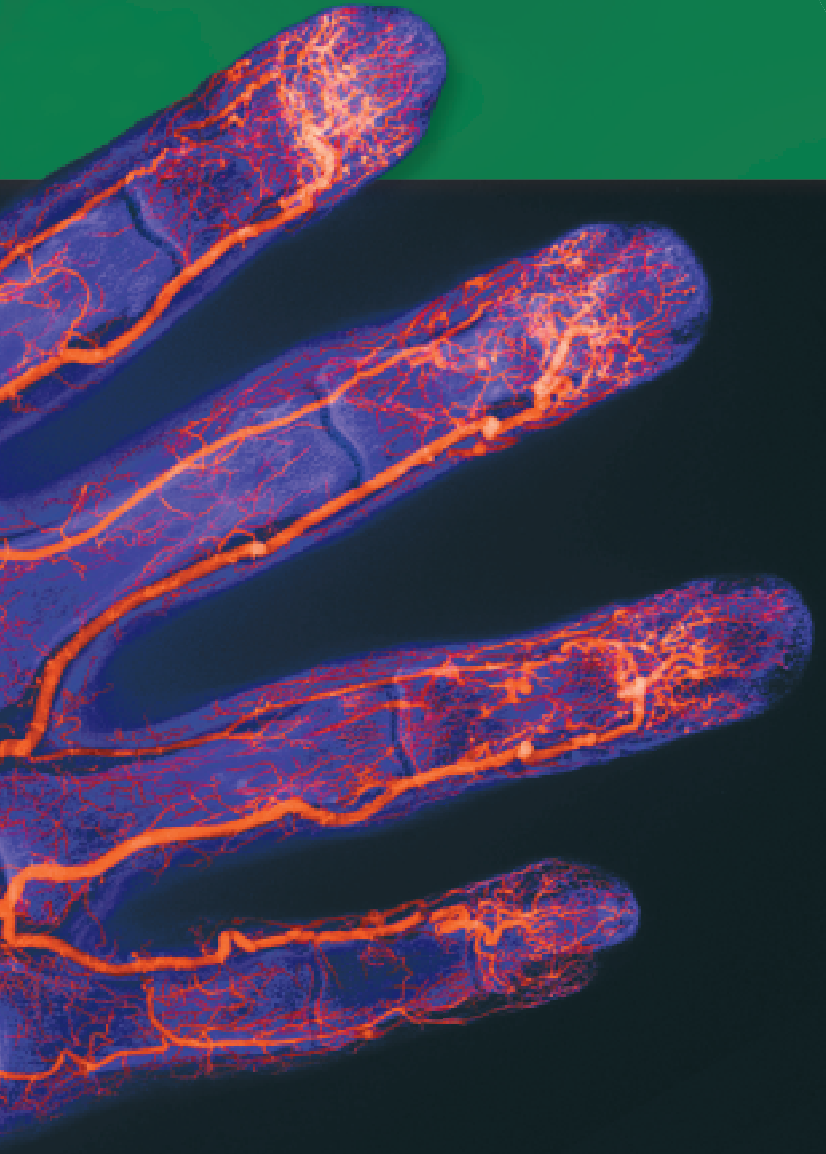
- Blood is a tissue made up of plasma, red blood cells, white blood cells, and platelets.
- Blood transports materials throughout the body and regulates temperature to maintain homeostasis.

8.3 The Lymphatic System and Immunity

- The lymphatic circulatory system is closely associated with the blood vessels of the cardiovascular circulatory system.
- The lymphatic system helps to maintain the balance of fluids within the body and is a key component of the immune system.
- The body's defence system is made up of non-specific defences and specific defences (immunity).
- The specific immune system contains a variety of cells that are specialized to recognize foreign substances and neutralize or destroy them.

You breathe oxygen into your lungs, and it reaches the cells of your fingers. You swallow pain-relief medication, and it eases the swelling in a sprained ankle. Blood vessels provide a transportation network that links the different parts of your body and its trillions of cells.

Your hand contains well over a kilometre of blood vessels. Some of these blood vessels you can see through the skin on the back of your hand. Many more can be revealed using medical technologies. However, even a spectacular image, such as the one shown here, would not include all the blood vessels in your hand. The circulatory system extends through every part of your hand, right down to the microscopic level, so that no cell in your hand is more than a cell's breadth away from a blood vessel.



Launch Lab

Watching Blood Flow

Your teacher will either show you a movie or direct you to the McGraw-Hill Ryerson web site, where you can observe a video clip showing the flow of blood through the tail of a goldfish.

Materials

- movie or video clip showing blood flow in a goldfish tail

Procedure

1. Observe the movie or video.
2. Discuss the following Analysis questions.

Analysis

1. What are possible functions of the blood that you saw flowing through the tiny vessels (tube-like structures)?
2. Suggest two reasons why the vessels in the goldfish's tail are so small. Why does the goldfish not have just one large vessel?
3. Describe two situations that could either speed up or slow down the movement of blood in the goldfish.
4. What substance or substances are in the vessels you observed?
5. What do you think is responsible for the movement of blood in the goldfish? Would this be responsible for the movement of blood in all animals? What about other organisms, such as plants? Explain your ideas.
6. Did the goldfish's blood appear to change direction, or did it flow in one direction? Write a hypothesis to explain what you observed.

In what ways is the transportation network of a city or town like the transportation network of your circulatory system?

SECTION 8.1

Structures of the Circulatory System

Section Outcomes

In this section, you will
- **identify** the major structures of the circulatory system
- **describe** the structure and function of blood vessels
- **describe** the action of the heart and the circulation of blood through the body
- **dissect** and **observe** the structures of a mammalian heart
- **design** an investigation to examine heart rate and blood pressure
- **identify** disorders of the circulatory system and technologies used to treat them
- **investigate** the relationship between blood pressure, heart rate, and exercise

Key Terms

circulatory system
atria
ventricles
septum
vena cavae
pulmonary arteries
pulmonary veins
aorta
valves
arteries
veins
capillaries
sinoatrial (SA) node
atrioventricular (AV) node
blood pressure
systolic pressure
diastolic pressure
pulmonary pathway
systemic pathway
coronary pathway

In a single-celled organism such as *Amoeba*, nutrients and respiratory gases enter the cell either by diffusion or by being actively transported across the cell membrane. Once inside the cell, these substances are distributed to the cell's organelles by the movement of its cytoplasm—a process called cytoplasmic streaming. Active transport and cytoplasmic streaming require energy, which is supplied by the energy-carrier molecule, ATP. Waste materials leave the cell by diffusion or through active transport and are released into the environment. Thus, single-celled organisms exchange matter directly with their external environment.

In multicellular organisms, such as humans, the process of matter exchange is more complex. The trillions of specialized cells of a multicellular organism are organized into functional, structural units, such as tissues and organs. The individual cells that make up these structural units require nutrients and oxygen, and they must rid themselves of wastes, just as single-celled organisms do. Thus, an efficient system for transporting materials within the body is necessary. The **circulatory system** is this transportation system.

Main Functions of the Circulatory System

The circulatory system has the following three main functions:

1. The circulatory system transports gases (from the respiratory system), nutrient molecules (from the digestive system), and waste materials (from the excretory system). You have already studied two of these systems. In Chapter 9, you will study the excretory system.
2. The circulatory system regulates internal temperature and transports hormones. Much of the body's heat is generated by the motor system, which you will examine in Chapter 10. Hormones are reaction-triggering chemicals that are produced by the endocrine system. You have already seen hormones in action in Chapter 6. Gastrin, secretin, and CCK are involved in regulating digestion. You will study the endocrine system and its role in homeostasis in your next biology course. (If you are interested in reading ahead to learn about this system, turn to Chapter 13.)
3. The circulatory system protects against blood loss from injury and against disease-causing microbes or toxic substances introduced into the body. In Section 8.2, you will learn about the role of platelets in protecting against blood loss and the role of white blood cells in providing immune responses to foreign agents. In Section 8.3, you will learn about a companion to the circulatory system, the lymphatic system, which also has a protective role in the body.

Major Components of the Circulatory System

The circulatory system is made up of three major components: the heart, the blood vessels, and the blood. The heart is an organ that pushes blood through the body with its pumping action and generates blood flow. The blood vessels serve as the "roadways" through which the blood moves. Together, the heart and blood vessels comprise the cardiovascular system. ("Cardio-" comes from a Greek word meaning "heart," and "-vascular" comes from a Latin word meaning "vessel.") The blood carries nutrients, oxygen, carbon dioxide, water, wastes, and many other materials throughout the body.

In the remainder of this section, you will focus on the cardiovascular system—the heart and blood vessels. You will focus on the blood in Section 8.2.

> **Q1** What are three main functions of the human circulatory system?
>
> **Q2** Name the three components that make up the human circulatory system.

The Structure of the Heart

Make a fist with each of your hands, and then hold your fists together at the knuckles. This is the approximate size of an adult human heart, such as the one shown in Figure 8.1. Now imagine holding a tennis ball in one hand and squeezing it as strongly as you can. This is the approximate force that the heart uses for a single contraction to pump blood through the body. The amount of energy that the heart needs to generate the force for one contraction, multiplied by the number of contractions over 50 years of life, would be sufficient to raise a battleship (more than 1 million tonnes) out of the water!

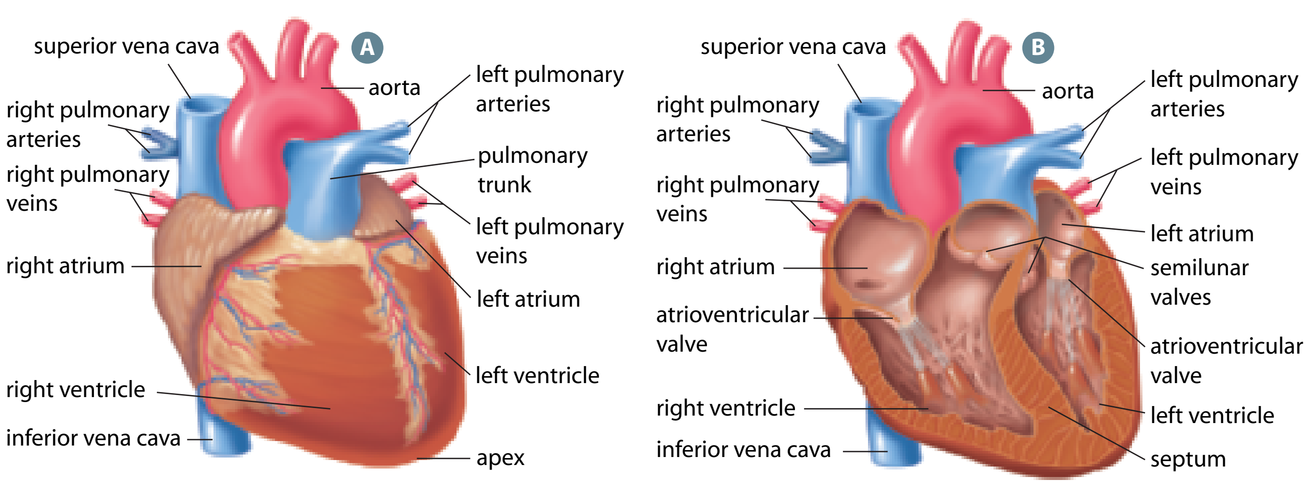
Located slightly to the left of the middle of the chest, the heart has several important functions. These functions include pumping blood through the body, keeping oxygen-rich blood separate from oxygen-poor blood, and ensuring that blood flows only in one direction through the body. The walls of the heart are made up of a special type of muscle tissue, called cardiac muscle, that is found nowhere else in the body. The contractions of cardiac muscle tissue are rhythmical and involuntary—you cannot consciously affect your heartbeat. The muscle cells relax completely in the brief milliseconds between contractions, thus preventing the heart from becoming fatigued.

The human heart, like the hearts of all mammals and birds, has four chambers: one top chamber and one bottom chamber on both the right and left sides. The two top chambers are called the **atria** (singular: atrium), and they fill with blood returning either from the body or the lungs. The two bottom chambers are called the **ventricles**. They receive blood from the atria and pump it out to either the body or the lungs. The atria and the ventricles are separated from each other by the thick muscular wall called the **septum**. Figure 8.2 shows some of the external and internal structures of the human heart.

The right side of the heart receives blood coming back from the body and then pumps this blood out to the lungs. Two large vessels, called the **vena cavae** (singular: vena cava), open into the right atrium. The superior vena cava collects oxygen-poor blood coming from the tissues in the head, chest, and arms. The inferior vena cava collects oxygen-poor blood coming from the tissues elsewhere in the body. The oxygen-poor blood flows from the right atrium into the right

Figure 8.1 Cradled in the hands of a surgeon, this human heart is about to be transplanted into a person whose own heart no longer functions properly.

Figure 8.2 An external view **(A)** and a cross-sectional view **(B)** of the human heart



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FYI
The bicuspid and tricuspid valves are held in place by long cord-like tendons called the chordae tendinae. These tendons attach the valves to small muscles on the inside wall of the ventricles. They ensure that during ventricular contraction the valves are not pushed back into the atria by the force of the flowing blood. Without them, blood would rush back into the atria, disrupting the direction of flow.

ventricle and then out into the pulmonary trunk before entering the left and right **pulmonary arteries**. From there, it continues to the left and right lungs for gas exchange. (These are the only arteries in the circulatory system that contain oxygen-poor blood.) The left side of the heart does the reverse. It receives oxygen-rich blood from the left and right lungs and pumps this blood out to the body. The oxygen-rich blood flows from the lungs through the **pulmonary veins** to the left atrium. (These are the only veins in the circulatory system that contain oxygenated blood.) The left atrium pumps blood into the left ventricle, where all the blood going to the body tissues leaves through a large vessel—the largest in the body—called the **aorta**. You will examine the route of blood flow in more detail later in this section.

As you can see in Figure 8.3, the heart has four valves inside it. These **valves** ensure that blood flows in the correct direction. The atria and ventricles are separated from each other by two valves called the atrioventricular valves. The atrioventricular valve on the right side is called the tricuspid valve because it is made up of three flaps. The atrioventricular valve on the left side is called the bicuspid valve because it has only two flaps. The other two valves are called semilunar valves because of their half-moon shape.

3. Name the four chambers of the mammalian heart.

4. What is the function of the valves in the heart? How many valves does the heart have?

The Structure of the Blood Vessels

There are three main types of blood vessels: arteries, veins, and capillaries. **Arteries** carry oxygen-rich blood away from the heart, and **veins** carry oxygen-poor blood toward the heart. Joining each artery and vein is a network of capillaries. Blood travels from an artery into the **capillaries**, where gases, nutrients, and other materials are transferred to tissue cells and wastes, including gases, move into the blood. The blood then moves from the capillaries into the veins and back to the heart. Compare the structure of arteries, veins, and capillaries in Figure 8.4.

An artery has highly elastic walls. This elasticity allows the artery to expand as a wave of blood surges through it during the contraction of the ventricles, and then to snap back again during the relaxation of the ventricles. The action of the artery keeps the blood flowing in the right direction and provides an additional

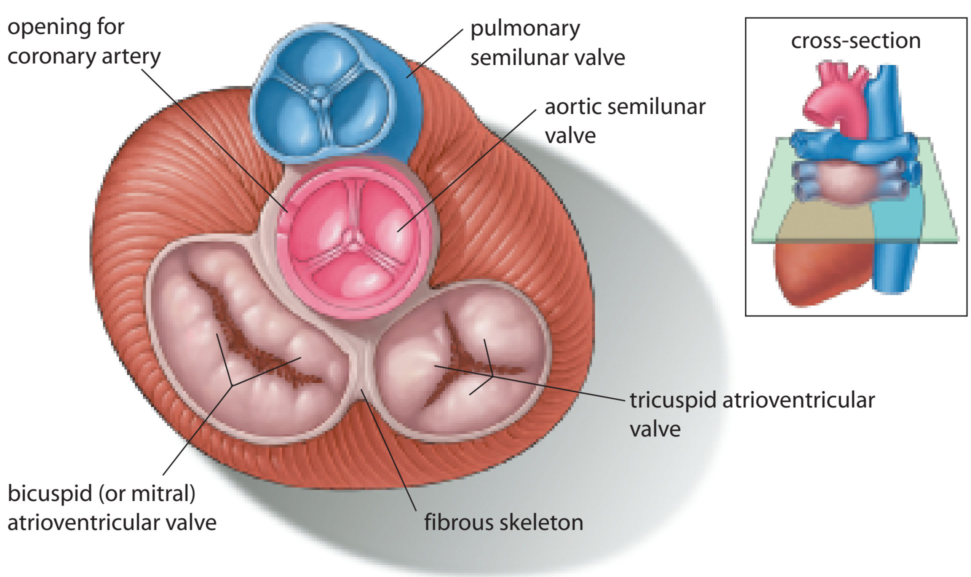

Figure 8.3 This cross-section of a mammalian heart shows the structure of the four valves. The bicuspid valve is also called the mitral valve because it is shaped like a mitre—the ceremonial headdress worn by high officials of the Roman Catholic church.

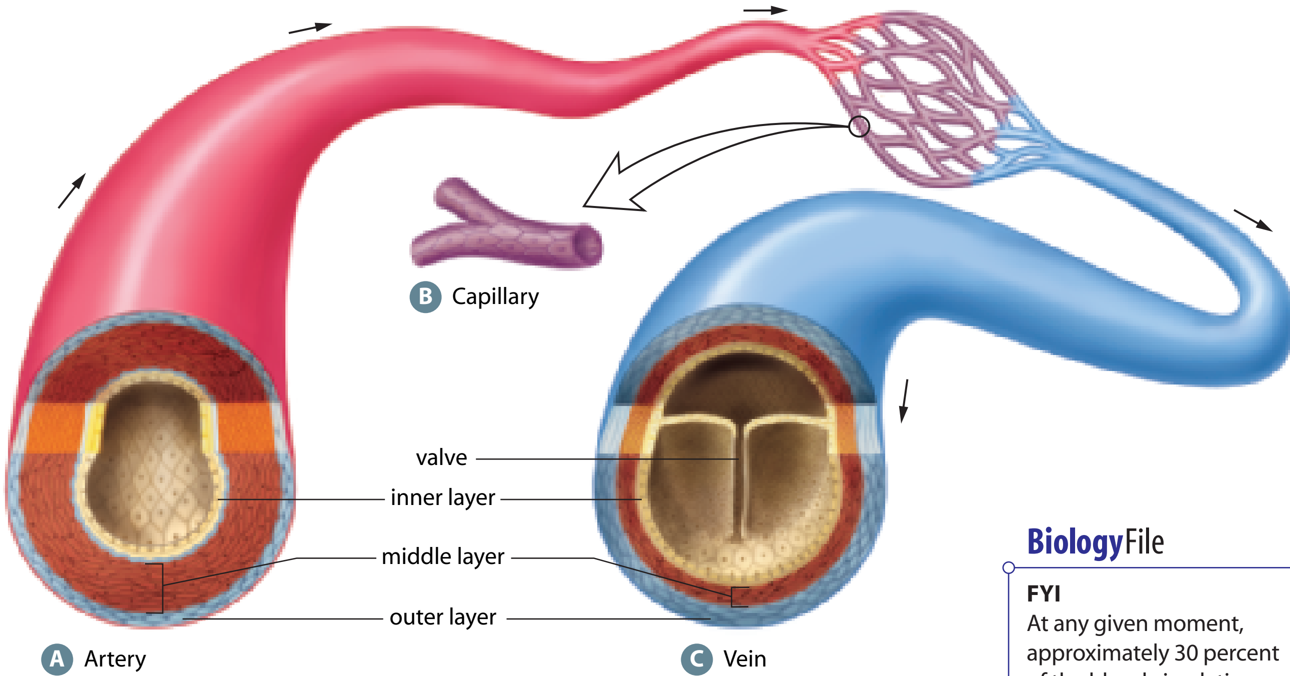

Figure 8.4 Arteries **(A)** and veins **(C)** have three layers. The outer layer is a covering of connective tissue mixed with elastic tissue. The middle layer consists of alternating, circular bands of elastic tissue and smooth muscle tissue. The inner layer is only one cell thick and consists of flat, smooth cells. The shape and texture of these cells serve to reduce friction as blood moves through them. Capillaries **(B)** consist of a single layer that is one cell thick.

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FYI

At any given moment, approximately 30 percent of the blood circulating through your body is found in the arteries, 5 percent is found in the capillaries, and 65 percent is found in the veins.

pumping motion to help force the blood through the blood vessels. When you measure your pulse, what you feel is the rhythmic expansion and contraction of an artery as blood moves through it. Veins have thinner walls than arteries and a larger inner circumference. Veins are not as elastic, and they cannot contract to help move the blood back to the heart. Instead, the contraction of muscles keeps the blood flowing toward the heart (see Figure 8.5). Veins also have one-way valves that prevent the blood from flowing backward. These one-way valves are especially important in your legs because they ensure that the blood flows upward to your heart, against the downward pull of gravity.

Capillaries are the smallest blood vessels—so small that 10 capillaries bundled together would have the diameter of a single human hair. Capillaries are spread throughout the body in a fine network. The capillary wall is a single layer of cells, and the average diameter of a capillary is about 8 μm, which is just large enough for the largest blood cells to pass through in single file (see Figure 8.6). In the next section, you will learn more about the role of capillaries in the exchange of matter and energy.

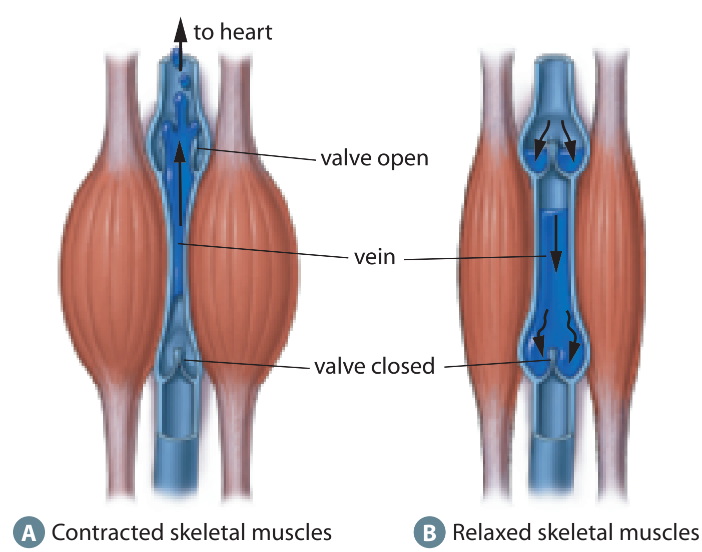

Figure 8.5 Blood is moved through the veins by the contraction and relaxation of muscles. **(A)** The muscles contract and squeeze the vein, pushing blood past the one-way valve. **(B)** The muscles relax, and the blood in the vein begins to flow back briefly. The slight backward flow forces the valve closed and prevents further back flow.

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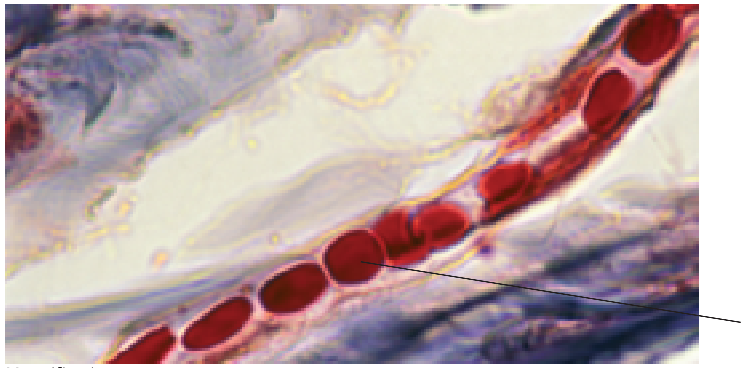
FYI
Sometimes, a one-way valve in a vein becomes weak and does not close completely. When this happens, blood can accumulate below the valve because not all the blood is being squeezed out of that section of the vein. The accumulating blood increases the size of the vein and makes it bulge out, causing a varicose vein.



Magnification: 400 ×

Figure 8.6 Networks of capillaries are present throughout your body. Their diameter is so small that red blood cells can pass through them only one cell at a time.

5. Which blood vessels carry blood away from the heart?
6. Which blood vessels carry blood to the heart?
7. Which blood vessels link the blood vessels you named in questions 5 and 6?
8. Briefly compare the structures of the three types of blood vessels, and explain how the structure of each suits its function.

The Beating Heart

The stimulus that triggers a heartbeat is an electrical signal that originates from within the heart itself. (The rate and strength of a heartbeat is under the control of the nervous system.) A bundle of specialized muscle tissue, called the **sinoatrial (SA) node**, stimulates the muscle cells to contract and relax rhythmically. (The SA node is also referred to as the pacemaker, because it sets the pace for cardiac activity.)

The SA node is located in the wall of the right atrium. It generates an electrical

INVESTIGATION 8.A

Target Skills

Observing and **identifying** external and internal features of a mammalian heart through either a real or virtual dissection

Tracing the direction of blood flow through a mammalian heart

Identifying Structures of the Circulatory System

In this investigation, you will perform a real or virtual dissection to examine the internal structures of the circulatory system. As necessary, refer to the table in Appendix F, Fetal Pig Dissection, to review the anatomical terms used to locate organs or incisions mentioned in the procedure.

Question

What features of a mammalian heart can you identify in a real or virtual heart? What route does blood take through the heart?

Safety Precautions

- Be extremely careful when using dissecting instruments, particularly scalpels. Wherever possible, make cuts away from your body.
- The hearts are preserved in a chemical solution. Wear plastic gloves, safety glasses, and an apron at all times, and work in a well-ventilated area. If some of the chemical comes in contact with your skin, wash it off. At the end of the investigation or class, wash your hands thoroughly.
- Dispose of all materials as instructed by your teacher, and clean your work area.

Materials

- disposable plastic gloves
- dissecting instruments
- apron
- large tongs
- safety glasses
- dissecting tray
- preserved sheep heart (or another mammalian heart)
- plastic bag and tie (to store the heart if necessary)
- newspapers and/or paper towels

Procedure

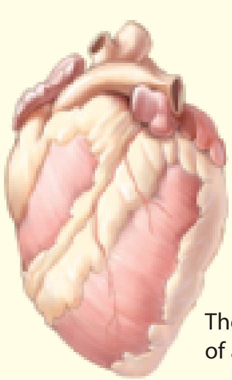
1. Obtain a preserved sheep's heart, and observe its external features. Rinse the heart thoroughly with water. This will remove any excess preservatives. Observe the pericardium, which is the sac surrounding the heart. If it is still attached, remove it. Note the fatty tissue accumulated on the heart. This is usually found along the edges of the heart chambers and surrounding the coronary arteries. Remove as much of the fatty tissue as possible.
2. Identify the apex, or pointed bottom, of the heart.
3. Use the illustrations and Figure 8.2 to help you locate the following structures:
   a) the aorta
   b) the superior vena cava
   c) the pulmonary artery
   d) the pulmonary vein
   e) the inferior vena cava
4. Begin a frontal cut through the heart at the apex, and move toward the base. Open the heart, and identify the chambers on the lower left and right sides. These are the left and right ventricles. There is a thick muscular structure separating the two ventricles. This is the septum. Identify the right and left atria, located above the ventricles. Compare the structures of the different chambers of the heart. Make a labelled drawing, and describe the structures in your own words.
5. The ventricles are separated from the atria above them by the atrioventricular valves. Identify these valves. You should also be able to see strong fibrous strings, called the chordae tendineae. Identify the left atrioventricular valve, which has two flaps or cusps, and the right atrioventricular valve, which has three cusps.
6. Complete a labelled drawing of your specimen, showing the external and internal features of the heart.

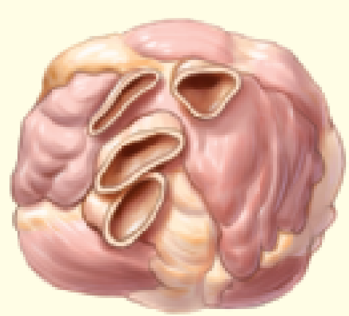
Analysis

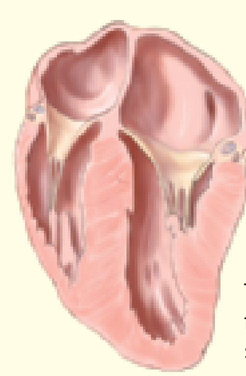
1. Explain how the appearance of the following structures relates to their function as part of the circulatory system. Give as much detail as possible, including size, texture, external structure, and internal structure.
   a) right atrium
   b) left atrium
   c) right ventricle
   d) arteries, including the aorta
   e) left ventricle
   f) veins
   g) heart valves
2. Using your own drawings and your current understanding of the route that blood takes through the body, trace the movement of blood from the tissues through the heart and back to the tissues. Start with the superior and inferior vena cavae.

Conclusions

3. Answer part **(a)** if you performed a real dissection. Answer part **(b)** if you performed a virtual dissection.
   a) In what ways was your understanding of the heart and circulation enhanced by your observation of a real heart?
   b) In what ways was your understanding of the heart and circulation enhanced by your observation of a virtual heart?
4. What experiences did you have that limited your observations or understanding? How could these limitations be overcome?


The external view of a sheep's heart


The large vessels of a sheep's heart


The internal features of a sheep's heart

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FYI

During the past minute, your heart beat approximately 80 times, sending your blood through a complete circuit of your circulatory system three times—a journey of almost 15 km. During the next minute, the same sequence of events will occur, as it will in the minute after that, and in the minute after that. Imagine the power, precision, and sophisticated structure of an organ that is capable of carrying out this sequence of events every minute, 24 hours a day, seven days a week, during your lifetime!

signal that spreads over the two atria and makes them contract simultaneously. As the atria contract, the signal reaches another node called the **atrioventricular (AV) node**. The AV node transmits the electrical signal through a bundle of specialized fibres called the *bundle of His*. These fibres relay the signal through two bundle branches that divide into fast-conducting *Purkinje fibres*, which initiate the almost simultaneous contraction of all cells of the right and left ventricles (Figure 8.7).

The change in voltage produced by the electrical signal can be measured using an electrocardiogram (ECG). This device records the electrical activity of the heart as it contracts and relaxes (see Figure 8.8). In this normal ECG reading, the small voltage increase marked as P shows the electrical activity just before atrial contraction. The large spike at QRS shows the electrical activity just before ventricular contraction. The small spike at T shows the electrical activity as the ventricles recover from their contraction, before the next stimulation by the SA node. The recovery of the atria cannot be measured because it takes place at the same time as when the ventricles contract. Changes in the spacing of these waves, or their total disappearance, can be used to diagnose different heart conditions.

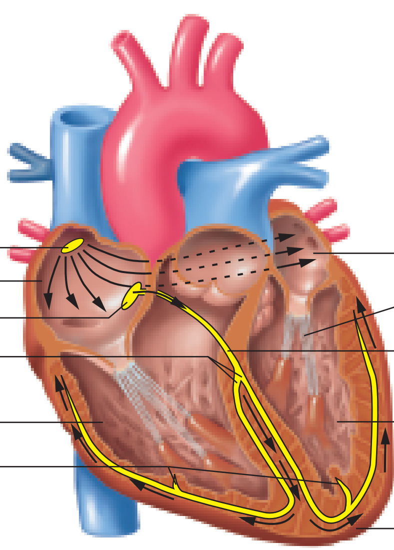

Figure 8.7 The SA node sends out an electrical stimulus that causes the atria to contract. When this stimulus reaches the AV node, it is passed through the bundle of His and the Purkinje fibres. The stimulus causes the ventricles to contract, starting from the apex and then upward, which forces blood toward the pulmonary artery and aorta. The chordae tendinae are strong, fibrous strings that prevent the valves in the heart from inverting when the heart contracts.

Q9 What are the SA and AV nodes, and how are they related to the beating of the heart?

Q10 Explain what an ECG tracing shows.

Blood Pressure

As blood passes through the vessels in the body, it exerts pressure against the vessel walls. This is called **blood pressure**. Changes in blood pressure correspond to the phases of the heartbeat. When the ventricles contract and force blood into the pulmonary arteries and the aorta, the pressure increases in these vessels. The maximum pressure during the ventricular contraction is called the **systolic pressure**. The ventricles then relax and the pressure in the pulmonary arteries and the aorta drops. The lowest pressure before the ventricles contract again is called the **diastolic pressure**.

Blood pressure is usually measured at an artery in the arm. It is recorded in millimetres of mercury, or mmHg (1 mmHg = 0.133 kPa) using a device called a sphygmomanometer (commonly known as a blood pressure cuff). The systolic pressure is presented over the diastolic pressure in the form of a fraction. The blood pressure of an average healthy young person is below 120 mmHg over 80 mmHg, or $\frac{120}{80}$. As the heart rate increases, such as during exercise, the ventricles must push a greater volume of blood per unit of time, so the pressure within the arterial system also increases. Although the diastolic blood pressure in a relaxed ventricle drops to almost 0 mmHg during each heartbeat, the blood pressure in the arteries never drops this low, so blood keeps flowing to the tissues. In Investigation 8.B, you will measure your own blood pressure.

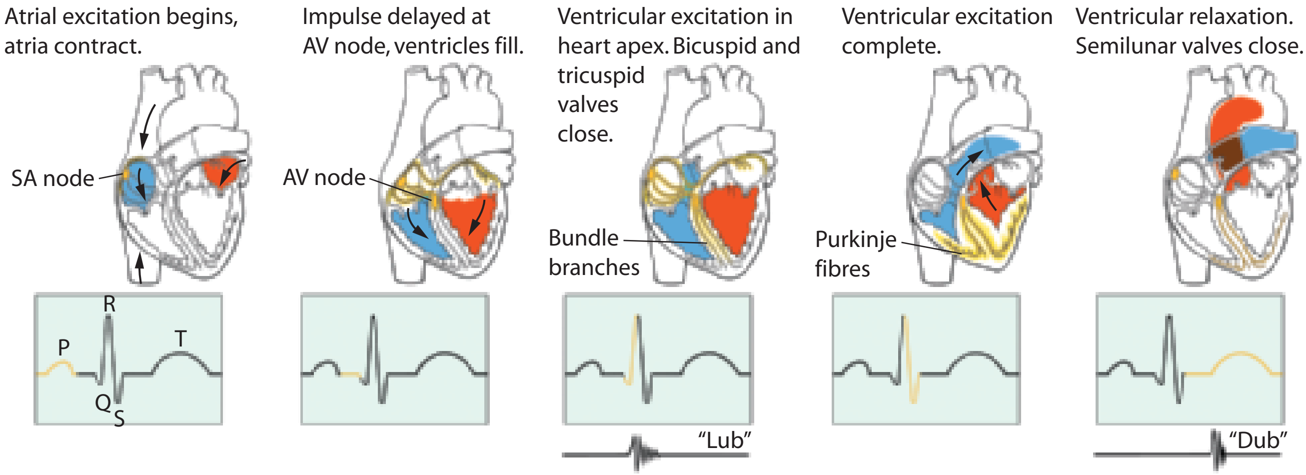

Figure 8.8 An electrocardiogram records the electrical activity measured by an electrocardiograph. The voltage changes are very small, measuring only a few milliVolts. Note the places on the electrocardiogram where the "lub" and "dub" sounds of the heartbeat occur. The closing of the AV valves during ventricle contraction produce the "lub" sounds, and the closing of the semilunar valves during ventricular relaxation causes the "dub" sound.

Q 11 Explain what a blood pressure reading of $\frac{120}{80}$ means.

Cardiac Output and Stroke Volume

The amount of blood pumped by the heart is often referred to as cardiac output and is measured in mL/min. Cardiac output is an indicator of the level of oxygen delivered to the body and the amount of work the body's muscles can perform. Two factors affect cardiac output: heart rate and stroke volume. Heart rate is the number of heartbeats per minute. Stroke volume is the amount of blood forced out of the heart with each heartbeat. Cardiac output = heart rate × stroke volume.

Stroke volume depends on how easily the heart fills with blood and how readily the heart empties again. The former is related to the volume of blood returning to the heart from the veins and the distensibility, or stretchiness, of the ventricles. The latter is related to the strength of the ventricular contraction and the pressure exerted by the artery walls.

The average person has a stroke volume of about 70 mL and a resting heart rate of about 70 beats per minute, for a cardiac output of about 4900 mL/min. Remember that the average person has about 5 L of blood in their body. This means that for the average person, the total volume of blood in the body circulates through the heart about once every minute.

Cardiovascular Fitness

Table 8.1 shows a hypothetical comparison of resting heart rate, stroke volume, and cardiac output for three individuals. For ease of comparison, cardiac output is assumed to be most often average. According to this table, individual C's heart is exceptionally fit, having a very high stroke volume. C can maintain the same level of cardiac output (and oxygen delivery) at a much lower heart rate than the less fit heart of B or the average heart of A. This means that C's heart is working more efficiently than A's and B's. A low resting heart rate is considered an indicator of cardiovascular fitness because it means that stroke volume is high.

Table 8.1 Relationship between stroke volume, heart rate, and cardiac output.

Individual	Resting heart rate (beats/min)	Stroke volume (mL/beat)	Cardiac output (mL/min)
A	70	70	4900
B	98	50	4900
C	35	140	4900

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Web Link
The artificial pacemaker generates electrical signals (also called impulses) to keep the heart beating. Two Canadian surgeons, Wilfred Bigelow and John Callaghan, and a Canadian electrical engineer, Jack Hopps, invented this life-saving device. How did the amputation of frostbitten fingers lead to the invention of the artificial pacemaker? What improvements to this device have been made to its original design?

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FYI

If the arteries, veins, and capillaries of the circulatory system were arranged end to end, they would stretch a distance of approximately 160 000 km. That is nearly four times the circumference of Earth at the equator, or a little more than 40 percent of the distance to the Moon!

Maximum heart rate is the highest heart rate attained during an all-out physical effort. This rate diminishes with age. Maximum heart rate does not appear to be related to cardiovascular fitness, however. The more important cardiovascular fitness indicator is the length of time it takes for the heart to return to its resting heart rate following physical activity. Recovery time diminishes as the heart becomes more fit.

Regular cardiovascular exercise will increase the resting stroke volume of the heart. Cardiovascular exercise enlarges the ventricular chambers, increases the distensibility of the ventricles, and strengthens the ventricle walls. As a result, the heart develops more power to push blood out with each contraction. (Strength training such as weight lifting, on the other hand, may simply increase the thickness of the walls. This may actually limit stroke volume by reducing the elasticity of the ventricles.) A good exercise program should include regular cardiovascular activity.

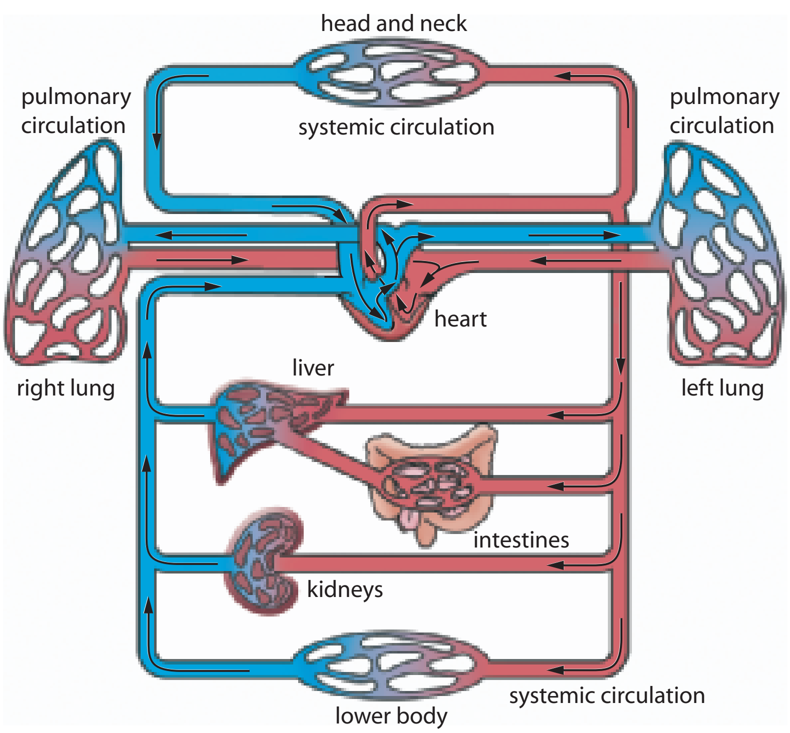


Figure 8.9 Trace the flow of blood through the pulmonary and systemic pathways. Arteries carry blood away from the heart; veins carry blood toward it. Note that in the systemic pathway, arteries carry oxygen-rich blood (red) and veins carry oxygen-poor blood (blue). The reverse is true in the pulmonary pathway: arteries carry oxygen-poor blood and veins carry oxygen-rich blood.

Pathways of the Circulatory System

The blood vessels are organized to carry blood along three different pathways: the pulmonary pathway, systemic pathway, and coronary pathway. As shown in Figure 8.9, the **pulmonary pathway** transports oxygen-poor blood to the lungs. When the blood reaches the lungs, oxygen and carbon dioxide are exchanged by diffusion between the blood in the capillaries and the air in the alveoli of the lungs through the actions of the respiratory system. Oxygen-rich blood returns to the left side of the heart by way of the pulmonary veins. The **systemic pathway** moves the oxygen-rich blood from the left ventricle of the heart to the body tissues. Oxygen and nutrients move into the tissue cells, and waste products move out of the tissue cells into the blood. The **coronary pathway** (see Figure 8.10) is dedicated to provide blood to the muscle tissue of the heart itself.

Tracing Blood Flow through the Pulmonary and Systemic Pathways

Blood flows through the different pathways in the body in a continuous cycle. To follow the route that blood takes, you can start at any point in the system. For example, begin by examining the oxygen-poor blood that is returning to the heart from the body. The oxygen-poor blood enters the pulmonary pathway by first flowing through the vena cavae into the right atrium. When the atria contract, the blood is pumped into the right ventricle. The ventricle contracts and pumps the blood out into the pulmonary trunk, which then divides into the left and right pulmonary arteries. The pulmonary arteries lead to capillaries in the left and right lungs, where the exchange of respiratory gases occurs. The blood simultaneously picks up oxygen from the alveoli in the lungs and gives up carbon dioxide.

The freshly oxygen-enriched blood continues through the capillaries of the lungs into the left and right pulmonary veins, which both enter the left atrium of the heart. The blood is now entering the systemic pathway. When the atria contract again, the left atrium pumps the blood into the left ventricle. All the blood going to the body tissues leaves the left ventricle through the aorta. The aorta divides into several large arteries that supply blood to the body tissues.

Tracing Blood Flow through the Coronary Pathway

The heart does not use the blood inside its chambers to get nutrients and remove wastes. The heart cannot use this blood because the oxygen in the blood cannot effectively diffuse through all the cell layers of the heart. An alternative pathway is needed to serve the functional needs of the heart cells.

The coronary pathway in Figure 8.10 provides matter and energy to the cardiac muscle cells by way of capillaries that are embedded directly in the heart wall. These capillaries receive blood from two coronary arteries that split off from the aorta just as it exits the ventricle, immediately after the semilunar valve. Each artery continues to branch into smaller and smaller vessels, so the entire surface of the heart is covered in a network of tiny blood vessels that encircle the heart like a crown. (The term "coronary" comes from the Latin word for crown, *corona*.) The oxygen-rich blood moves through these vessels into the capillary bed, where gas exchange occurs between the capillaries and the cells of the cardiac tissue. The oxygen-poor blood then flows out, into vessels that get progressively larger, finally forming the coronary veins. The coronary veins join together, and the oxygen-poor blood enters the right ventricle, ready to flow to the lungs to pick up more oxygen.

Q 12 How is systemic circulation different from pulmonary circulation?

Q 13 What is coronary circulation?

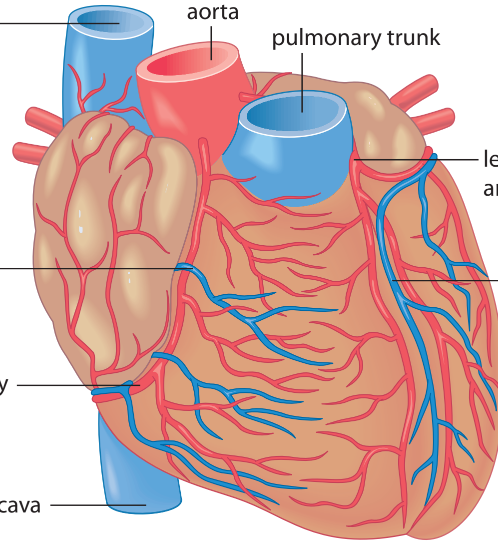


Figure 8.10 Only a few of the many blood vessels that "feed" the heart are shown in this view of the coronary pathway.

Cardiovascular Disorders and Treatments

Cardiovascular disease is the leading cause of death for Canadians. Many of the risk factors associated with cardiovascular disease, such as smoking, obesity, and insufficient exercise, can be reduced or eliminated by lifestyle changes.

Arteriosclerosis is a general term that is used to describe several conditions in which the walls of the arteries thicken and lose some of their elastic properties, thus becoming harder. The most common type of arteriosclerosis is called atherosclerosis. This is a condition in which there is a buildup of plaque (fatty deposits, calcium, and fibrous tissues) on the inside of artery walls (see Figure 8.11). As the artery narrows due to this buildup, blood flow is decreased and blood

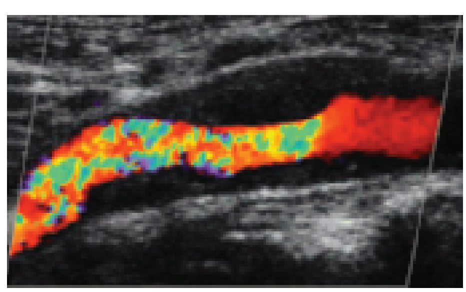


Figure 8.11 An accumulation of plaque can restrict blood flow through the artery. Such buildups are especially dangerous if they occur in arteries of the heart, neck, brain, legs, and kidneys. In this ultrasound scan of blood flow through a neck artery, blood flow is greatest when red and slowest when green.

Biology File

Try This

How long does it take your heart to return to its resting rate? First, find your pulse at your wrist or under your jawbone. Record your pulse for 15 s and multiply this number by 4. This is your resting heart rate. Now, do jumping jacks or another vigorous activity for 1 minute. Immediately measure your pulse again. Continue measuring your pulse at 1-minute intervals until your heart rate returns to its resting rate. Plot these results on a graph of heart rate versus time.

If you have a physical condition that makes it inadvisable to exercise vigorously, try this: after recording your resting heart rate, sit quietly, breathe deeply, and relax your body. After a few minutes check your heart rate to see how much you have lowered your heart rate below its resting rate. See how long it takes to return to normal.

INVESTIGATION 8.B

Target Skills

Designing a procedure to investigate factors that affect heart rate and blood pressure

Measuring blood pressure

Determining a relationship between blood pressure and a factor selected for investigation from patterns and trends in data

Working cooperatively to measure and record blood pressure and another factor selected for investigation

Factors Affecting Heart Rate and Blood Pressure

In this investigation, you will design an experiment to determine how your heart rate and your blood pressure change after exposure to different factors, such as physical activity, different foods, and caffeinated beverages.

Question

How can you isolate factors that affect blood pressure and heart rate?

Hypothesis

Make and record a hypothesis about the effects of at least two different factors on heart rate and blood pressure.

Safety Precautions

Do not over-inflate the blood pressure cuff. Students with circulatory or blood pressure problems should not be test subjects.

Materials

- blood pressure cuff
- watch with a second hand or a digital display of seconds

Experimental Plan

1. Working in a group, prepare a list of ideas for testing your hypothesis, using the materials available in your classroom.
2. Decide on one idea you can use to design an experiment that can be conducted in your classroom.
3. What will be your manipulated variable? What will be your responding variable(s)? What will be your control variable(s)? How many trials will you run? Remember that you should test one variable at a time. Plan to collect quantitative data.
4. Outline, step-by-step, a procedure for your experiment. Assemble the materials you will require.
5. Design a table for collecting your data.
6. Obtain your teacher's approval before starting your experiment.

Data and Observations

7. Conduct your experiment, and record your results. Prepare a graph or chart to help you communicate your findings to other groups in the class.

Analysis

1. What was the resting blood pressure and heart rate for each test subject?
2. How did the blood pressure change as a result of the factor you were testing? How did the heart rate change as a result of the variable you were testing?
3. How long did each change last after termination of the testing factor?

Conclusions

4. Compare your results with the results of other groups in the class. Explain any differences.
5. What is the adaptive advantage of a temporary increase in blood pressure? What is the adaptive advantage of a temporary increase in heart rate?

Extension

6. High blood pressure is a common problem in North America. Fortunately, many different treatments are available. Some examples include treatments used in Western medicine, traditional Aboriginal medicine, traditional Chinese medicine, Ayurvedic medicine, naturopathy, homeopathy, massage therapy, and yoga. Research three different treatments for high blood pressure, and prepare a brief report to compare the main features of these treatments. If someone wanted to receive treatment for high blood pressure, which would you recommend? Justify your choice.
7. If possible, obtain two types of blood pressure cuffs. Newer cuffs give digital readings, while older cuffs require the use of a stethoscope to listen to the sounds of blood moving through the vessels. Use both types of blood pressure cuff to measure a partner's blood pressure. Compare the readings you got, and describe the differences in your experiences with the two cuffs.

pressure is increased. Depending on where the buildup of the plaque occurs in the body, atherosclerosis may lead to angina (chest pain), blood clots, shortness of breath, heart attack, or heart failure. Self-respectful lifestyle choices (such as exercise, not smoking, and eating a diet low in saturated fat and high in fruits and vegetables) contribute to reducing the risk of developing this condition.

Once arteriosclerosis sets in, several treatment options are available. Medicines such as Aspirin™ are able to prevent platelets from sticking together, thus reducing the formation of clots. Special "clot-busting" medicines such as urokinase and t-PA can be used to break down existing clots and improve blood flow. Surgical treatment is also possible. Angioplasty is a procedure in which a surgeon inserts a tube into a clogged artery, as shown in Figure 8.12. When the tube reaches the site where the artery is clogged, a tiny balloon is inflated to force the artery open. Sometimes, a small, permanent metal tube, called a vascular stent, is inserted into the blockage during the procedure. This stent holds the vessel open and reduces the chance of the blockage redeveloping.

Another increasingly common surgical procedure is called a coronary bypass operation. A segment of healthy artery or vein is taken from elsewhere in the body and used to create a new pathway around a blocked vessel near the heart. One end of the new segment is attached to the aorta, and the other end is attached to a point in the blood vessel beyond the blockage to bypass it, as shown in Figure 8.13. The words "double" and "triple" refer to the number of vessels with blockages that must be bypassed.

Some cardiovascular problems are congenital, meaning they are defects in the heart that have been present since birth. Some of the more common congenital heart defects include problems in the walls dividing the chambers of the heart, in the valves, or in the structure of the blood vessels near the heart. A heart murmur is a relatively common heart defect that describes any misflow of blood through the heart, such as one or more of the valves not opening or closing properly. Valve defects can be heard with a stethoscope as a whooshing or rasping sound, which is caused when blood leaks through the valve. Note that these defects may also arise later in life, in which case they are called acquired, not congenital.

The latest technology has been applied to help surgeons successfully repair or reduce the damage caused by congenital

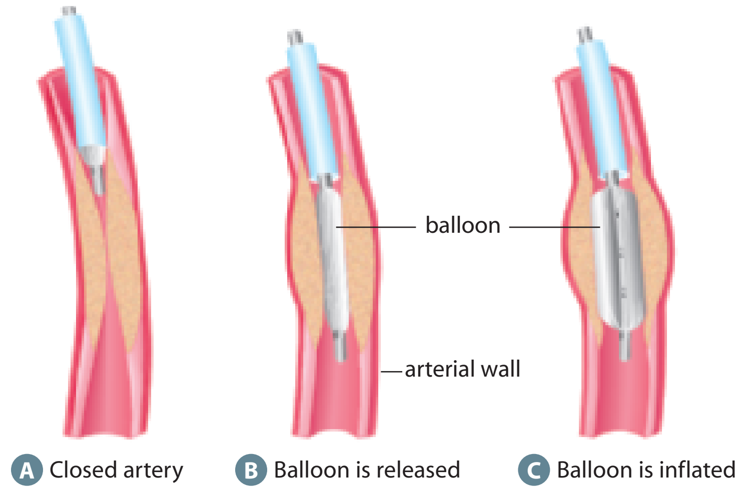


Figure 8.12 An angioplasty: The balloon is inflated to open up the blockage in the artery.

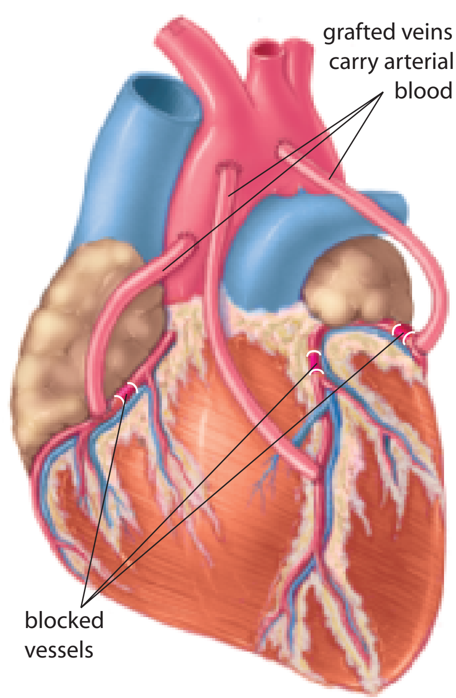


Figure 8.13 Coronary bypass operation: this heart shows a triple bypass, meaning that three new pathways were constructed to avoid blockages in three separate blood vessels.

BiologyFile

FYI

If blood is not kept flowing through the large deep veins of the legs, it can pool and begin to coagulate. The resulting blood clots are called thrombi (sing. thrombus) and result from a number of factors including lack of activity and use of oral contraceptives. Because airline passengers remain inactive on long flights, you may have heard the condition called "economy class syndrome," though its proper name is "deep vein thrombosis." This can be a fatal condition if the thrombus travels to the lungs and blocks the flow of blood there.

heart defects. Digitizing technology can take data from a CT (computed tomography) scan, CAT (computed axial tomography) scan, or MRI (magnetic resonance imaging) scan and create an exact plastic or wax model of a body part, such as a heart (see Figure 8.14). This model allows surgeons to plan and even practise the surgery before performing the surgery on the patient. The Internet allows surgeons from all over the world to input data and create models for their patients.

Thought Lab 8.1 Cardiovascular Health, Technology, and Society

Target Skills

Exploring solutions to problems associated with the circulatory system

Consulting a wide variety of sources that reflect different viewpoints on existing and proposed solutions to problems associated with the circulatory system

Analyzing society's support of solutions to problems associated with the circulatory system

Evaluating the validity of the gathered viewpoints

The heart-lung machine is one of the most significant medical breakthroughs of the twentieth century. During open heart surgery, this machine, shown in the photograph, takes over a person's circulatory and respiratory functions, allowing surgeons to repair or replace valves, perform a heart bypass operation, or perform a heart transplant.

According to statistics compiled by the Canadian Heart and Stroke Foundation, cardiovascular disease is the leading cause of death in Canada, and (combined with stroke) the main cause for hospitalization. Cardiovascular disease is also the most costly disease in Canada, putting the greatest burden on our national health care system. For example, the total cost to the Canadian economy of cardiovascular disease in 1998 was estimated at 18.5 billion dollars. Nearly one-third of that cost was accounted for by hospital care. More startling, perhaps, is the fact that, for many people, cardiovascular disease is preventable.

Procedure

1. Use a variety of print and/or electronic resources to identify the factors that either individually or in combination lead to cardiovascular disease. Summarize how each factor contributes to cardiovascular disease.
2. Identify two technologies that are used or that are being developed to treat cardiovascular disease. What investment of time, people, and money was (or is) required to develop these technologies?
3. Describe how certain lifestyles can predispose an individual to cardiovascular disease.

Analysis

1. Healthcare costs represent a large investment on the part of society. The money to support these costs comes from taxpayers—members of society. Although some people feel that our healthcare dollars can be spent more wisely, many people agree that the development of technologies for treating disease is worth the financial cost. In your opinion, should more money be allocated toward preventing disease or toward treating disease? Justify your response.
2. Why are most heart and cardiovascular problems preventable?
3. What can every Canadian do to reduce the impact of cardiovascular disease on our health care system?

Extension

4. Write a newspaper-style editorial that addresses the question, "Should our health care system continue to pay for individuals who lead a lifestyle that predisposes them to cardiovascular disease?"

The heart-lung machine was invented during a period of approximately 20 years, starting in 1930, by surgeon John Gibbon and his wife Mary Gibbon, a laboratory technician. In 1953, Dr. Gibbon used the machine to perform the first successful open-heart surgery.

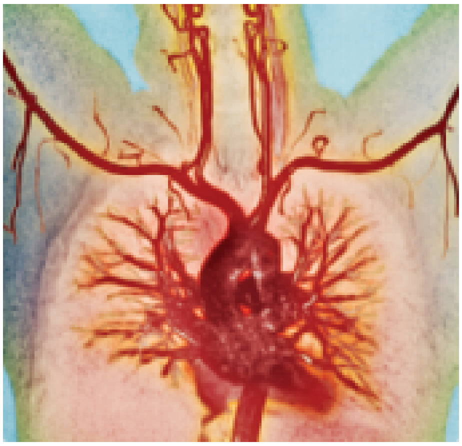


Figure 8.14 Magnetic resonance imaging scans are digitized to make three-dimensional models that help with corrective heart surgery.

Section 8.1 Summary

- The human circulatory system is made up of the heart, blood vessels, and blood.
- The blood delivers nutrients and oxygen to the tissues and removes waste materials from the tissues.
- The heart is a muscular pump with two atria that receive blood and two ventricles that propel blood through the body.
- There are three pathways for blood through the body: the pulmonary pathway, the systemic pathway, and the coronary pathway.
- Arteries, veins, and capillaries are the three main types of blood vessels. In the circulatory and coronary pathways, arteries carry oxygen-rich blood; veins carry oxygen-poor blood. (In the pulmonary pathway, arteries carry oxygen-poor blood and veins carry oxygen-rich blood.) The arteries and veins are joined by the capillaries, where gases, nutrients, and other materials are transferred to tissue cells, and wastes move into the blood.
- The pumping action of the heart is triggered by an electrical signal from the sinoatrial node (pacemaker) in the right atrium.
- Changes in blood pressure correspond to phases in the cardiac cycle.
- Many cardiovascular disorders can be treated with lifestyle changes, medications, and/or surgery.

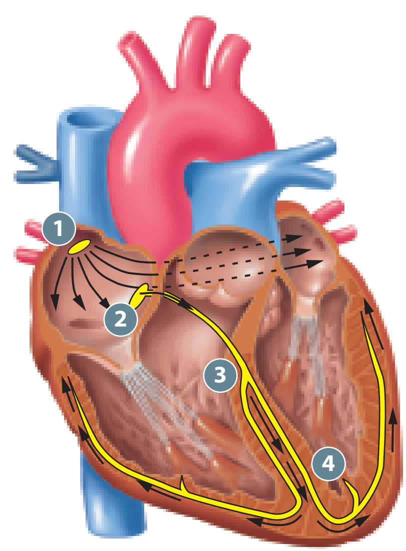
BiologyFile

FYI

Because blood passes through the mammalian heart twice to complete a full circuit, mammals are said to have a double circulatory system with two pumps: one to send blood into the pulmonary pathway and one to send blood into the systemic pathway. Birds and some reptiles also have a double circulatory system, but fish, amphibians, and most reptiles have a single circulatory system. In a single circulatory system, blood goes through the heart only once to complete a circuit, so the heart has only one ventricle.

Section 8.1 Review

1. Use graphics software to sketch a diagram that shows the four chambers of the mammalian heart. Label your diagram, and use arrows to show the route that blood takes through the heart. Use one colour of arrows (such as red) to indicate the flow of oxygen-rich blood and another colour of arrows (such as blue) to indicate the flow of oxygen-poor blood. ICT
2. Describe two structural differences between an artery and a vein.
3. Do all arteries carry oxygen-rich blood and all veins carry oxygen-poor blood? Explain your answer.
4. Arrange the following structures in the order that blood flowing through the coronary pathway encounters them: pulmonary artery, pulmonary vein, aorta, superior vena cava, right atrium, left atrium, right ventricle, left ventricle. Begin with the pulmonary artery.
5. Illustrate, using a flowchart or other graphic organizer, how the "lub" and "dub" sounds of the heart are created. Be sure to include proper labels if you are using a diagram to answer this question.
6. Copy the diagram into your notebook and then label the SA node, the AV node, branches of the atrioventricular bundle, and the Purkinje fibres.



7. Identify two possible causes of high blood pressure. Describe a treatment you could use to lower your blood pressure if it were too high.

Blood and Circulation

Section Outcomes

In this section, you will
- **describe** the main components of blood
- **perform** a microscopic analysis of blood
- **explain** the role of blood in regulating body temperature
- **explain** the role of the circulatory system, at the capillary level, in the exchange of matter and energy
- **identify** certain blood disorders and the technologies used to treat them

Key Terms

plasma
formed portion
red blood cells
erythrocytes
hemoglobin
white blood cells
leucocytes
platelets
vasodilation
vasoconstriction
interstitial fluid
hemophilia
leukemia

Blood is sometimes called a connective tissue because it plays a role in linking all the cells and organs in the body. It is considered to be a tissue even though (unlike most of the body tissues) it appears to be a fluid. In fact, blood consists of two distinct elements: a fluid portion and a solid portion. The fluid portion is called **plasma**, and it consists of water plus dissolved gases, proteins, sugars, vitamins, minerals, hormones, and waste products. Plasma makes up about 55 percent of the blood volume. The solid portion of the blood is called the **formed portion**. It consists of red blood cells, white blood cells, and platelets. These cells and platelets are produced in the bone marrow, which is found inside the bones. The formed portion makes up the other 45 percent of the blood volume, as shown in Figure 8.15.

The Formed Portion of Blood

Table 8.2 compares the features of the main components in the formed portion of human blood. Note the differences in the form and function of these cells, even though they all belong to the same tissue.

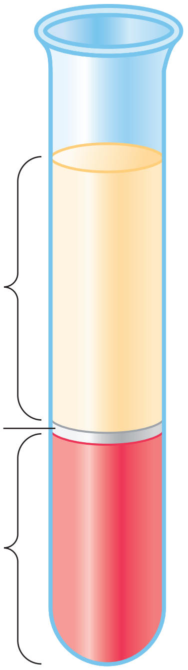


Figure 8.15 The three main components of blood can be separated using a special medical device called a blood centrifuge. When the blood is separated, it briefly settles into layers, as shown here.

Red Blood Cells

Red blood cells, also called **erythrocytes**, make up approximately 44 percent of the total volume of blood. ("Erythroctye" comes from two Greek words that mean "red" and "cell.") Red blood cells are specialized for oxygen transport. The oxygen-carrying capacity of the blood is dependent on the number of erythrocytes that are present and the amount of hemoglobin that each red blood cell contains (see Figure 8.16).

A mature red mammalian blood cell has no nucleus. Instead, each disk-shaped red blood cell is packed with about 280 million iron-containing molecules of the respiratory pigment **hemoglobin**. Hemoglobin allows large quantities of oxygen to be transported in the blood because it has special properties that allow it to pick up, or chemically bind with, oxygen. Hemoglobin then releases the oxygen, by the process of diffusion, in the presence of cells that require it. Recall that hemoglobin also transports some of the carbon dioxide waste from cells. After carbon dioxide diffuses into the blood, it enters the red blood cells, where a small amount is taken up by hemoglobin.

A condition called anemia occurs if there are too few red blood cells or too little hemoglobin inside the red blood cells in the bloodstream. Either of these

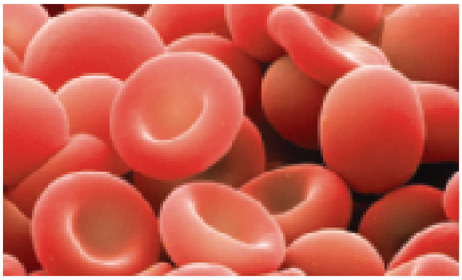
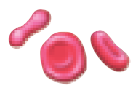
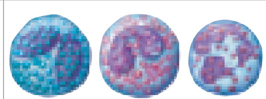
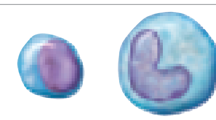


Figure 8.16 A mammalian red blood cell, also known as an erythrocyte, is a biconcave disk. Because the respiratory pigment hemoglobin reflects red wavelengths of light, oxygenated red blood cells appear to be a bright red colour. As oxygen is released, the colour that is reflected is a darker blue-red.

Table 8.2 The Cellular Components of Blood

Point of Comparison	Red blood cells	White blood cells: Granulocytes and monocytes	White blood cells: Lymphocytes	Platelets
Origin	red bone marrow	red bone marrow	thymus, red bone marrow	red bone marrow, lungs
Cells present per mm^3 of blood (approximate)	5 500 000 (male) 4 500 000 (female)	6000	2000	250 000
Relative size	small (8 μm diameter)	largest (up to 25 μm)	large (10 μm)	smallest (2 μm)
Function	to carry oxygen and carbon dioxide to and from cells	to engulf foreign particles	to play a role in the formation of antibodies (defence function)	to play a role in the clotting of blood (defence function)
Life span	120 days	a few hours to a few days	unknown	2–8 days
Appearance				

deficiencies will reduce the amount of oxygen that is flowing through the body. A person who has anemia may appear pale and usually experiences fatigue. Anemia may be caused by a dietary deficiency of iron, a key component of hemoglobin.

White Blood Cells

White blood cells, also called **leucocytes**, are part of the body's response to infection. Leucocytes make up about one percent of your total blood volume but may increase to more than double normal levels when your body is fighting an infection. All white blood cells have nuclei and appear to be colourless.

Leucocytes can be divided into three groups: granulocytes, monocytes, and lymphocytes. Granulocytes consist of neutrophils, basophils, and eosinophils; monocytes can leave the bloodstream and become further specialized as macrophages, which destroy bacteria. Granulocytes and monocytes, typically found in circulating blood, engulf and destroy foreign bodies, as shown in Figure 8.17. Some lymphocytes produce proteins (called antibodies) that incapacitate pathogens and allow them to be easily detected and destroyed. The next investigation introduces the different types of white blood cells. The body's defence system is discussed in greater detail in Section 8.3.

Platelets

Platelets are the third major substance in the formed portion of the blood. **Platelets** are fragments of cells that form when larger cells in the bone marrow break apart. These fragments contain no nucleus and break down quickly in the blood.

Platelets play a key role in clotting blood, which prevents excessive blood loss after an injury. Many (but not yet all) of the stages of clotting have been determined.

- Injury to a blood vessel starts a cascade of cellular events.
- Substances released by the broken blood vessel attract platelets to the site.
- The collecting platelets rupture and release chemicals that combine with other blood components to produce an enzyme called thromboplastin.

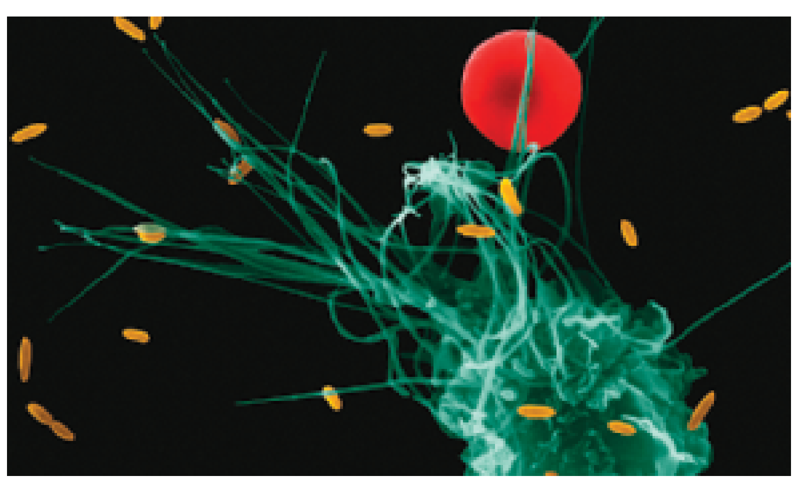
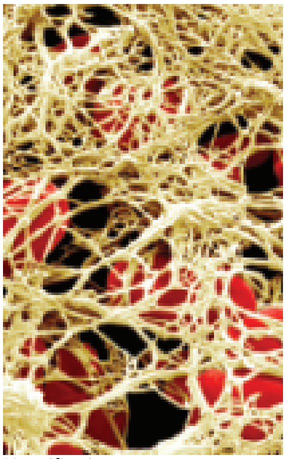


Figure 8.17 A leucocyte, or white blood cell, attacking *Escherichia coli (E. coli)* bacteria. A single red blood cell is also visible.



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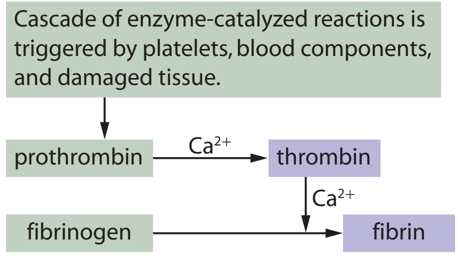


Figure 8.18 Fibrin threads wind around the platelet plug in the damaged area of a blood vessel, providing the framework for a clot. Trapped red blood cells make the clot appear red.

- As long as there are calcium ions (Ca^{2+}) present, thromboplastin will react with prothrombin (a plasma protein produced by the liver) to produce thrombin.
- Thrombin is an enzyme that reacts with fibrinogen (another plasma protein) to produce fibrin.

Fibrin is an insoluble material that forms a mesh of strands around the injured area. This mesh traps escaping blood cells and forms the clot.

Q 14 How could you demonstrate that blood is a mixture?

Q 15 How does the structure and number of red blood cells compare with the structure and number of white blood cells?

Q 16 What are platelets?

Plasma

Plasma, the fluid portion of the blood, is the medium in which the blood cells are suspended. In addition to carrying all the blood cells, plasma contains other substances, as shown in Table 8.3. Plasma also plays a role in the transport of carbon dioxide in the blood. Unlike oxygen, which is transported in the blood by the hemoglobin inside cells, carbon dioxide dissolves in the water portion of the blood and forms carbonic acid inside the cytoplasm of the red blood cells. It diffuses out of the red blood cells, into the plasma, as bicarbonate ions and is carried from tissues to the lungs for gas exchange.

BiologyFile

FYI

The diameter of fibrin is about 1000 times smaller than that of a human hair. And yet fibrin is extremely strong and pliable. In 2006, researchers at the University of North Carolina discovered that fibrin fibres can be stretched to more than six times their length before they break—a property that surpasses that of spider silk.

The Functions of Blood

The functions of blood include serving as a medium for transporting materials in the body and regulating the concentration of substances and heat in the body.

Transport

One of the primary functions of blood is to transport materials throughout the body. As blood circulates around the body, it provides an ideal pathway for the distribution of materials and energy.

Blood is closely connected to the body systems that are responsible for digestion and for the action of hormones. For example, blood in capillaries in the walls of the small intestine absorb many of the nutrients that are end products of digestion. Blood also absorbs nutrients that are synthesized by cells in parts of the body other than the digestive tract. These nutrients, which include glucose and amino acids, are carried to the liver, where they are converted into storage products or prepared for transport to other parts of the body. As well, blood picks up chemicals and gases through the respiratory system and carries them throughout the body to where they are needed.

In another key transport role, blood transports and removes the waste products of cellular processes. Uric acid, the end products of protein metabolism, excess amounts of various mineral ions,

Table 8.3 The composition of plasma

Constituent	Percentage
Water	∽ 92%
Blood proteins Fibrinogen Serum albumin Serum globulin	∽ 7%
Other organic substances Non-protein nitrogen (urea) Organic nutrients	∽ 0.1%
Inorganic ions: calcium, chlorine, magnesium, potassium, sodium, bicarbonates, carbonates, phosphates	∽ 0.9%

INVESTIGATION 8.C

Identifying Blood Cells

Target Skills

Determining, through microscopic inspection, the shape and abundance of the different cells in a prepared slide of human blood

Compiling and **displaying** information about the cells in human blood

The different types of blood cells have different forms and functions. This investigation will enable you to examine these differences by looking at blood through a microscope.

Question

What characteristics of blood cells can you use to help you describe and compare them?

Safety Precautions

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

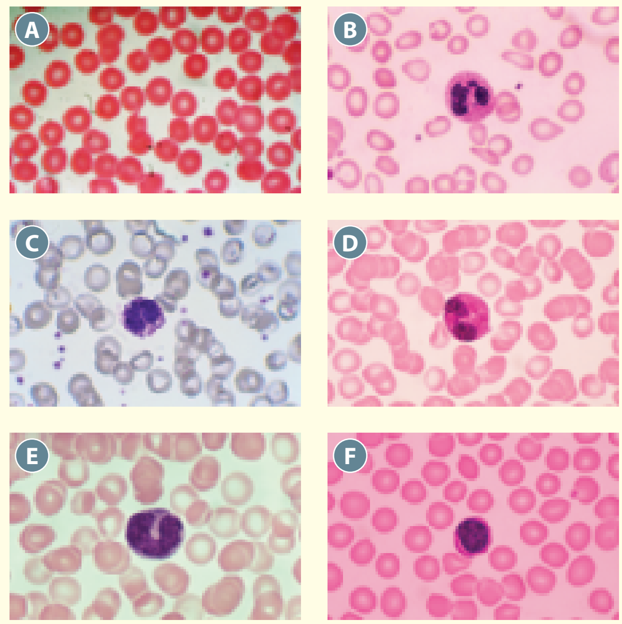
Materials

- light microscope
- prepared slides of human blood

Procedure

1. Place the slide of blood on the microscope stage, and focus using the low-power lens.
2. Scan the slide to find an area where you can observe individual blood cells.
3. Rotate the lens to medium power, and focus on the visible cells. Then rotate the lens to high power. Focus again on the visible cells. Note the differences between the red blood cells and the white blood cells.
4. Use the photographs to help you identify the cells you are observing.
5. Make a drawing of each type of cell. Label the cell membrane, the cytoplasm, and the nucleus (where applicable) of each cell, and estimate the size of the cell.
6. Repeat steps 1 to 5 until you have identified the types of blood cells shown in the photographs.
7. Summarize your observations using a table like the one below.

Formed element	Approximate number in one visual field	Approximate size (mm)	Appearance	Sketch



(A) Red blood cells **(B)** Neutrophil **(C)** Basophil **(D)** Eosinophil **(E)** Monocyte **(F)** Lymphocyte. Cells **(B)**–**(F)** are white blood cells among red blood cells. All images magnified 400 ×.

Analysis

1. The red blood cells of mammals do not have a nucleus, whereas the white blood cells do have a nucleus. Suggest one possible reason for this difference.
2. Were you able to observe any platelets? If yes, describe them and add the information to your table. If no, explain why you might not have seen any.

Conclusions

3. Which characteristics did you find most useful in helping you distinguish among the different blood cells?
4. **a)** Based on the blood samples you examined, how does the abundance of red blood cells compare with the abundance of the different white blood cells you observed?

   b) Compare your answer to part (a) with the data in Table 8.2 on page 283. What additional information or procedures would help you make more accurate estimates of the cells in human blood?

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Many serious athletes choose to train at high altitudes, where the air is thinner and the partial pressure of oxygen is lower. What benefit does this provide for athletes? There are several technological methods for achieving the same benefit. What are they, how do they affect the body, and why are they illegal?

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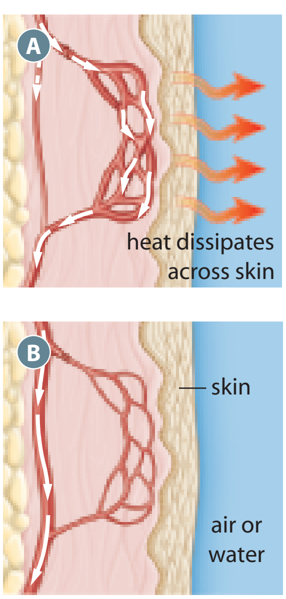


Figure 8.19 Vasodilation **(A)** and vasoconstriction **(B)**

and other waste products are carried by the blood to the kidneys for processing and excretion. Carbon dioxide is another waste product of cells that is carried by the blood to be released at the lungs.

In addition, blood serves as a medium for conveying chemical messengers, or hormones, from their origins in various glands to the organs on which they act. Hormones play a central role in regulating and coordinating the internal systems of the body. Without the bloodstream to serve as a pathway for hormones, the body would be unable to respond effectively to fluctuations in its external or internal environment, and the finely-balanced mechanisms that keep the many different components of the body functioning together would quickly break down.

Homeostatic Regulation

Another important function of blood is to maintain homeostasis within the body, especially in relation to temperature regulation. Temperature regulation involves balancing heat production with heat loss. Blood coming to the skin from the interior of the body is usually warmer than the skin. As more blood passes by the skin, more heat is lost from the body. Just as the rate of diffusion is affected by the concentration gradient, the rate of heat loss is affected by the heat gradient—the difference in temperature between the skin and the external environment. The greater the heat gradient is, the faster heat is lost through the body surface.

When the body's internal environment becomes too warm, the body must be able to rid itself of heat in order to maintain a constant internal temperature. Blood transports heat from where it is formed by cellular respiration and muscular activity to the blood vessels in the skin. Under the control of the nervous system, these vessels dilate to increase the amount of blood flowing and, therefore, to increase the amount of heat that can be lost from the skin. This process is called **vasodilation** (see Figure 8.19A). There are several mechanisms for the release of heat, including the evaporation of water in sweat. Dehydration can be a serious problem if the body needs to rid itself of excessive heat through perspiring, for example, during a fever.

When the external environment is cold, body heat is conserved by **vasoconstriction**—the constriction of the blood vessels near the surface of the skin (see Figure 8.19B). This reduces the amount of heat that is dissipated from the skin. At the same time, waves of muscle contraction, called shivering, increase the production of heat by cellular metabolism. The heat that is produced is spread through the body by the blood.

Vasoconstriction and vasodilation are controlled by a number of factors. In some cases, they may be triggered by the brain in response to changes in blood pressure. If the blood pressure is too high, vasodilation will reduce it. If the blood pressure is too low, vasoconstriction will increase it. Vasodilation and vasoconstriction may also be triggered by increased metabolic activity. Exercise, for example, results in vasodilation to increase the blood flow to the tissues.

Some substances can interfere with the body's internal temperature regulation mechanisms by promoting either vasodilation or vasoconstriction. Alcohol and nicotine, for example, promote vasodilation and cause blood to rush to the surface of the skin.

Under normal conditions, a countercurrent heat exchange system helps to maintain a steady temperature in the core of the body. This system works because the deep arteries and veins entering and leaving the body's extremities lie adjacent to one another, so the warmer blood that flows from the body core to the extremities exchanges heat with the cooler blood returning from the extremities to the body core. Blood returning from the extremities can flow either through a surface vein

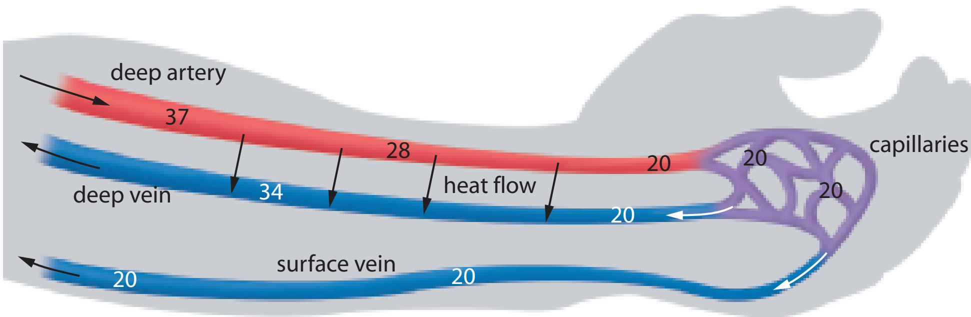


Figure 8.20 The countercurrent heat exchange mechanism between the blood vessels in the human arm: The deep vein and artery are adjacent to one another, so heat is exchanged from one to the other. As a result, arterial blood is cooled as it nears the hand, and venous blood is warmed as it leaves the hand and returns to the body core. When heat conservation is important, more blood returns to the heart through the deep vein. In higher-temperature conditions, when heat conservation is not a concern, more blood returns through the surface vein. Numerals indicate the temperature of the blood in degrees Celsius.

or through a deep vein. Figure 8.20 illustrates how the countercurrent exchange mechanism works to regulate the temperature in your arm. Keep in mind that the extremities and the skin are not kept at 37 °C. The temperature of these parts of the body may be significantly below the internal core temperature.

17 How does blood link the circulatory system with other body systems?

18 Name three factors that can trigger vasoconstriction or vasodilation.

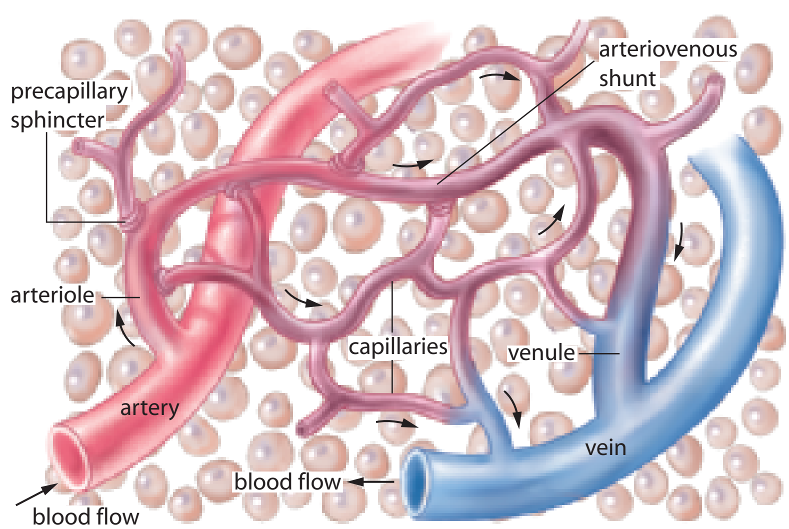
Circulation and the Action of Capillaries

The proper functioning of all the body cells depends on capillaries because they are the only vessels that are thin enough for the exchange of matter by diffusion. Tissue cells need to be supplied with oxygen and nutrients, and they need to release the carbon dioxide and waste materials that have accumulated during cell processes. In fact, the prime function of the circulatory system is to deliver blood to the capillaries that lie close to the cells, thus supplying the cells with energy and nutrients and removing their metabolic waste products.

Capillaries are present in networks, or beds, throughout the body, and most of the cells in the body are located beside capillaries. There are about one billion capillaries in the human body, with a total surface area of approximately 6300 m^2. This is nearly the area of a football field!

Figure 8.21 shows the anatomy of a capillary bed. A capillary bed is formed by many capillary vessels lying between a branch of an artery and a branch of a vein. The blood flow through a capillary bed is not necessarily constant. If the cells beside a particular capillary bed do not need to be serviced, blood can be shunted directly from the artery to the vein, bypassing the capillaries through the action of sphincters that tighten and close the opening. Blood also bypasses

Figure 8.21 Anatomy of a capillary bed: The cells that make up living tissues are a distance of one to three cell-widths from a capillary. Why must cells lie so closely to capillaries?



some capillary beds when it is needed in some other part of the body. After eating, for example, the capillaries of the digestive system are open, but the capillaries that supply blood to certain muscles are closed. This is one reason that exercising after eating is so difficult.

The cells of the body are constantly bathed in a liquid called **interstitial fluid**. (In some books, this fluid is called extracellular fluid or tissue fluid.) Any material exchanged between the capillaries and the cells must pass through the interstitial fluid.

Capillaries have an arterial end, a mid-section, and a venous end, as shown in Figure 8.22. When blood enters a capillary at the arterial end, it appears to be bright red because the hemoglobin in the red blood cells is rich in oxygen. The diffusion of materials, including the oxygen attached to the hemoglobin in red blood cells and the nutrients suspended in the blood's plasma, takes place along the mid-section of a capillary. The direction of diffusion is determined by a material's concentration gradient. For example, nutrients and oxygen are higher in concentration in the blood, so they diffuse into the interstitial fluid toward the cells. Carbon dioxide and other wastes are higher in concentration in the interstitial fluid, so they diffuse out of the cells through the interstitial fluid and into the capillaries.

The blood flow through the capillaries is slower than through any other part of the circulatory system, thus providing time for diffusion to occur.

The blood pressure in the capillary beds is lower than in the arteries but a little higher than in the veins, ensuring that the blood continues to flow in one direction from arteries to veins. The blood pressure decreases the farther away the blood is from the heart, which is why the blood pressure in the veins is lower that the blood pressure in the capillaries. Recall that muscle action and valves keep the slow-moving blood flowing in the correct direction in the veins.

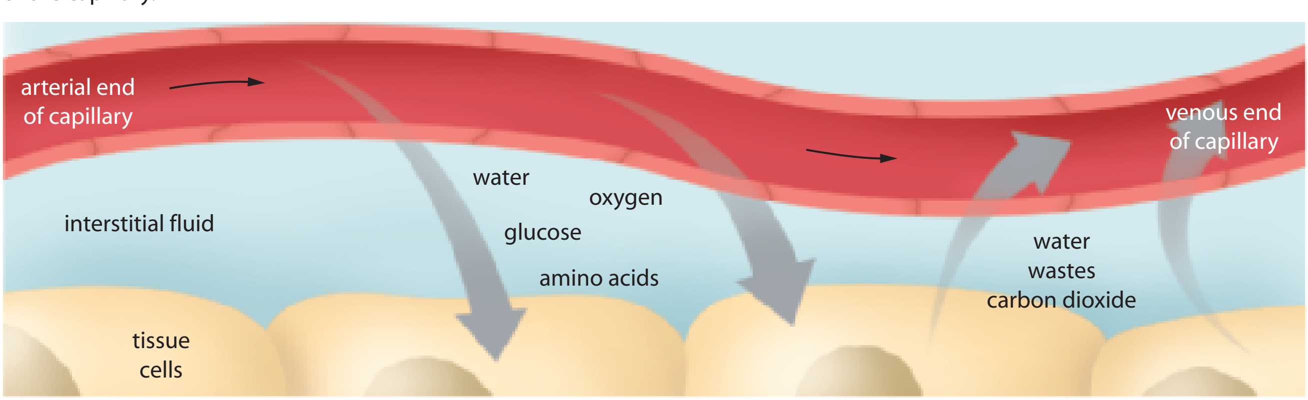
19 What is interstitial fluid?

20 What role do capillaries play in maintaining homeostasis, in relation to gases, nutrients, and fluids?

Blood Disorders

There are several relatively common blood disorders. One of these disorders, an inherited, life-threatening disorder called **hemophilia**, is the result of insufficient clotting proteins in the blood. Severe hemophilia occurs when there is less than 1 percent of the clotting protein in the blood. Approximately 70 percent of people with hemophilia have this severe form, and they are in constant danger of bleeding to death if they injure themselves. People with hemophilia are treated with injections of a substance called Factor VIII, which is a protein involved in coagulation that is missing from their blood.

Figure 8.22 The exchange of materials between the blood in a capillary and the fluid surrounding the individual cells in the body takes place across the wall of the capillary.



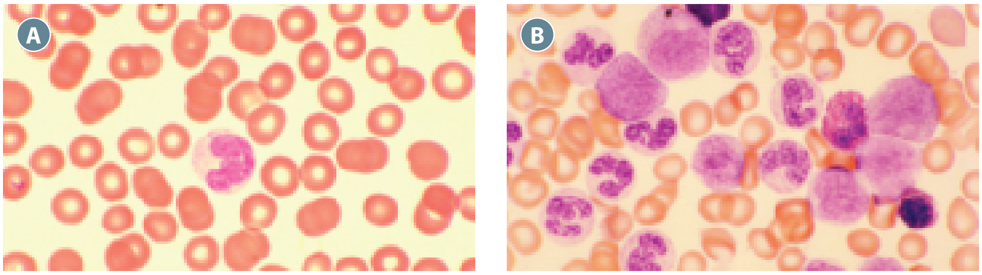


Figure 8.23 Normal blood cells **(A)** and blood cells from a person with myeloid leukemia **(B)**. Notice the relative numbers of white blood cells to red blood cells.

Leukemia is a cancer of the white blood cells. There are two main types of leukemia: myeloid and lymphoid. Myeloid leukemia is characterized by the presence of too many leucocytes. These leucocytes are immature and unable to fight infection. As well, they crowd out the red blood cells, which causes anemia and fatigue (see Figure 8.23). Lymphoid leukemia is a cancer of the lymphocytes, but the symptoms are very similar to those of myeloid leukemia. Both of these leukemias can occur in one of two states: acute or chronic. The symptoms of acute leukemia appear suddenly, and death follows quickly. Chronic leukemia may go undetected for months or years.

Thought Lab 8.2 Keeping the Blood Supply Safe

Target Skills

Identifying and **evaluating** possible solutions to blood shortages

Investigating the roles and responsibilities of governments, medical organizations, and members of society in making decisions regarding the application of scientific and technological developments

The earliest successful blood transfusions from person to person were done in the mid-1800s. Scientists discovered how to preserve and store blood in the 1910s, and blood banks became part of the medical scene, enabling physicians to save many more lives. While the technology to preserve and store blood ensured availability in times of need, other challenges in blood bank management have arisen. A key one is ensuring that the blood supply is not only plentiful but is also safe.

Canadian Blood Services has been managing Canada's blood supply since 1998, after Canada's tainted blood scandal of the 1980s. Prior to the creation of Canadian Blood Services, the Canadian Red Cross was in charge of Canada's blood supply. During the years of the scandal, blood donations were not screened for HIV and hepatitis C viruses despite officials' knowledge that these life-threatening viruses could be present in the blood supply system. Contaminated blood was used in transfusions, and hundreds of Canadians received it. Many developed AIDs, while others suffered liver damage from hepatitis C. A $150 million compensation package was eventually negotiated for 1200 victims of the tainted blood.

In this assignment, you will research blood transfusions. Based on your research, you will prepare a document or design a presentation describing society's interests and roles in the blood supply system and identify possible technological solutions to blood safety and blood shortages.

Procedure

1. Use print and/or electronic resources to research answers to the Analysis questions below. ICT
2. Summarize, in the form of a report or multimedia presentation, the results of your research. Include an explanation of the importance of blood transfusions and identify possible technological solutions to problems of blood supply and blood supply safety.

Analysis

1. Why is it considered important for members of society to donate blood on a regular basis? Do all members of society share this view? Explain.
2. Who can and who cannot donate blood?
3. What blood products are isolated from donated blood and how are each of these products used?
4. What are five common misconceptions that people have about donating blood?
5. Identify technologies that are being developed that one day might replace the need for people to donate blood.

Extension

6. Visit the web site for Canadian Blood Services and identify the procedures in place to safeguard Canada's blood supply. Do you think they are adequate for another blood-borne infection, such as West Nile? Justify your answer. ICT
7. Should the government and the public be involved in the management of Canada's blood supply or should its management be privatized? Choose a position and present your arguments in support of it.

The Tomorrow Project

Although research into the causes of cancer at the cellular level is continuing, scientists now know that at least 50 percent of human cancers can be attributed to environmental or behavioural factors. Launched in October 2000 by the Alberta Cancer Board, the Tomorrow Project is a long-term cancer study that aims to determine how individual lifestyle can affect a person's chances of developing the disease.

Strength in Numbers

The research team at the Tom Baker Cancer Centre in Calgary believes in big numbers—50 000 to be exact. That is the number of Albertans that the team intends to recruit to take part in the Tomorrow Project. The goal is to assemble a random sample of Albertans who are between the ages of 35 and 69 at the time of enrolment and who have never been diagnosed with cancer. Participants fill out surveys about their health and lifestyle, diet, and physical activity. Some participants are also asked to provide blood samples, allowing researchers to study genetic-environmental interactions. The project will continue to collect health and lifestyle information from participants every few years until age 85 or death.

In the surveys, participants answer a variety of questions about their family medical history, stress level, favourite foods, body measurements, and spirituality, as well as whether or not they smoke or are exposed to second-hand smoke. The researchers are looking at risk factors that are thought to influence the incidence of cancer. Different types of cancer can have different risk factors. For example, a high body mass index (BMI) is considered to be a specific risk factor that may increase a person's chance of developing endometrial, kidney, colon, or postmenopausal breast cancer.

The Day after Tomorrow

Cancer exacts a heavy toll on Canadian society. In April 2005, the Canadian Cancer Society estimated that 149 000 new cases of cancer and 69 500 deaths from cancer will occur in Canada in 2005. If the current trend continues, the Cancer Society estimates that during the next 30 years, 5.7 million Canadians will develop cancer and 2.7 million Canadians will die of the disease.

Why do some people remain healthy, while others develop cancer? The results of the Tomorrow Project will not be known for many years to come. By tracking the lifestyle choices of a large sample of people over a long period of time, however, researchers hope that they will eventually learn more about risk factors that could be modified to decrease the incidence of cancer.

• • •

1. What is the current status of the Tomorrow Project? Elect one student to contact the Tomorrow Project headquarters in Calgary to find out information and then share it with the class. This person could also share information that is available on the project's web site. ICT

2. What type of cancer is the leading cause of premature death due to cancer for both men and women in Canada? What are the modifiable risk factors associated with this type of cancer?

Treatment of leukemia includes blood transfusions to increase the number of red blood cells and healthy white blood cells, and chemotherapy. Advances in chemotherapy have vastly improved survival rates, particularly for children. About 20 years ago, children diagnosed with leukemia had less than a 50 percent chance of survival. The survival rate is now greater than 85 percent. Another possible treatment is bone marrow transplants, which provide healthy marrow from which new, healthy white blood cells can grow. (Blood cells are formed in the bone marrow, which is the soft tissue of large bones in the body.) Bone marrow transplants are very invasive and painful, however, so they are usually considered as a last resort.

Section 8.2 Summary

- Blood is a tissue that is made up of a fluid portion (called plasma) and a formed (or cellular) portion.
- The fluid portion of the blood, plasma, is made up of water, blood proteins, other organic substances and inorganic ions. Water is the most significant component.
- The formed portion is made up of different types of cells, including red blood cells (erythrocytes), white blood cells (leucocytes), and platelets.
- Red blood cells transport oxygen, white blood cells are a key component of the body's defence system, and platelets are needed for clotting.
- Blood has various roles in the body, including transportation of materials and temperature regulation.
- Gases and other materials diffuse into and out of the blood through capillaries.
- There are various disorders of the blood. Advances in treatments and ongoing research in new areas, such as stem cell research, are improving the chances that people with blood disorders will have a full recovery.

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Advances in the treatment of leukemia include the use of blood from umbilical cords and the transplanting of stem cells. Stem cells are cells from which specialized cells of the body develop. How do these two treatment options work? What are the controversies associated with them?

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Section 8.2 Review

1. Use a word processor or spreadsheet software to create a chart similar to the one shown below. Use this chart to summarize the cellular components of blood. ICT

Point of Comparison	Red blood cells	White blood cells		Platelets
		Leucocytes	Lymphocytes	
Origin				
Cells present per mm^3 of blood				
Relative size				
Function				
Life span				
Appearance				

2. Identify seven substances normally found in blood plasma.
3. In your own words, explain the role the blood and circulatory system play in the following systems
   a) digestive system
   b) endocrine system
   c) respiratory system
   d) excretory system
4. Use graphics software to create a drawing that clearly illustrates which types of matter are exchanged between the capillaries and the cells. Label the forces that act and the direction of these forces. ICT
5. The hematocrit refers to the percentage of an individual's red blood cells. A small blood sample is placed in a special hematocrit tube. Blood can be separated into its components by putting it into a centrifuge and "spinning it down." When the centrifuge spins, the red blood cells are forced to the bottom of the tube because they are the heaviest element in the blood. A decreased hematocrit can be the result of a low number of red blood cells, decreased volume of red blood cells, or reduced hemoglobin concentration.
   a) Identify one blood disorder that may be indicative of a decreased hematocrit, and list the physical symptoms that are usually associated with this disorder.
   b) Use word processing software to create a flow chart summarizing the steps in the blood clotting mechanism. ICT

SECTION
8.3

The Lymphatic System and Immunity

Section Outcomes

In this section, you will
- **describe** and **explain** the function of the lymphatic system
- **identify** and **list** the main cellular and non-cellular components of the human defence system
- **describe** the role of the cellular and non-cellular components of the human defence system

Key Terms

lymphatic circulatory system
lymph
non-specific defences
cell-mediated immunity
phagocytosis
macrophages
immunity
specific defences
antibody-mediated immunity
antibodies
lymphocytes
B cells
T cells
antigens
helper T cells
killer T cells
suppressor T cells
memory T cells
ABO system
Rh factor

As you have seen, the circulatory system transports nutrients, respiratory gases (oxygen and carbon dioxide), and wastes. Hormones and other chemical messengers are also transported in the blood, enabling different organs and processes to communicate with each another. The cardiovascular circulatory system, however, is not the only vascular transport system in the body. As you can see in Figure 8.24, another system of vessels, called the lymphatic system, is closely associated with the capillaries and veins.

The **lymphatic circulatory system** is a network of vessels, with associated glands or nodes, that extends throughout the body (see Figure 8.25). The lymphatic vessels collect a fluid called **lymph**, which is made up of interstitial fluid. Lymph is either colourless or pale yellow and, in composition, is much like the plasma of blood. The lymphatic system helps to maintain the balance of fluids in the body.

As blood circulates through the body, some of the plasma escapes from the capillaries and becomes part of the interstitial fluid that constantly bathes all the cells of the body. Rather than re-entering the capillaries of the cardiovascular system, much of this

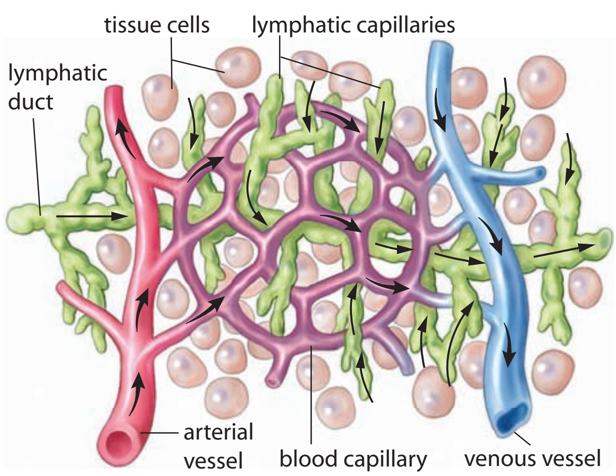

Figure 8.24 Lymph vessels are closely associated with the capillaries of the cardiovascular system. Fluid that escapes from the cardiovascular capillaries forms part of the interstitial fluid. Some of this fluid is collected in the lymphatic capillaries and eventually returned to the blood.

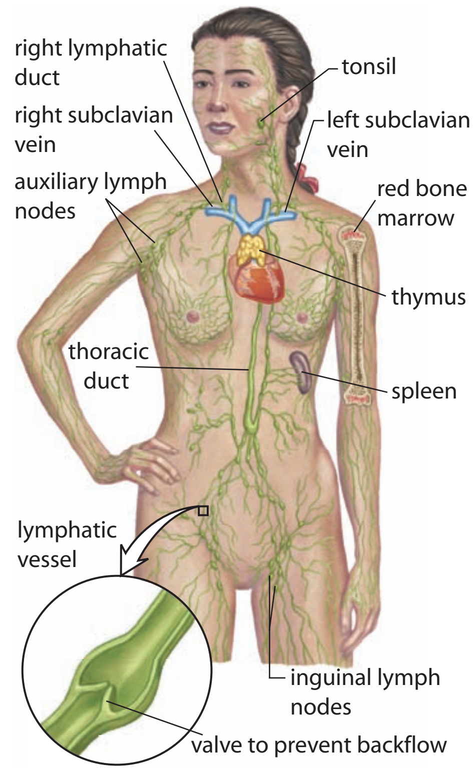

Figure 8.25 The human lymphatic system is spread throughout the body. Its largest vessels are in the region of the abdomen and thoracic cavity.

interstitial fluid is absorbed into the vessels of the lymphatic circulatory system. Eventually, it rejoins the main circulatory system through ducts that empty into the large veins near the heart. Unlike blood, which both arrives at and leaves the heart in a continuous circuit of cardiovascular vessels, lymph forms in closed-ended tubes in capillary beds. It is delivered to the heart to be mixed back into the general blood circulation. Figure 8.26 shows how the lymphatic system works to maintain the steady flow of water and other substances between the blood, the interstitial fluid, and the lymphatic system. Some specialized lymph capillaries are found in the intestinal villi. These capillaries carry some digested fats throughout the body.

The lymphatic system also works with the white blood cells to protect the body against infection. White blood cells called lymphocytes mature in the lymph nodes, the glands that are found throughout the lymphatic system. The lymph nodes also contain macrophages, which trap and destroy bacteria that are circulating within the body. An infection may cause your immune system to increase in the number of macrophages and lymphocytes in the lymph nodes. When you become ill, you can sometimes feel the swelling in the lymph glands behind your jawbone or under your arms.

Q21 What is the lymphatic system, and how is it related to the circulatory system?

Q22 How does the lymphatic system help to protect the body from infection?

The Defence System

The air you breathe, the water you drink, and the food you eat are all inhabited by billions of microscopic organisms. The internal environment of the body, which is kept stable through homeostatic mechanisms, provides an ideal place for many types of microscopic organisms to live and reproduce. Many of these organisms cause little or no damage to us, but others, called pathogens, can be very dangerous. (The word "pathogen" comes from two Greek words that, together, literally mean "producer of suffering.")

The human body defends itself against the constant attack of pathogens by either preventing the entry of pathogens or destroying them if they do enter. These defences can be divided into three groups: barriers to keep pathogens out, general or non-specific defences against a wide variety of pathogens, and specific defences against particular pathogens.

The Skin: Preventing the Entry of Pathogens

The first lines of defence are all of the physical and chemical barriers of the body, such as eyelashes, the cilia of the respiratory tract, tears, and stomach acid. However, the largest barrier is the skin. Although thousands of bacteria, fungi, and other pathogens can be found on the skin, it is a hostile environment for the survival of many micro-organisms. The outer layer of the skin is dry and contains large amounts of tough, relatively indigestible keratin. The skin's oil contains bactericides, and perspiration forms an acidic layer that is inhospitable for microbial growth.

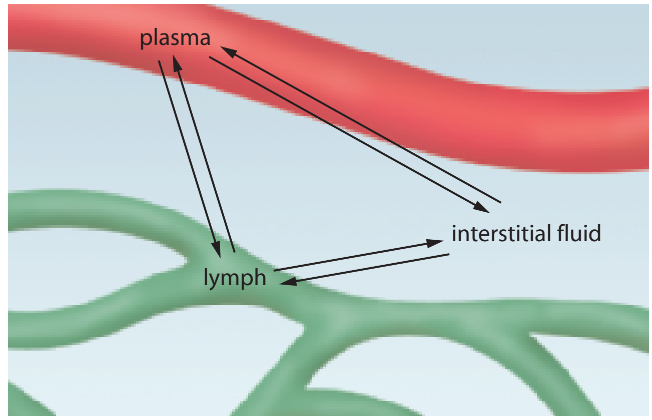

Figure 8.26 The lymphatic system plays an important role in maintaining the correct water balance in the interstitial fluid of the body. The arrows indicate a steady-state relationship between the lymphatic system, the circulatory system, and the interstitial fluid.

Non-Specific Defences (Cell-Mediated Immunity)

The second line of defence is the **non-specific defences**, which include three types of white blood cells—macrophages, neutrophils, and monocytes—and so is called **cell-mediated immunity**. Neutrophils and monocytes are white blood cells that kill bacteria using **phagocytosis**, a process in which they ingest the bacteria. **Macrophages**, which develop from monocytes, also use phagocytosis. They are found in the liver, spleen, brain, and lungs, and circulate in the blood and interstitial fluid. Non-specific defence also includes natural killer cells, which target body cells that have become cancerous or infected by viruses.

Specific Defences (Antibody-Mediated Immunity)

The third line of defence is **immunity**. Immunity is developed by the actions of the **specific defences**, using antibodies, and so is called **antibody-mediated immunity**. **Antibodies** are proteins that

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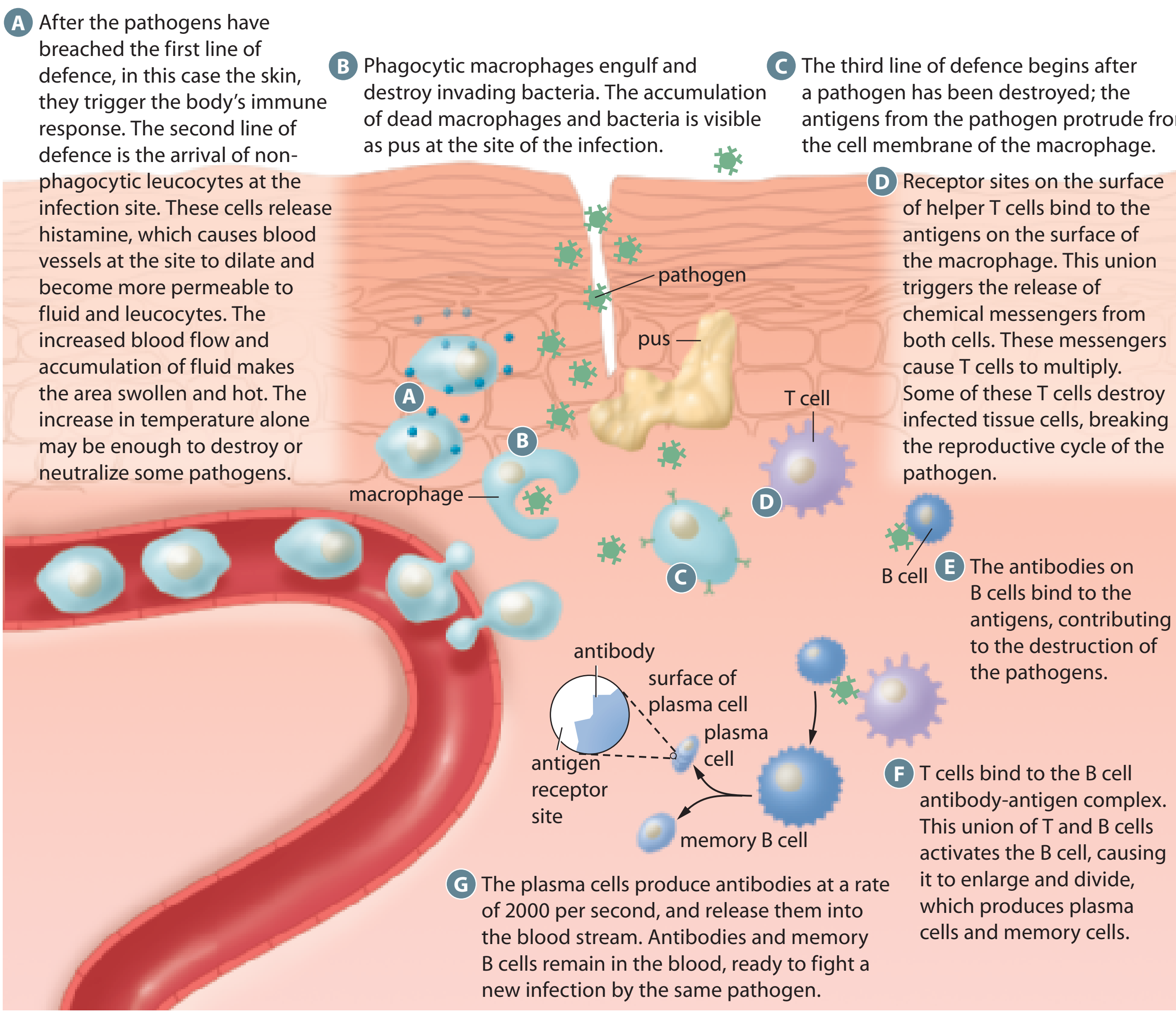
Phagocytosis is a special form of ingestion used by cells of the immune system as well as other microbes such as bacteria. In phagocytosis, the cell extends its membrane to form a bag around the target. Eventually the edges of the bag meet, fuse together, and draw the target in. The result is a closed sac containing the target within the cell and an intact cell membrane.

recognize foreign substances and act to neutralize or destroy them. Because of exposure to foreign substances over time, as well as variations in genetic make-up, each person develops an immune system that is unique in its ability to deal with a wide variety of possible infections. We are not all exposed to the same diseases, and some diseases require a stronger response than others because they are more virulent than others.

The specific immune system is primarily a function of the lymphocytes in the circulatory system. The **lymphocytes** are divided into two specialized groups, depending on where they mature. B lymphocytes, or **B cells**, mature in the bone marrow. T lymphocytes, or **T cells**, mature in the thymus gland, which is located near the heart.

Before you were born, your body was already "cataloguing" the molecules that are present in your body. This cataloguing is critical, so that your body can recognize proteins and other molecules as part of the "self." If your body could not tell what molecules were supposed to be present, it would be unable to respond to invading pathogens. **Antigens** are molecules that are found on the surface of the cells and on pathogens. Antigens provide an identification system. Antigen receptors on T and B cells allow them to recognize foreign antigens and begin responding to the invasion. Antibodies have the same shape as the antigen receptor for a specific antigen, so they can bind with and neutralize the antigen. Figure 8.27 illustrates some of the roles played by

Figure 8.27 A simplified illustration of the body's immune response, triggered by the entry of pathogens at the site of an infection. Pathogens may include bacteria, viruses, fungi, protists, and other microscopic organisms.



The immune response to antigen

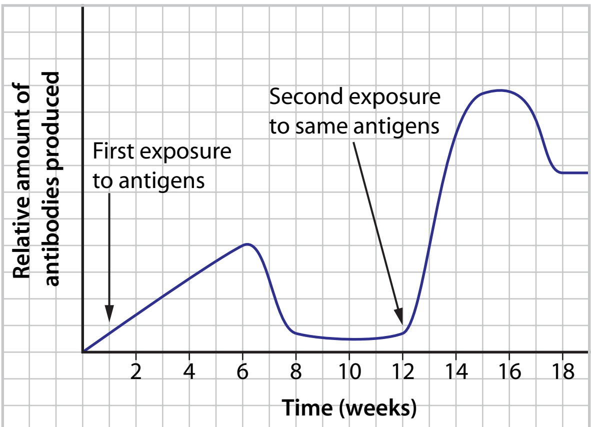


Figure 8.28 On the first exposure to an antigen, the immune response takes time to produce the antibodies necessary to fight the infection. If the same antigen is introduced again, the response is more rapid and generates much higher levels of antibodies.

both macrophages and lymphocytes as the second and third lines of defence.

Most antibodies are specific, so they can bind with only one type of antigen. Different B cells produce different antibodies, and this variation increases the possibility that the body will have an antibody that can recognize and bind to an invading pathogen. Once a B cell is activated, it enlarges and divides to produce memory B cells and plasma cells. The plasma cells produce enormous quantities of the same antibody carried by the B cell and release these antibodies into the bloodstream to fight the invading pathogens. After the infection has been fought off, memory B cells remain in the blood, ready to trigger another immune response when necessary (see Figure 8.28).

23 What are the three lines of defence that the body uses to protect itself from pathogens and other foreign invaders?

T Cells (Cellular Immunity)

Several different types of T cells work together to fight off invading pathogens, using a process called cellular immunity. When a pathogen is destroyed by phagocytosis, antigens from the pathogen move to the surface of the macrophage that destroyed it. When a specific type of T cell, called a **helper T cell**, recognizes the antigen, it gives off chemical signals that stimulate the action of macrophages, B cells, and other T cells. **Killer T cells**, or cytotoxic T cells, bind with infected cells and destroy them by puncturing a hole in their cell membranes (see Figure 8.29). Killer T cells may be activated indirectly by the chemical signals from a helper T cell or directly by the presence of the invading pathogen and associated antigen. **Suppressor T cells** slow and suppress the process of cellular immunity to ensure that normal tissue does not get destroyed. Some T cells do not respond to the invading antigens the first time they are exposed to them. Instead, these **memory T cells** remain in the bloodstream and are able to act quickly if the antigen is encountered again.

24 Describe the importance of specific defenses to immunity.

25 What is the relationship between B cells and T cells?

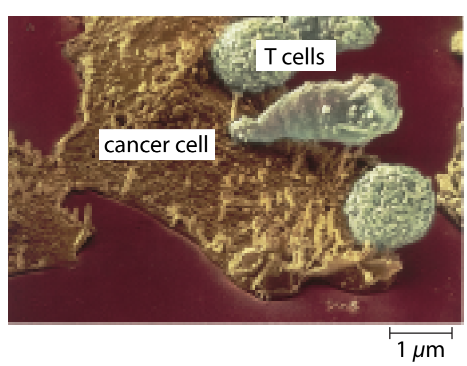


Figure 8.29 A scanning electron microscope shows killer T cells attacking and destroying an invading cancer cell.

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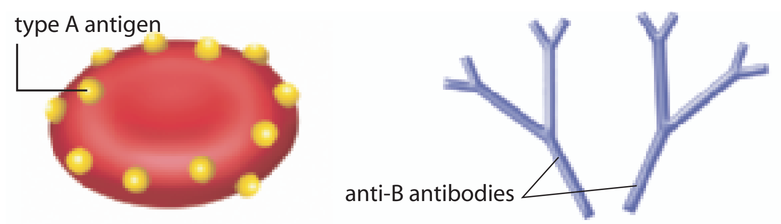
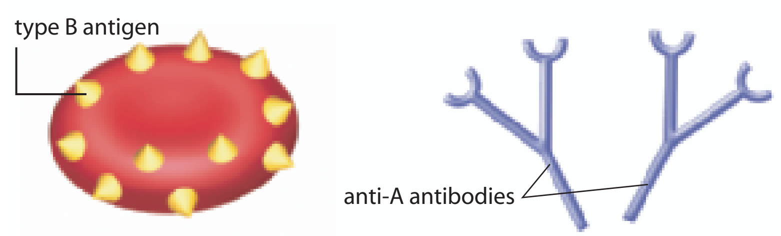
Helper T cells are also called T-4 cells. A T-4 cell count is a blood test that measures the number of helper T cells in the blood. T-4 cells signal other immune system cells to fight infections, and they are the prime target of the HIV virus. Too few T-4 cells indicates that your immune system is not capable of responding properly. A low T-4 cell count is a signal that HIV/AIDS patients should start taking medications to prevent AIDS-related infections.

Blood Types

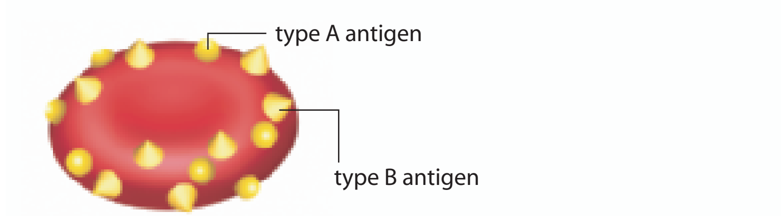
A *blood transfusion* is the transfer of blood from one person into the blood of another. Many early blood transfusions resulted in the illness, and sometimes the death, of some recipients. Eventually, scientists discovered that only certain types of blood are compatible because red blood cell membranes carry specific substances that are antigens to blood recipients. Several groups of red blood cell antigens exist. The most significant of these is the group of antigens in the ABO system.



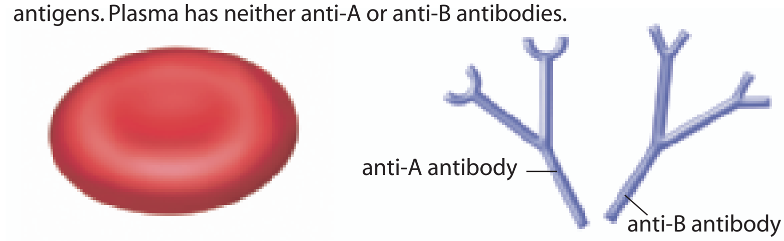
Type A blood: Red blood cells have type A surface antigens. Plasma has anti-B antibodies.



Type B blood: Red blood cells have type B surface antigens. Plasma has anti-A antibodies.



Type AB blood: Red blood cells have type A and type B surface antigens. Plasma has neither anti-A or anti-B antibodies.



Type O blood: Red blood cells have neither type A nor type B surface antigens. Plasma has both anti-A and anti-B antibodies.

Figure 8.30 In the ABO system, blood type depends on the presence or absence of antigens A and B on the surface of red blood cells. In these diagrams, A and B antigens are represented by different shapes on the red blood cells. The possible anti-A and anti-B antibodies in the plasma are represented for each blood type.

The ABO System

In the **ABO system**, the presence or absence of type A and type B antigens on red blood cells determines a person's blood type. (Refer to Figure 8.30.) The presence or absence of these antigens is an inherited characteristic.

As shown in Table 8.4, a person who has type A antigen on the surface of the red blood cells has type A blood. A person with type B blood has type B antigen on the surface of the red blood cells. Notice that a person who has type AB blood has both antigens, and a person with type O blood has neither antigen on the surface of the red blood cells.

A person who has type A blood has anti-B antibodies in the plasma. A person with type B blood has anti-A antibodies, and a person with type O has both antibodies in the plasma. These antibodies appear within several months after birth. The presence of these antibodies can cause agglutination. *Agglutination* is a clumping of red blood cells that occurs when incompatible blood types are mixed. Agglutinated red blood cells can clog blood vessels, blocking circulation and causing severe damage to organs.

Table 8.4 The Human Blood Types

Blood Type	Antigen on Red Blood Cells	Antibody in Plasma
A	A	anti-B
B	B	anti-A
AB	A and B	none
O	none	anti-A and anti-B

The Rh System

Another group of antigens found in most red blood cells is the **Rh factor**. (Rh is an abbreviation for rhesus monkey—*Macaca mulatta*—in which these antigens were first discovered.) People with the Rh factor on their red blood cells are termed Rh positive (Rh^+). People without it are Rh negative (Rh^-). Individuals who are Rh^- usually do not

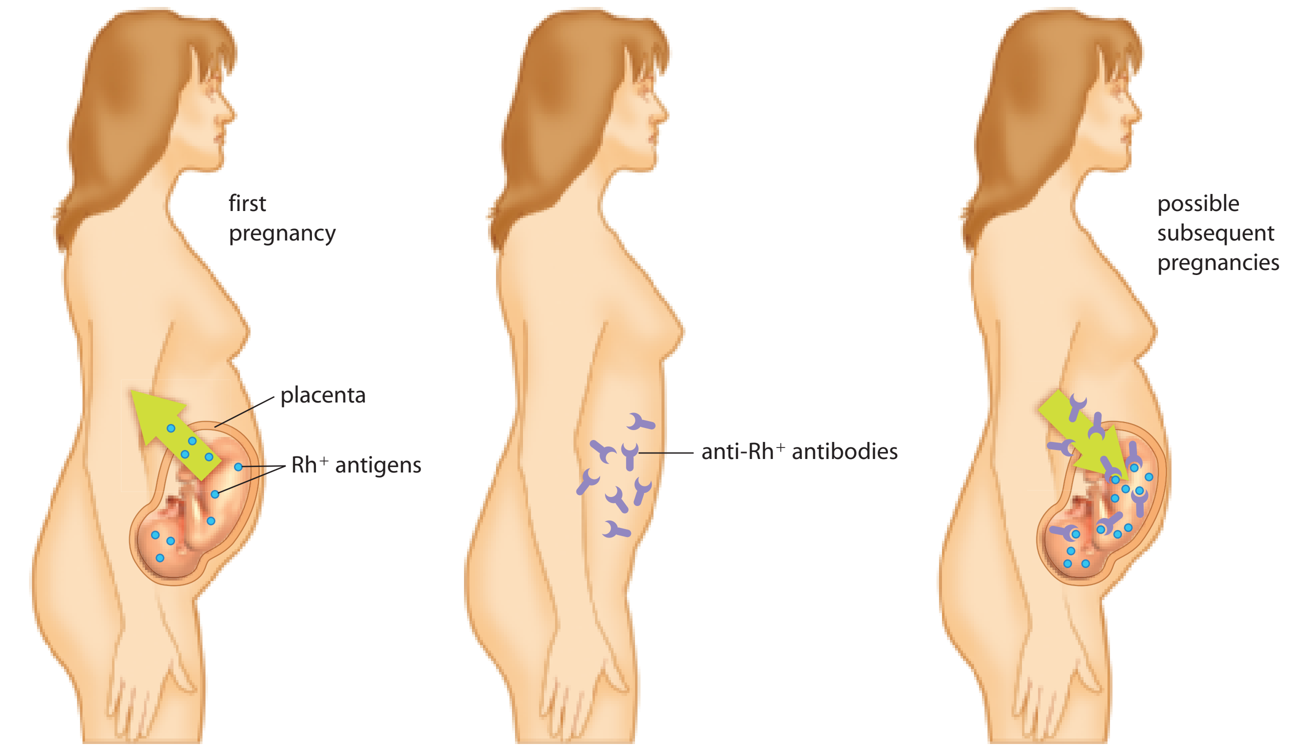


Figure 8.31 If a baby inherits its Rh$^+$ blood from the father and if the mother is Rh$^-$, problems can develop if the blood cells of mother and baby mix prior to and during birth.

have antibodies to the Rh factor, but they may make them when they are exposed to the Rh factor during a blood transfusion or pregnancy.

As shown in Figure 8.31, during pregnancy, if a mother is Rh$^-$ and the father is Rh$^+$, a child may be Rh$^+$. The Rh$^+$ red blood cells of the child may leak across the placenta into the mother's bloodstream. The presence of these Rh$^+$ antigens causes the mother's immune system to produce anti-Rh antibodies. Usually, in a subsequent pregnancy with another Rh$^+$ baby, the anti-Rh antibodies may cross the placenta and destroy the child's red blood cells. This is called hemolytic disease of the newborn (HDN). (Hemolysis is the bursting of red blood cells.) This condition can lead to brain damage, deafness, and death.

In HDN, as the red blood cells break down, the liver produces a substance called bilirubin in such excess that bilirubin ends up in the blood and other tissues and fluids of the baby's blood. Bilirubin is a pigment that causes the baby's blood and tissue to turn yellow. This condition is called jaundice. The presence of jaundice is a sign for diagnosing HDN. Treatment at this stage may involve a blood transfusion for the child or inducing early labour to prevent the situation from becoming worse.

The Rh problem is prevented by injecting Rh$^-$ women with an antibody preparation against the Rh factor within 72 hours after the birth of an Rh$^+$ child. The anti-Rh antibodies in the injection attack any of the baby's red blood cells in the mother's blood before these cells can stimulate her immune system to produce her own antibodies. This procedure will not help if the woman has already begun to produce antibodies. Thus, the timing of the injection is crucial.

26 Compare the four blood types in the ABO system.

27 What is the Rh factor, and what problems can the presence or absence of Rh antibodies cause during pregnancy?

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Complications associated with hemolytic disease of the newborn include anemia, hyperbilirubemia, and hydrops fetalis. What are these conditions and how can they be treated before and after birth?

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While the immune system can trigger attacks on healthy tissues, as seen in autoimmune disorders, it can also be attacked by pathogens. The human immunodeficiency virus (HIV) infects the white blood cells, principally T cells. The result is a slow decline of the immune system, which renders the body vulnerable to infection by other pathogens. These opportunistic pathogens are ones that a healthy immune system would control with ease. In people with HIV, the resulting infections can be quite serious, even fatal.

Immune System Disorders

Recall that the body identifies "self" cells very early in development. When T cells or antibodies mistakenly attack the body's own cells (the "self" cells) as if they had foreign antigens, the condition is called an **autoimmune disorder**. The exact cause of autoimmune disorders is not known, but research is active. So far, researchers know that there is a tendency to inherit the condition and that the condition often begins after recovery from an infection.

Rheumatoid arthritis is a chronic autoimmune disorder that is characterized by inflammation of the lining of the joints (see Figure 8.32). It is most common in individuals between the ages of 25 and 50. It is caused by the body's own immune system attacking the joints, causing pain, stiffness, swelling, fever, fatigue, and decreased appetite. The immune response can continue attacking cartilage, bone, tendons, and ligaments. Rheumatoid arthritis can cause permanent disability.

Treatments include Aspirin™, non-steroidal anti-inflammatory drugs (NSAIDs), and steroids. These medications all act to reduce the pain and inflammation, but they do not address the cause of the disorder. Stronger medications, called disease-modifying antirheumatic drugs (DMARDs), work on the immune response and slow the progress of the disorder.

Figure 8.32 Rheumatoid arthritis can cause painful debilitating joint deformity.

There have been some recent breakthroughs in drug treatments for autoimmune disorders, but they are still in the early stages of development. For example, researchers have been able to reverse Type 1 diabetes in mice by stopping the immune system from destroying its own insulin-producing cells in the pancreas. They "trained" immature white blood cells to properly distinguish "self" from "non-self" cells. These results are promising for the treatment of other autoimmune

Thought Lab 8.3 Barriers of Defence

Target Skills

Researching main components of the human immune system

Designing a model or simulation to demonstrate the functioning human immune system

In this assignment, you will research the human immune system. Based on your research, you will design a model or a simulation to represent the main components of the immune system.

Procedure

1. Conduct your research in a library or on the Internet. Identify the primary elements of the human immune system, including all three lines of defence. ICT
2. In a small group, decide how you would like to create your representation of the components of the immune system. Also decide what materials you will need.
3. Acquire the materials you need, and create your model or simulation. Ensure that all the parts are clearly labelled.
4. Display your model or simulation for the class to evaluate.

Analysis

1. Compare your model or simulation with those of other groups. Identify the differences.
2. Do you think that your model or simulation clearly shows the elements of the immune system? Explain why or why not.
3. If you could redo this activity, how would you improve what you did and the way you did it? What would you change?

disorders, although there is still considerable work to be done.

Allergies

An allergy is an exaggerated response by the immune system to a harmless material, such as pollen, mould, or animal dander. There are two major types of allergic reactions: immediate (or acute) and delayed. An immediate reaction is the most common type of allergic reaction. It occurs within seconds of exposure to the allergen and usually disappears within 30 minutes. In an immediate reaction, specialized antibodies trigger certain cells to release histamines, which are chemicals that increase the permeability of blood vessels, making the area red and swollen. The specialized antibodies can also trigger the release of cellular fluids, which can result in watery eyes and a runny nose.

Some forms of asthma, the most common chronic disease among North American children, are an immediate reaction to allergens that are inhaled. The inhaled allergens trigger a massive release of histamines, which sets off spasms of the bronchioles, the tiny air passageways in the lungs. In people who have asthma, these passageways are especially sensitive. Spasms can also be triggered by stimuli such as cold air and fatigue. The result can be coughing, wheezing, and sometimes fatal suffocation.

Asthma can be treated with anti-inflammatory drugs that can open the passageways of the bronchi, and thus ease the symptoms of an immediate reaction. Researchers are exploring new medications that may provide long-term relief from the inflammation that characterizes this disease.

Delayed allergic responses are set off by T cells that have been sensitized by previous contact with the allergens. In these cases, the reaction is slower and lasts for a longer time. Allergic reactions to certain types of cosmetics and jewellery are examples of this type of allergy.

Food allergies have become increasing common in Canada. Why have they become a health issue? Is it due to better diagnosis, the increased use of food additives, or unknown environmental factors? The answer is not yet clear, but researchers do know that people have become sensitized to foods that have been part of the human diet for thousands of years. Students and teachers in many schools now have EpiPens™ that contain single-dose injections of epinephrine (adrenaline), in case a person has an immediate, dangerous reaction—called anaphylaxis—to an allergen such as nuts or nut products.

Symptoms of food allergies can be immediate or delayed. Immediate reactions may include a runny nose, vomiting, severe diarrhea, or a life-threatening asthmatic attack. Delayed reactions may occur as skin problems, wheezing, or aches and pains. The following foods and food additives are associated with those reactions that occur most frequently or severely:

- peanuts, soybeans, nuts, seeds, and their oils or extracts
- corn products
- dairy products and/or lactose (a sugar common in dairy products)
- egg products
- fish and/or seafood
- monosodium glutamate
- sulfites (sulfur-based preservatives that are especially dangerous for people with asthma)
- tartrazine (also called Yellow Dye #5; used to colour foods and cosmetics)
- wheat and/or gluten

Section 8.3 Summary

- The lymphatic circulatory system is associated with the vessels of the cardiovascular circulatory system.
- The lymphatic system helps to maintain the balance of fluids in the body.
- The lymphatic system is an important part of the body's defence system.

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Peanuts are not actually nuts, but the seeds of a member of the legume family. Peanuts are one of the most allergenic foods, and the reaction they cause can be fatal. When people who are highly sensitive to peanuts are exposed either directly or indirectly to them, they may experience anaphylaxis. What is anaphylaxis, and how is it treated? What advances have been made to improve our understanding and approaches to treating peanut allergies?

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The proliferation of spam in email inboxes around the world has spawned a host of technologies to combat this inconvenient and annoying practice. What does the development of anti-spam technology have to do with the battle against HIV and AIDS?

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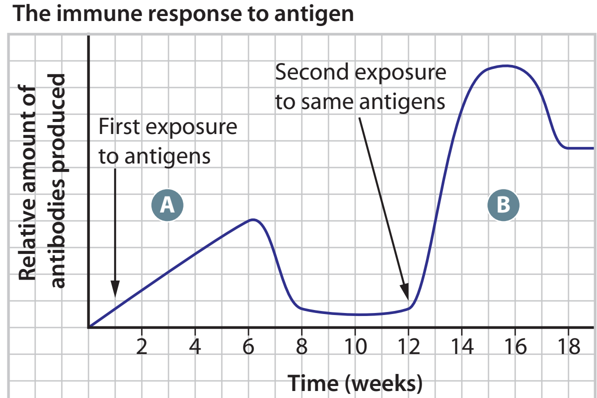
- There are three lines of defence against invading pathogens: barriers, non-specific defences, and specific defences.
- Skin is the largest barrier against pathogens.
- Non-specific defences are made up of the actions of macrophages, neutrophils, and monocytes. All three kill pathogens by the process of phagocytosis.
- Specific, or immune, defences use a wide variety of cells, including B cells and T cells
- Antigens are molecules that are located on the surface of a cell and act as an identification badge.
- Antibodies recognize foreign substances and act to neutralize or destroy them. B cells are primarily responsible for antibody immunity.
- Helper T cells, suppressor T cells, killer T cells, and memory T cells work together to create cellular immunity.
- In the ABO system, blood is classed as type A, B, AB, or O. Membranes of red blood cells may contain type A and/or B antigens, or neither antigen.
- In the plasma, antibodies may be anti-A or anti-B. If the corresponding antigen and antibody mix, agglutination occurs.
- The Rh antigen is another type of antigen. During pregnancy, problems can occur if an Rh^- mother forms antibodies to the Rh antigen while carrying or during the birth of an Rh^+ child. These antibodies can cross the placenta to destroy the red blood cells of any subsequent Rh^+ child.

Section 8.3 Review

1. Explain how the lymphatic system is related to the cardiovascular system.
2. Describe the two main functions of the lymphatic system.
3. Use graphics software to make a sketch of a lymph vessel and a vein. Use the caption of this sketch to compare a lymph vessel with a vein. ICT
4. Describe the difference between an antibody and an antigen.
5. Use graphics software to draw sketches of a lymphocyte, a neutrophil, and a monocyte. (See Investigation 8.C: Identifying Blood Cells for help with your sketches.) Explain the function of these white blood cells. ICT
6. Use graphics software to draw a diagram that illustrates how harmful cells are destroyed by macrophages. ICT
7. Explain, in detail, what the letters represent in the ABO system.
8. Explain how a mother who is Rh^- and carrying an Rh^+ baby could encounter no complications during her first pregnancy but could face blood compatibility problems during a second pregnancy with an Rh^+ child.
9. Explain what is happening in region A and region B of this graph.

The immune response to antigen



10. Explain the general causes of an autoimmune disorder.
11. Use word processing or spreadsheet software to make a chart similar to the one below. Use the information in your textbook to complete the chart. ICT

Immune System Disorder	Causes	Symptoms	Treatments
rheumatoid arthritis			
food allergies			
asthma			

Chapter 8 SUMMARY

The cardiovascular system, made up of the heart and blood vessels of the circulatory system, delivers the nutrients and gases received and processed from the external environment to the body's trillions of cells. The blood circulates through this system, transporting the products of digestion and respiration along the circulatory pathways and moving waste materials from the excretory system. It regulates internal temperature by moving heat produced by the muscular system. It also transports hormones.

The heart is a four-chambered, double pump that moves the blood through the three circulatory pathways. The pulmonary pathway transports blood to the lungs. The systemic pathway moves blood from the lungs to the body tissues and back again. The coronary pathway circulates blood to the muscle tissue of the heart. In the systemic and coronary pathways, arteries carry oxygen-rich blood away from the heart, and veins carry oxygen-poor blood back to the heart, where it is pumped through the lungs to exchange carbon dioxide for oxygen. The tiny capillaries, which link the arteries and veins within the tissue cells, are where the exchange of gases, nutrients, and wastes actually takes place.

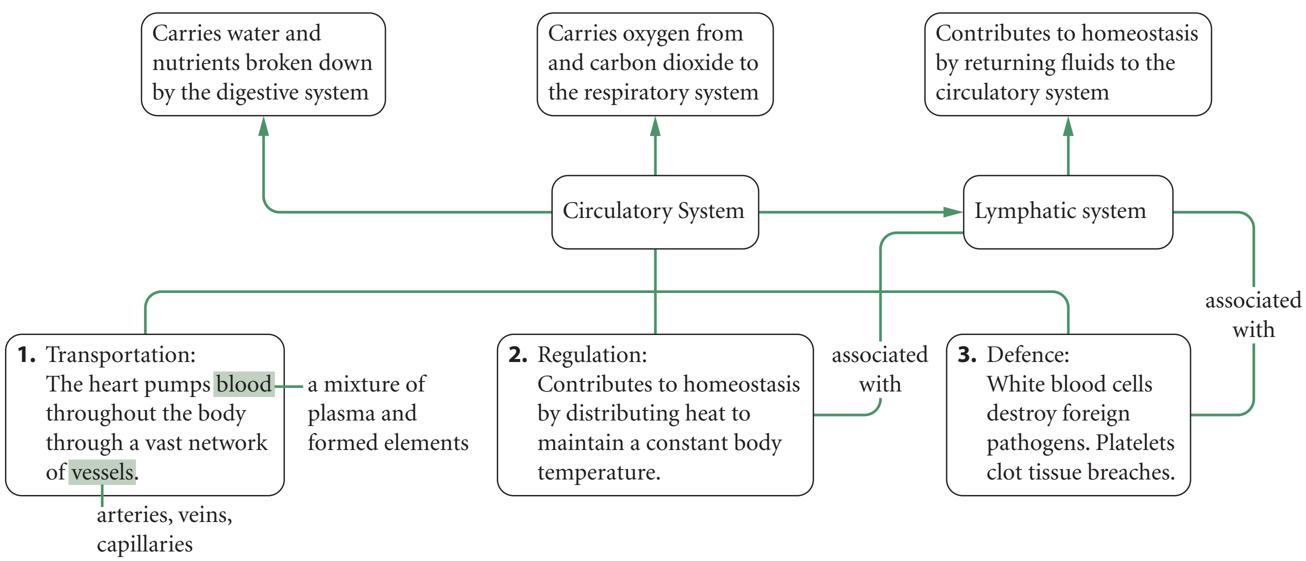
The blood itself is a tissue, made up of red blood cells, white blood cells, and platelets, contained in the formed portion, and plasma in the fluid portion. Each of the elements of the blood has specific functions in the circulatory system. Red blood cells transport oxygen; the white blood cells are part of the body's defence system; and platelets assist the circulatory system in healing itself.

The lymphatic circulatory system is a network of vessels, linked to glands or nodes, which circulates lymph to maintain the body's balance of fluids. The lymphatic system also works with the body's defense system to help defend the body against disease.

The body's defence system includes barriers (the skin, eyelashes, cilia, tears), non-specific defences found in the white blood cells (macrophages, neutropils, monocytes), and specific defences (antibodies). A person's blood type indicates the type of antigens found on the red blood cell surface. In the ABO system, a person may be type A (with only A antigens), type B (with only B antigens), type AB (with both A and B antigens), or type O (with neither A nor B antigens). Another group of antigens found in most red blood cells is the Rh factor. Within the plasma there are naturally occurring antibodies to the antigens that are *not* present on a person's red blood cells. Mixing blood types can result in agglutination.

Disorders of the cardiovascular system (such as arteriosclerosis, high blood pressure), the blood (such as hemophilia, leukemia), or the immune system (autoimmune diseases) all impair the transport of nutrients, gases, and wastes throughout the circulatory system.

Chapter 8 Graphic Organizer



Chapter 8 REVIEW

Understanding Concepts

1. List three factors that assist the flow of blood through the veins.
2. Which chamber of the heart is the largest and strongest chamber? Explain your reasoning.
3. Use word processing software to create a flow chart to trace the flow of blood through the heart. Start with the superior vena cava and end as blood enters the aorta. Include the names of all of the valves in the heart in your flow chart. ICT
4. Use word processing software to create a flow chart that explains the electrical activity in a mammalian heart. Relate the events that occur to specific regions of the heart muscle in your flow chart. ICT
5. What is the difference between a heart attack and a stroke?
6. List three functions of the blood, and identify the cells involved in each.
7. Describe the three primary pathways taken by the blood.
8. Identify the types of cells that are destroyed by the phagocytic activity of the macrophages.
9. How is lymph circulated in the body? How is this similar to how blood is circulated? How is it different?
10. Describe the role of T cells in the body's response to infectious agents.
11. The immune system helps the body resist pathogens. Identify three ways that pathogens can enter the body.

Applying Concepts

12. Design a simple test, based on just a few drops of a person's blood, that could determine whether or not the person is anemic. Provide detailed reasoning to support your design.
13. A person's blood pressure is measured before and after exercise. What effect would you expect the exercise to have on the systolic blood pressure and on the diastolic blood pressure? Explain.
14. You and your friends are sitting in a hot tub after a day of outdoor activity. What do you predict is happening to your circulatory system?
15. Design an experiment to test the effect of two separate factors on blood clotting. Provide detailed reasoning to support your design.
16. A pharmaceutical company develops an artificial blood cell that is very effective at transporting oxygen but is unable to transport carbon dioxide. Assuming that a blood transfusion has no effect on the level of plasma in the blood, explain what would take place if the artificial blood cell were used in a blood transfusion. How would this affect the patient?
17. Use graphics software to sketch cross sections of arteries, veins, capillaries, and lymph vessels. Use word processing or spreadsheet software to create a table to compare and contrast these blood vessels. ICT
18. Use graphics software to design a concept map or other graphics organizer that illustrates the relationships among different immune system cells. ICT
19. Some early transplant patients experienced life-threatening complications because their immune systems responded to "invading" cells that originated in another body. Which immune system cells increased? Draw a graph that would illustrate how the immune system is responding to this antigen organ.
20. Use word processing or spreadsheet software to make a chart that outlines the advantages and disadvantages of specific immunity and non-specific immunity. ICT
21. Imagine that you work in a hospital. You see on a patient's chart that she has type B blood, and she is about to receive blood from a donor blood container labelled type B. As an extra precaution, you mix a sample of the patient's blood with the donor blood on a glass slide. You observe that agglutination occurs. You need to discover whether it is the patient's chart or the blood container that is in error. You have access to samples of blood types A, AB, and O, but there is no more type B blood stored in the blood bank.
    a) Prepare a table illustrating the results that you would expect to see if you combine type B blood with each of the other blood types you have available.
    b) If it turns out that the label on the blood container is in error, what other blood type could be used instead of type B?
22. Describe how you would use a stethoscope to determine each of the following. Include details of what you would expect to find in each case.
    a) damage to the left atrioventricular valve
    b) damage to the aortic semilunar valve
    c) damage to the AV node

Use the following information to answer the next question.

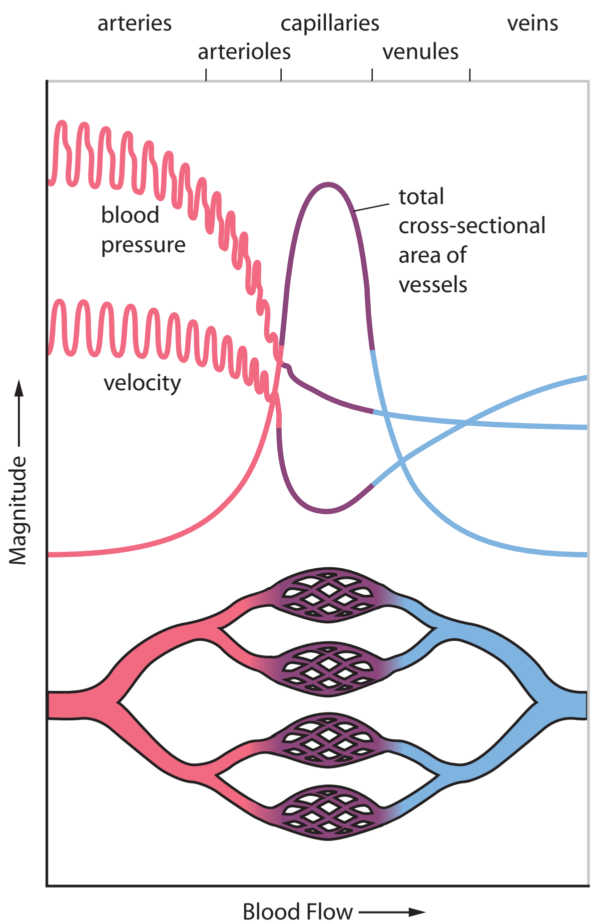
Heart Failure

Heart failure is a progressive disorder in which damage to the heart weakens the circulatory system. Heart failure does not mean the heart has stopped working. Rather, it means that the heart's pumping power is weaker than normal. With heart failure, blood moves through the heart and body at a slower rate, and pressure in the heart increases.

23. Use computer software to create a graphic organizer illustrating how heart failure can affect
- **a)** the heart muscle itself
- **b)** blood pressure
- **c)** internal and external respiration
- **d)** temperature regulation ICT

Use the following graph to answer the next question.

Blood pressure and velocity at various points in the circulatory system



The illustration above compares blood pressure and the velocity of blood as it flows through the circulatory system.

24. **a)** Describe the change in blood pressure as blood flows from arteries through capillaries to veins.
b) Describe the change in the speed of blood as it flows from arteries through capillaries to veins.
c) Compare the pressure of the blood in the veins with the speed at which it flows in the veins, and use the total cross-sectional area of the blood vessels to suggest at least one reason for the pattern that you observe in the veins.

Use the information below to answer the next question.

Hemophilia

Hemophilia is a rare inherited bleeding disorder in which the blood does not clot normally. People with hemophilia may bleed for a longer time than others after an injury or accident. They also may bleed internally, especially in the joints (knees, ankles, and elbows). Babies born with hemophilia are missing or have a low level of a protein needed for normal blood clotting or blood coagulation. The protein is called a clotting factor.

25. **a)** Use word processing software to create a flow chart that summarizes the steps in the blood clotting process. Identify at least one step in this process that could be linked to hemophilia. ICT
b) Explain why people with hemophilia would be prone to internal bleeding.

Making Connections

26. Explain why babies and young children might contract infectious diseases more frequently than adolescents do.

27. How do cells that provide cellular immunity sometimes trigger allergic reactions when they come in contact with environmental allergens?

28. What are some daily habits you could adopt to help reduce your chances of contracting a contagious disease (such as a cold or flu) from people you come into contact with on a regular basis?

29. Daphnia, a very small crustacean, has a heart rate that is much faster than a human heart rate. Why does such a small animal have such a fast heart rate? Would you expect the heart rates of large animals to be, on average, slower than the heart rates of small animals? Explain.

30. Explain how angioplasty can be used to open an obstructed coronary artery.