Circulation 23

If you are of average size, your heart pumps about 5 liters of blood every minute. This is about equal to the total volume of blood in your body. The blood rushes under pressure through thick-walled arteries to smaller arterioles and finally through a network of millions of tiny capillaries. Here the blood slows down and materials are exchanged between it and the extracellular fluid that bathes all body cells. A muscle cell, brain cell, or bone cell may be far from the external environment, but it is never more than a fraction of a millimeter from the blood in a capillary. Via the capillary net, every cell obtains food and oxygen and disposes of carbon dioxide and other wastes. Chapter 23 tells the story of blood, the vessels that carry it, and the heart that pumps it.

Organizing Your Knowledge

Exercise 1 (Modules 23.1 - 23.2)

These modules give an overview of circulatory systems—their basic functions and parts. Review the information by matching the following words and phrases. Each answer is used only once.

A. Ventricle
B. Open system
C. Capillary
D. Atrium
E. Blood
F. Closed system
G. Capillary bed
H. Diffusion
I. Interstitial fluid
J. Artery
K. Gastrovascular cavity
L. Vein

_____ 1. Network of small blood vessels
_____ 2. Circulatory system of vertebrates
_____ 3. Inadequate for transport over a long distance
_____ 4. Vessel that carries blood away from the heart
_____ 5. Solution in spaces between cells
_____ 6. Heart chamber that pumps blood out via arteries
_____ 7. Carries out circulatory functions in a jellyfish
_____ 8. Circulatory system of insects, spiders, and so on
_____ 9. Heart chamber that receives blood from veins
_____ 10. Vessel that conveys blood from arteries to veins
_____ 11. Vessel that returns blood to the heart
_____ 12. The circulatory fluid

Exercise 2 (Module 23.3)

The fish heart pumps blood through two sets of capillaries. As the blood of a fish passes through the tiny gill capillaries, it loses pressure. Therefore, once it has picked up oxygen, it delivers this oxygen to the capillaries in body tissues rather half-heartedly. The mammal heart is like two fish hearts side by side. Each side pumps blood only through one set of capillaries. The right heart pumps blood only to the lungs. The left heart then raises the pressure and sends this blood on its way to body tissues. On the next page, compare fish and mammal circulatory systems. Trace the flow of blood in each animal by numbering the parts blood passes through in order.

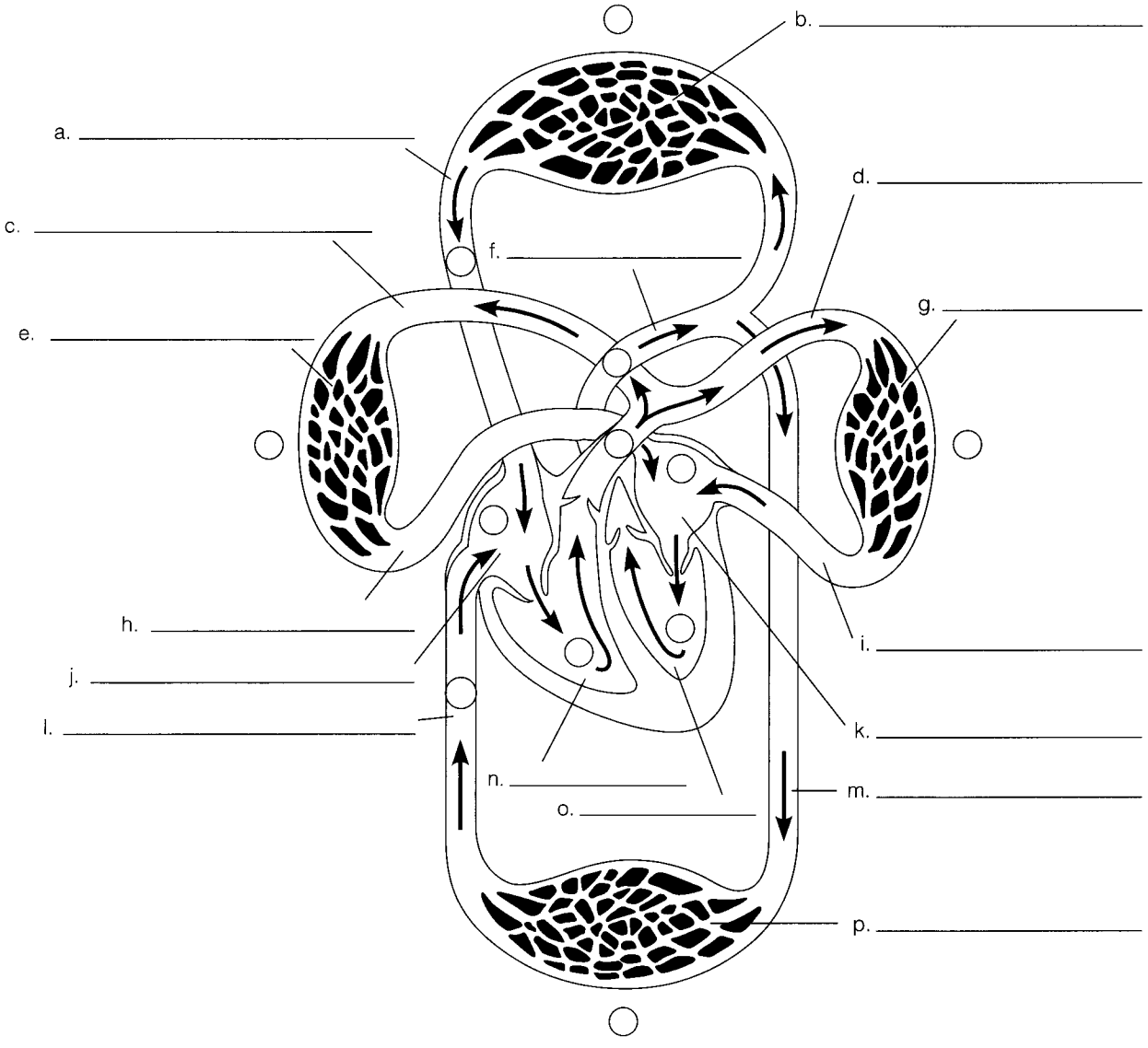
A. Fish
__1__ a. Ventricle
_____ b. Systemic capillaries
_____ c. Atrium
_____ d. Gill capillaries

B. Mammal
__1__ a. Right ventricle
_____ b. Left atrium
_____ c. Lung capillaries
_____ d. Right atrium
_____ e. Systemic capillaries
_____ f. Left ventricle

Exercise 3 (Module 23.4)

Web/CD Activity 23A *Mammalian Cardiovascular System Structure*
Web/CD Activity 23B *Path of Blood Flow in Mammals*

To review the mammalian cardiovascular system, start by labeling the parts indicated in this diagram. Then color the vessels that carry oxygen-rich blood red and those that carry oxygen-poor blood blue. Finally, trace the path of blood flow by numbering the circles (1–11).



Exercise 4 (Module 23.4)

Web/CD Activity 23A *Mammalian Cardiovascular System Structure*
Web/CD Activity 23B *Path of Blood Flow in Mammals*

One way to learn about circulation and the parts of the heart is to trace the circulation of a drop of blood from one location in the body to another, naming all the structures that the drop of blood passes on its way. Use Figures 23.4A and 23.4B in the text. (A tip: Remember that blood always has to circulate from an artery to capillaries to a vein. There aren't any shortcuts. For example, to get from the capillaries of the big toe to capillaries of the little toe, blood must go back to the heart, to the lungs, back to the heart, and then to the little toe.)

Imagine a drop of blood starting in a brain capillary, circulating to the foot, and then circulating to the hand. The blood flows from the capillary into a vein that runs down the neck, and empties into the [1]_____, the large vein that serves the head and arms. From there, the blood enters the [2]_____ of the heart. This chamber pushes the blood into the [3]_____, which pumps it out through the [4]_____ to the lungs. In the capillaries of the lungs, the blood picks up oxygen. Then it returns to the heart via the [5]_____. It enters the [6]_____, which pumps the blood to the [7]_____. This chamber pumps blood out through the [8]_____, the largest blood vessel in the body. This vessel branches and rebranches, and finally the blood is delivered to [9]_____ in the foot, where nutrients and oxygen are dropped off at the tissues. The drop of blood travels back to the heart via leg veins, which join the [10]_____, which empties into the heart. The [11]_____ atrium and ventricle again pump blood through the [12]_____ circuit to the lungs. The [13]_____ atrium and ventricle then pump the blood out through the aorta into the [14]_____ circuit. This time the drop of blood flows down a large [15]_____ to the hand, where the blood again passes through a network of capillaries.

Try going on, tracing the flow of blood from the hand, to the intestine to pick up food molecules, or to the kidneys for filtration, and then back to the brain. Once you have done this a couple of times, try it without the diagram, or make your own sketch.

Exercise 5 (Modules 23.4 - 23.5)

Web/CD Activity 23A *Mammalian Cardiovascular System Structure*
Web/CD Activity 23B *Path of Blood Flow in Mammals*

Complete the following chart, comparing the structure of capillaries, arteries, and veins.

	Capillaries	*Arteries*	*Veins*
Carry blood from	1.	2.	3.
Carry blood to	4.	5.	6.
Thickness of walls (thick, thin, or in-between)	7.	8.	9.
Layers in walls (names)	10.	11.	12.
Valves? (yes or no)	13.	14.	15.

Exercise 6 (Module 23.6)

Web/CD Activity 23B *Path of Blood Flow in Mammals*

The following exercise relates to the function of heart valves and cardiac output. Indicate which of the following statements refer to the atrioventricular (AV) valves and which refer to the semilunar (SL) valves.

_____ 1. Between atria and ventricles

_____ 2. Open during systole

_____ 3. At exits from ventricles

_____ 4. Prevent backflow from ventricles to atria

_____ 5. Prevent backflow from aorta and pulmonary artery to heart

_____ 6. Close during systole

_____ 7. "Lub" of "lub-dupp" heart sounds

_____ 8. "Dupp" of "lub-dupp" heart sounds

Exercise 7 (Module 23.6)

Cardiac output is the amount of blood that the left ventricle pumps into the aorta per minute. It is equal to the amount of blood pumped per beat times the number of beats per minute.

1. What is your cardiac output right now? An average heart pumps about 75 mL of blood per beat. To calculate cardiac output, take your pulse, then multiply 75 mL times the number of beats per minute.

   Cardiac output = 75 mL × _____ beats per minute = _____ mL of blood per minute

2. Now run in place for a minute, take your pulse, and make the same calculation.

   Cardiac output = 75 mL × _____ beats per minute = _____ mL of blood per minute

3. How much did output change with exercise? _____ mL of blood per minute

Exercise 8 (Modules 23.7 - 23.8)

Find a word or phrase in Module 23.7 or 23.8 that goes with each of the following.

_____ 1. Lowering these dietary lipids can reduce heart attack risk

_____ 2. Region that sets heart rate

_____ 3. Death of cardiac muscle cells due to heart vessel blockage

_____ 4. Relays signal to contract from atria to ventricles

_____ 5. Vessel blocked in heart attack

_____ 6. Buildup of plaques on the inside of blood vessels

_____ 7. Surgery that routes blood around blocked arteries

_____ 8. Location (outside heart) of centers that control heart rate

_____ 9. "Fight or flight" hormone that can speed up the heart

_____ 10. A device that "shocks" the heart to restore its rhythm

Exercise 9 (Modules 23.9 - 23.10)

Web/CD Activity 23C *Mammalians Cardiovascular System Function*

Pay special attention to Figure 23.9A; it contains a lot of information. Included are sizes, arrangement, and names of the blood vessels and the changes that occur in pressure and velocity as blood passes through them. After reading the modules and studying the figures, match each of the following statements with one of the blood vessels listed on the left.

A. Aorta
B. Arteries
C. Arterioles
D. Capillaries
E. Venules
F. Veins
G. Vena cava

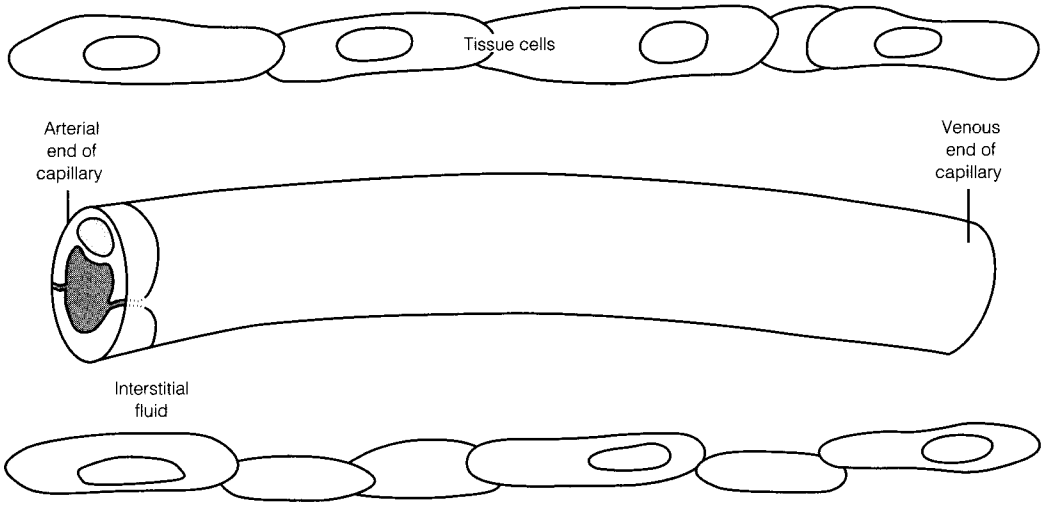
____ 1. Pressure is lowest here.
____ 2. Pressure and speed drop the most in these vessels.
____ 3. Pressure is usually measured in this kind of vessel.
____ 4. Blood moves fastest here.
____ 5. These vessels have the strongest pulse.
____ 6. Blood moves most slowly here.
____ 7. These vessels are the narrowest.
____ 8. Diastolic pressure here might be 80 mm Hg.
____ 9. Pressure here might be 20 mm Hg.
____ 10. Pressure is highest here.
____ 11. Systolic pressure here might be 120 mm Hg.
____ 12. Velocity of blood increases sharply as blood flows through these vessels.
____ 13. Hypertension may cause damage to the walls of these vessels, aggravating atherosclerosis.
____ 14. Blood flows rapidly here, but there is no pulse.
____ 15. Muscles and breathing help propel blood through these vessels.

Exercise 10 (Module 23.11)

The two mechanisms that control blood distribution, discussed in Module 23.11, sound very much alike. Sometimes, smooth muscle in arterioles *leading to* a capillary bed relax or contract to allow blood into the capillaries or divert it away. The second mechanism, illustrated in Figure 23.11B, involves muscle at the beginnings of the *capillaries themselves* that control blood flow. Nerve impulses and hormones can control these mechanisms. Sometimes changes in the tissues surrounding capillaries influence increase or decrease in vessel diameter. Can you imagine two physical or chemical changes that might occur in exercising leg muscles that might trigger vessel dilation and cause an increase in blood flow through the capillaries in the muscles? Write those changes below.

Exercise 11 (Module 23.12)

Through the thin walls of capillaries, materials are exchanged between the blood and the interstitial fluid that surrounds body cells. Complete this diagram showing the movement of blood through a capillary and exchange of materials with the interstitial fluid. Draw a red arrow to show blood moving from an arteriole into the capillary. Draw a blue arrow to show blood moving out of the capillary into a venule. (Why use two different colors?) Two forces are responsible for exchange of fluid between the blood and the interstitial fluid: Blood pressure tends to push fluid out of a capillary, and osmotic pressure tends to push water in. Draw large and small arrows at the arterial end of the capillary to show the relative strengths of blood pressure and osmotic pressure. Do the same at the venous end. Now draw arrows to show the net movement of fluid at the venous and arterial ends. (Do your arrows show net movement of fluid into or out of the capillary at the arterial end? Why? Is there net movement of fluid into or out of the capillary at the venous end? Why?)



Exercise 12 (Modules 23.13 - 23.15)

Most of the information on blood is summarized in the figure in Module 23.13. Study the composition of blood, and then compare the three blood cell types by filling in the blanks in the following table.

Cell Type	*Relative Size*	*Relative Numbers*	*Function*
Platelets	Smallest	1.	2.
3.	4.	5.	Oxygen transport
Leukocytes	6.	Least numerous	7.

Exercise 13 (Module 23.16 and Summary)

All the components necessary for blood clotting are present in blood all the time. Tissue damage activates them so that clotting occurs, in a sort of "chain reaction." Try to visualize blood flow and blood clotting by filling in the missing words in the following story.

You step into the Microtron, and you are quickly reduced to a size slightly smaller than a red blood cell. The support team injects you into a small artery in the arm. Blood pressure is fairly [1]_____ here. You feel a boom of pressure on your eardrums about once per second; this is simply the [2]_____, and it will gradually disappear as the blood in the artery flows into the narrower [3]_____ that lead to the capillary beds. Bright lights on the subject's arm enable you to see what is around you: Most of the cells around you are [4]_____, flexible disks carrying [5]_____ to the body's cells. There are also a few larger, irregular [6]_____, important in body defense. They slowly crawl along the blood vessel walls. Some even move against the current. It is best to avoid them, because some are [7]_____, capable of eating bacteria and debris. All around you are tiny "blobs." These must be [8]_____, which are involved in maintaining osmotic balance, defense, and blood clotting. There are also swarms of small fragments of cell cytoplasm, called [9]_____, that assist in the clotting process.

As you enter a [10]_____, blood slows almost to a stop, and the scene brightens. The walls of these vessels are a single layer of [11]_____, only one cell thick. You can even see gaps between cells, where fluid in the capillary is exchanged with the [12]_____ fluid. There isn't much room here, though. The capillaries are so narrow that the red blood cells have to line up single file in some places.

You are just under the skin of the fingertip. The team pricks the subject's skin with a pin. You are moving directly toward the wound, so you use your gripper to hang onto the vessel wall. The clotting process is already under way. The damaged lining of the vessel exposes [13]_____ to the blood. [14]_____ stick to the exposed tissue and release a cloud of chemicals. These chemicals cause even more platelets to adhere. But in this case, the damage is too serious for a platelet plug to stop the leak. Chemicals released from the platelets and damaged cells in the vessel wall trigger [15]_____ in the blood to change into an enzyme called thrombin. This enzyme then causes the small blobs of fibrinogen floating in the blood to change shape and form sticky strands of [16]_____. These strands stretch like a tangle of cords across the hole in the vessel, trapping red blood cells. The blood strains against the fibrin clot, but finally it holds and leakage stops.

A phagocyte has caught your leg! You break free, but in the process you loosen a big chunk of the clot. It could travel to the heart, lodge in one of the [17]_____, and cause a [18]_____! You let the flow of blood carry you along. As blood leaves the capillary bed and enters a [19]_____, blood flow speeds up. The vessel walls thicken, and it gets darker again. You enter an even larger [20]_____, and the blood slows down even more. Ahead you can dimly make out the flaps of a [21]_____, which keeps the blood moving toward the heart. Fortunately, the clot is briefly caught in an eddy downstream from the valve. You use your laser to break it into fragments small enough to pose no threat to the subject. This is a good time to make your exit, and you are soon back in the lab discussing your adventure.

Exercise 14 (Module 23.17)

Stem cell research promises to cure several blood diseases. Review the potential of stem cells by matching each phrase on the left with a term from the list on the right.

_____ 1. Cancer of the white blood cells
_____ 2. Spongy bone tissue where blood cells develop
_____ 3. Unspecialized cell that differentiates to become blood cell
_____ 4. A cell that divides uncontrollably
_____ 5. A standard cancer treatment
_____ 6. Location where bone marrow is obtained for transplantation
_____ 7. The newest method of gathering stem cells gets them from here
_____ 8. A white blood cell
_____ 9. Where stem cells first form
_____10. A device used to gather stem cells from donor blood

A. placenta
B. leukocyte
C. cancer cell
D. centrifuge
E. leukemia
F. embryo
G. red marrow
H. stem cell
I. radiation
J. pelvic bone

Exercise 15 (Summary)

This chapter introduces a lot of vocabulary connected with circulation. Circle the term that does not fit with the others in each of these groups, and briefly explain what the other terms in each group have in common.

1. venule artery atrium capillary
2. fibrin leukocyte platelet red blood cell
3. sphygmomanometer systolic pressure fibrinogen hypertension
4. pulmonary veins right ventricle lungs aorta
5. fibrin leukocyte platelet hemophilia
6. semilunar valve AV node SA node pacemaker
7. diastole systole pulse leukocyte
8. oxygen red blood cell hemoglobin epithelium
9. pulmonary artery systemic circuit aorta left ventricle

Testing Your Knowledge

Multiple Choice

1. Rhythmic stretching of the arteries caused by heart contractions is called
   a. hypertension.
   b. heart murmur.
   c. hemophilia.
   d. pulse.
   e. diastole.

2. Which of the following animals has an open circulatory system?
   a. fish
   b. human
   c. frog
   d. *Hydra*
   e. spider

3. Which of the following *cannot* move freely in and out of a capillary?
   a. sugar
   b. oxygen
   c. carbon dioxide
   d. water
   e. plasma protein

4. Heart valves function to
   a. keep blood moving forward through the heart.
   b. mix blood thoroughly as it passes through the heart.
   c. control the amount of blood pumped by the heart.
   d. slow blood down as it passes through the heart.
   e. propel blood as it passes through the heart.

5. Which of the following correctly traces the electrical impulses that trigger each heartbeat?
   a. ventricles, pacemaker, AV node, atria
   b. pacemaker, AV node, atria, ventricles
   c. atria, pacemaker, AV node, ventricles
   d. pacemaker, atria, AV node, ventricles
   e. pacemaker, AV node, atria, ventricles

6. A heart attack occurs when
   a. a heart valve malfunctions.
   b. a coronary artery is blocked.
   c. the heart is weakened by overwork.
   d. the aorta is blocked.
   e. the pulmonary artery is blocked.

7. The cells responsible for defense against infections are
   a. red blood cells.
   b. white blood cells.
   c. epithelial cells.
   d. platelets.
   e. pacemaker cells.

8. If cells are not receiving enough oxygen, a hormone signals the bone marrow to produce more
   a. leukocytes.
   b. fibrin.
   c. plasma.
   d. platelets.
   e. erythrocytes.

9. The primary sealants that plug leaks in blood vessels are
   a. platelets and fibrin.
   b. red blood cells and albumin.
   c. fibrin and white blood cells.
   d. white blood cells and platelets.
   e. hemoglobin and platelets.

10. Which of the following best describes an artery?
    a. carries blood away from the heart
    b. carries oxygenated blood
    c. contains valves
    d. has thin walls
    e. carries blood away from capillaries

11. Blood moves most slowly in
    a. capillaries.
    b. the aorta.
    c. veins.
    d. arterioles.
    e. venules.

12. In a fish, blood circulates through ____, while in a mammal, it circulates through ____ .
    a. two circuits . . . four circuits
    b. one circuit . . . two circuits
    c. four circuits . . . two circuits
    d. one circuit . . . four circuits
    e. two circuits . . . one circuit

13. The amount of blood flowing to skeletal muscles is greatly increased during exercise. This redirection of blood into muscles is accomplished by
    a. contraction of muscle in the walls of arteries.
    b. relaxation of muscle in walls of arterioles.
    c. opening of valves in veins.
    d. opening of valves in arteries.
    e. relaxation of muscle in the walls of veins.

Essay

1. Explain how the circulatory system changed to accommodate lung breathing and greater activity as land vertebrates evolved.
2. Cardiac output is the amount of blood the left ventricle of the heart pumps per minute. Cardiac output can be as much as four times greater when you are exercising than when you are at rest. What two things could the heart increase to increase cardiac output when you are exercising?
3. How does high blood pressure contribute to cardiovascular disease?
4. Briefly describe and explain changes in blood pressure as blood flows from arteries to capillaries to veins.
5. Describe the structural characteristics of capillaries that make them well suited for exchange of materials between blood and tissues.

Applying Your Knowledge

Multiple Choice

1. Just after blood leaves the left ventricle of the human heart, it passes through the
   a. pulmonary artery.
   b. left atrium.
   c. aorta.
   d. superior vena cava.
   e. right ventricle.
2. In which of the following animals are blood and interstitial fluid the same?
   a. grasshopper
   b. jelly
   c. fish
   d. dog
   e. sparrow
3. The heart specialist listened to Paul's heart through a stethoscope. Instead of the normal "lub-dupp, lub-dupp" heart sounds, he heard "siss-dupp, siss-dupp." The doctor said, "Hmm . . . I'm not sure it is anything to worry about, but I think there is something wrong with
   a. one of your coronary arteries."
   b. the pacemaker."
   c. an atrioventricular valve."
   d. your aorta."
   e. a semilunar valve."
4. Which of the following terms would be *least* useful in describing the circulatory system of a fish?
   a. capillary bed
   b. pulmonary artery
   c. ventricle
   d. atrium
   e. cardiovascular system
5. In circulating by the shortest route from the lungs to the foot, how many times would a drop of blood pass through the left ventricle?
   a. 0
   b. 1
   c. 2
   d. 3
   e. 4
6. A recording of the electrical activity of a patient's heart shows that the atria are contracting regularly and normally, but every few beats the ventricles fail to contract. Which of the following is probably not functioning properly?
   a. AV node
   b. semilunar valve
   c. coronary artery
   d. pacemaker
   e. AV valve
7. Which of the following functions most like a valve in a vein?
   a. a kitchen faucet
   b. a revolving door
   c. the volume control on a radio
   d. a turnstile
   e. a sliding patio door
8. In circulating from the brain to the arm, a drop of blood would *not* have to pass through which of the following?
   a. left atrium
   b. aorta
   c. superior vena cava
   d. pulmonary vein
   e. inferior vena cava

9. Emphysema damages the tissues of the lungs and slows pulmonary blood flow. This causes blood to back up, stretching and weakening the walls of the heart and blood vessels. Which of the following do you think would be most affected by this backup of blood from the lungs?
   a. aorta
   b. right atrium
   c. left atrium
   d. right ventricle
   e. left ventricle

Essay

1. A runner's heart rate is 160 beats per minute, and 90 mL of blood is pumped by the left ventricle with each beat. What is the runner's cardiac output?
2. The figures for blood pressure in an artery are usually given like this: 130/80 mm Hg. But it takes only one figure to specify blood pressure in a vein: 5 mm Hg. Why the difference?
3. Recall the forces that cause fluid to leave and reenter a capillary. How do you think high blood pressure would affect this balance of forces? How does this help explain that one of the symptoms of high blood pressure is swelling of the tissues with fluid?
4. Sometimes a baby is born with its large blood vessels reversed: The right ventricle pumps blood out through the aorta, and the left ventricle is connected to the pulmonary artery. The system is otherwise normal. How would this alter blood flow? Why would this be disastrous if not quickly corrected by surgery?

Extending Your Knowledge

1. What kinds of changes in the lifestyles of many Americans have led to the recent downturn in the incidence of cardiovascular disease? Have you made any changes in your health habits to avoid future heart or circulatory problems? Are there any changes you would like to make?
2. Have you had your blood pressure checked lately? Do you remember what your blood pressure was? How high does pressure have to be to indicate high blood pressure? Even young people can have high blood pressure. If you haven't had yours checked lately, it might be a good idea. Many pharmacies have simple devices you can use to check your blood pressure yourself.