11.1 The Need for a Circulatory System

What do all living things require to go on living? Recall from previous studies that all living things must obtain and use nutrients, get rid of waste, interact with their environment, and perform other processes.

Unicellular organisms perform all of the processes necessary for life using only a single cell. Most multicellular animals, on the other hand, require organ systems to carry out life processes. In these complex multicellular animals, cells organize into tissues, tissues into organs, and organs into organ systems.

The circulatory, digestive, respiratory, and other organ systems all rely on each other in order to function properly. The circulatory system is responsible for transporting (or circulating) nutrients, dissolved gases, wastes, and other chemicals to and from individual cells in an organism.

The Need for Circulation

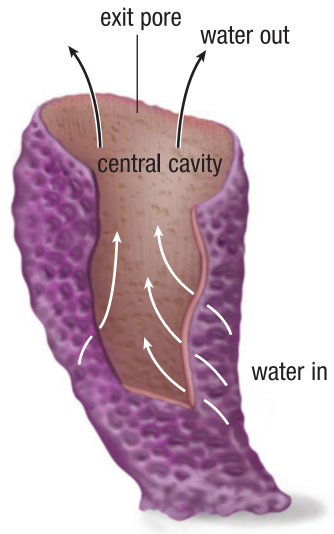

Figure 1 Circulation in the sponge is achieved by setting up a current that pulls water in through the body pores and out through the top opening.

Not all organisms need a circulatory system. Unicellular organisms, such as bacteria, some algae, and some fungi, are in direct contact with their environment. A circulatory system is not necessary to transport gases through these organisms. For most of these organisms, gases such as oxygen and carbon dioxide diffuse across the cell membrane. Unicellular organisms do not require the transport of nutrients either. For example, some unicellular organisms engulf other cells to obtain their nutrients, and some simply absorb organic molecules.

Some simple multicellular animals also do not need a circulatory system. Sponges, for example, consist of a body that has only two cell layers (**Figure 1**). The cells that line the body cavity have flagella that beat to circulate water through the cavity. As the water passes over the cells, oxygen is absorbed, nutrients are trapped, and carbon dioxide and wastes are eliminated. Because the body is only two cell layers thick, all the body cells are close enough to the external environment to allow for exchange of substances. In a single day, a sponge can move a volume of water 20 000 times its body volume. The water in its central cavity is completely flushed about every 4.3 s, bringing in oxygenated water and suspended nutrients.

The need for a circulatory system arose as an evolutionary adaptation to increasing body size. In larger and more complex multicellular animals, some body cells do not come into contact with the fluids of the external environment—air or water. Individual body cells in a multicellular animal are in a fixed position and have no means of moving around. A circulatory system ensures that oxygen and nutrients are delivered to every cell. A circulatory system also allows waste products that are removed from cells to be released into the external environment.

All of the cells of organisms must be surrounded by a fluid. This fluid provides the medium for diffusion of gases, nutrients, and wastes. In unicellular and simple multicellular animals, cells are directly in contact with the fluid of the external environment. In more complex animals, individual cells are surrounded by tissue fluid, which enables diffusion of substances.

The Functions of a Circulatory System

The circulatory system has several functions. It delivers oxygen from the respiratory system, nutrients from the digestive system, hormones from the endocrine system, chemicals or cells from the immune system, and metabolic wastes from the cells to the lungs and kidneys. In warm-blooded animals, the circulatory system also plays a role in distributing thermal energy throughout the body to maintain body temperature. You will learn about how the circulatory system is designed to carry out these functions as you progress through this chapter.

Types of Circulatory Systems

Although circulatory systems vary among animals, all circulatory systems have three fundamental features:

- a fluid that transports (circulates) materials through the body
- a network of tubes in which the fluid circulates
- a pump that pushes the fluid through the tubes

Different species of animals have either an open or a closed circulatory system, depending on the animals' size and complexity.

LEARNING TIP

Word Roots
The prefixes *hem-*, *hemo-*, and *hemato-* mean "of or relating to the blood." For example, hemoglobin is a blood protein. Hematology is the study of blood.

Open Circulatory Systems

Most invertebrates, such as snails, insects, and crustaceans, have an open circulatory system. In an open circulatory system the circulating fluid is pumped into an interconnected system of body cavities, or sinuses, where it bathes the cells directly (**Figure 2**). The circulating fluid, called **hemolymph**, is a mixture of blood and tissue fluid. Contraction of one or more hearts forces the hemolymph out of the circulatory tubes, called blood vessels, through the sinuses. When the heart relaxes, the hemolymph is drawn back to the heart through open-ended pores. Body movements can also help in the circulation of hemolymph.

hemolymph a mixture of blood and tissue fluid that is the circulating fluid in an open circulatory system

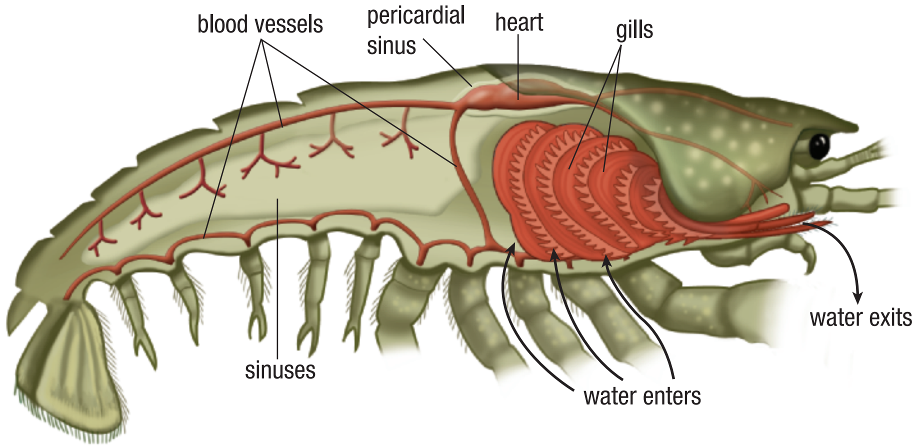

Figure 2 The lobster has an open circulatory system that distributes hemolymph through the sinuses.

To understand how an open circulatory system works, try visualizing an airtight bucket filled with water (**Figure 3**). Two hoses are inserted through holes in the side of the bucket. The other ends of the hoses are connected to a squeeze bulb that forces liquid in only one direction. As the bulb (heart) squeezes, the fluid (hemolymph) is forced through one hose (blood vessel) into the bucket (sinus). The fluid in the bucket is forced into the other hose (blood vessel) and back to the bulb (heart).

The hemolymph is under low pressure and circulates slowly through the body. This low pressure makes the open circulatory system relatively inefficient; however, an open circulatory system is appropriate for certain animals. Many animals with an open circulatory system have a low metabolic rate, so they do not need to eat often. This low metabolic rate is important because diffusion is limited by slow blood flow in these animals. Nevertheless, some animals, such as the bumblebee, with a high metabolic rate have an open circulatory system. In these animals the open circulatory system is efficient at cooling the body by dissipating the thermal energy produced during metabolism.

Not all open circulatory systems are used for transporting oxygen. Insects, for example, have a separate system of branching air tubes that deliver oxygen to all parts of the body. The main functions of the insect circulatory system are to transport nutrients and other chemicals to the cells, as well as to transport waste products out of the cells.

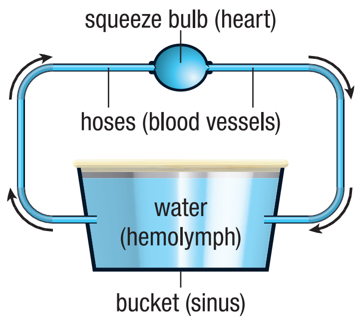

Figure 3 A model of an open circulatory system

Closed Circulatory Systems

All vertebrates, as well as some invertebrates, such as earthworms, squids, and octopuses, have closed circulatory systems. In a closed circulatory system the fluid (often blood) is contained within a network of tubes, or blood vessels. This system separates blood from the tissue fluid by keeping the blood enclosed in the vessels. The tissue fluid surrounds the cells and provides a medium for diffusion of substances from the bloodstream to the cells. In contrast, in an open circulatory system, a mixture of blood and tissue fluid flows through the blood vessels and sinuses.

Considerable variation has evolved in closed systems. The earthworm, for example, has five pairs of aortic arches, which are enlarged blood vessels. The aortic arches work like hearts by contracting to pump the blood through the system (**Figure 4**).

Fish have a closed circulatory system consisting of a single continuous loop, or circuit. The circuit carries blood to the gills. At the gills, the blood takes in oxygen from the surrounding water and releases carbon dioxide to the water (**Figure 5**). From the gills, blood circulates to the rest of the body, delivering oxygen and removing carbon dioxide. The heart of a fish has two chambers: an atrium and a ventricle. The **atrium** (plural: atria) receives the collected blood from the body and pumps it into the ventricle. The **ventricle** then contracts to pump the blood to the gills and around the body.

atrium a chamber of the heart that receives blood from the body

ventricle a chamber of the heart that pumps blood to the body

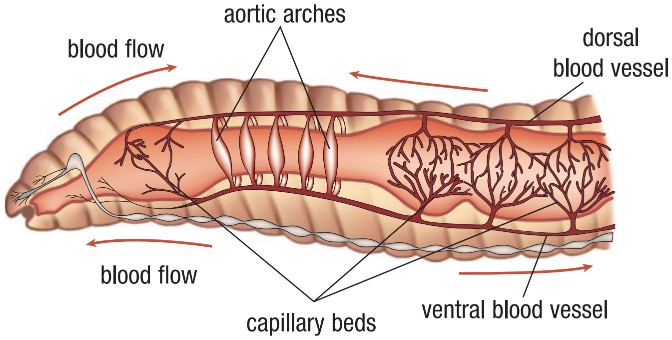

Figure 4 The blood of an earthworm is enclosed within a system of blood vessels.

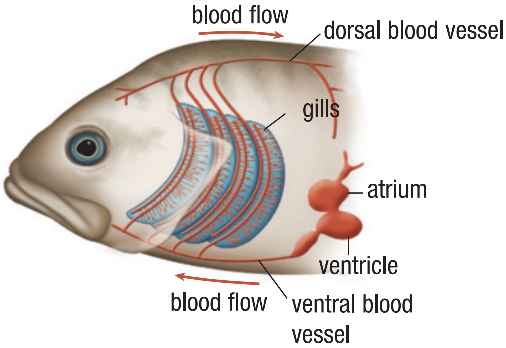

Figure 5 The circulatory system of fish is a single circuit. Blood is pumped through the gills, where it is oxygenated, and then pumped throughout the body.

FROM SIMPLE TO COMPLEX

The heart evolved from the simple aortic arches of ancient invertebrates to the two-chambered heart that is found in fish (**Figure 6(a)**). As more time passed, the heart further evolved to the three-chambered heart that amphibians possess. The heart of amphibians has two atria and a single ventricle (**Figure 6(b)**). The left atrium receives oxygenated blood from the lungs and skin. The right atrium receives deoxygenated blood from the body. The single ventricle pumps blood to both the lungs and the body. In most reptiles, such as snakes and lizards, the ventricle of the heart is partially separated into two areas by a wall of tissue called the **septum** (**Figure 6(c)**). In mammals, birds, and crocodilians, the septum is complete and separates the tip of the heart into a left and right ventricle, resulting in a four-chambered heart (**Figure 6(d)**).

septum a wall of tissue that divides a body cavity or structure into smaller parts; for example, the ventricle of a mammal's heart is divided into two cavities by a septum

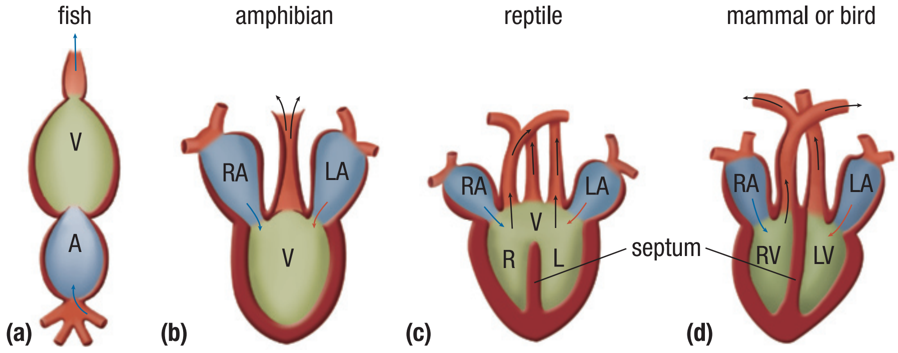

Figure 6 As animals evolved in size and complexity, the heart evolved from a simple two-chambered structure to a four-chambered structure. In this diagram, A represents atrium, V represents ventricle, R represents right, and L represents left.

TWO-CIRCUIT CIRCULATORY SYSTEM

Mammals, along with birds and crocodilians, developed a more complex closed circulatory system. The main difference is the evolution of a two-circuit system in which circulation to the lungs is separated from circulation to the rest of the body. This separation of the circuits is possible because of the structure of the heart. The four chambers create a double pump where the two circuits intersect. The **pulmonary circuit** circulates blood to the lungs for gas exchange with the external environment. The **systemic circuit** circulates blood around the body to deliver oxygen, nutrients, and other substances to the body cells, and to pick up carbon dioxide (**Figure 7**).

A four-chambered heart has two ventricles that pump blood from the heart and two atria that receive blood returning to the heart. One atrium receives oxygenated blood from the lungs, while the other atrium receives deoxygenated blood from the body. Likewise, one ventricle pumps deoxygenated blood to the lungs, while the other pumps oxygenated blood to the body.

pulmonary circuit the part of the circulatory system that delivers blood to the lungs

systemic circuit the part of the circulatory system that delivers blood around the body

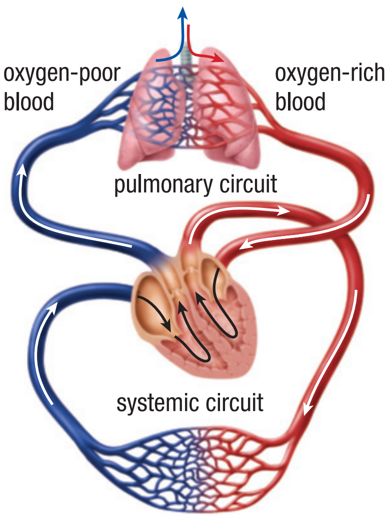

Figure 7 The mammalian circulatory system is a two-circuit system.

11.1 Summary

- Unicellular and simple multicellular organisms do not need a circulatory system. They obtain the materials they need through direct contact of their cell(s) with the external environment.
- The development of a circulatory system is an evolutionary adaptation to an increase in size and complexity.
- Circulatory systems vary in structure, but all have three features in common—a fluid, a network of tubes, and a pump (heart). The two main functions of the circulatory system are transport and protection.
- In open circulatory systems the circulating fluid, or hemolymph, is a mixture of blood and tissue fluid. In closed circulatory systems the blood is confined by a network of blood vessels and is separate from the tissue fluid.
- The circulatory system of fish consists of a single circuit with a two-chambered heart. Mammals, birds, and crocodilians have a two-circuit system consisting of a pulmonary circuit (circulating to the lungs) and a systemic circuit (circulating to the rest of the body).
- Mammals, birds, and crocodilians have a four-chambered heart that permits the separation of the pulmonary and systemic circuits.

Investigation 11.1.1

Fetal Pig Dissection (page 510)
Make note of the types of circulatory systems you have read about in this section. At the end of this chapter, you will have an opportunity to dissect a fetal pig and observe the structures of a typical mammalian circulatory system.

11.1 Questions

1. Why do more complex multicellular animals require a circulatory system? K/U
2. What are the functions of the circulatory system? K/U
3. What three features are common to all circulatory systems? K/U
4. (a) Use a graphic organizer to compare and contrast the similarities and differences between an open circulatory system and a closed circulatory system. Give at least one example of an organism with each type of circulatory system.
   (b) Why can insects and other invertebrates survive with an open circulatory system? K/U C
5. (a) Explain the difference between the pulmonary circuit and the systemic circuit.
   (b) What structural feature of the heart makes a two-circuit system possible? Explain. K/U A
6. You have already learned that the digestive system relies on the circulatory system for the distribution of nutrients to the cells of the body. How do you think the digestive system contributes to the functioning of the circulatory system? T/I A
7. Use the Internet and other sources to research the evolution of the heart from two chambers to four chambers. Write a brief summary of your research, including the reason for the evolution and the advantages of the four-chambered heart. T/I C

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