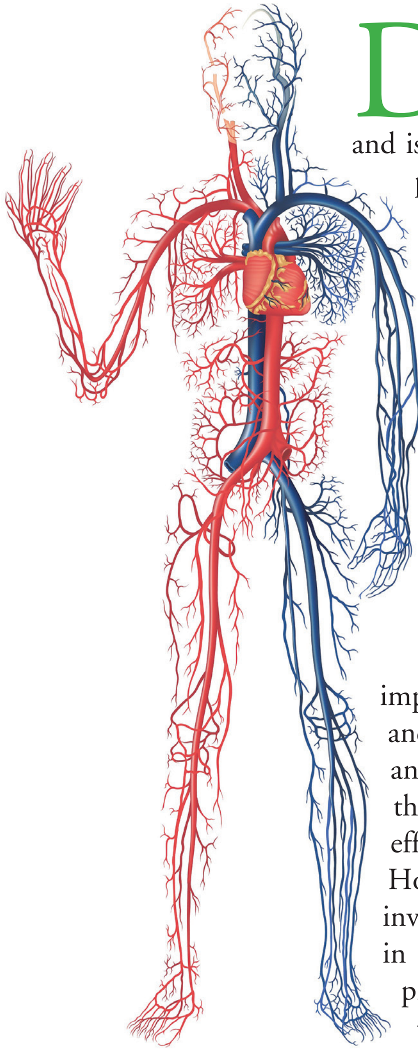
In This Chapter:

CHAPTER 8

THE HEART AND LUNGS AT WORK

After completing this chapter you should be able to:

- explain the function and control of the cardiovascular and respiratory systems;
- describe the relationship between the cardiorespiratory system and energy production;
- explain the measures that are used to evaluate and describe the various components of the cardiovascular and respiratory systems;
- describe the acute and chronic effects of physical activity on the body;
- analyze the effects of different environmental conditions on the body during physical activity.



During an average human life the heart will beat about three billion times, beginning soon after conception and continuing until death. The heart is one of the first organs to begin functioning and is often associated with life and death. This life-sustaining organ that pumps blood throughout our bodies is only one part of our circulatory system. The others – blood vessels (the passageways) and blood (the transport medium) – complete the transport system that delivers supplies to the tissues that need them for survival and growth. Oxygen is perhaps the most important supply to be delivered at rest and during periods of physical activity.

The systems of the body, however, are by no means independent of one another. Pulmonary structure and function are closely linked with the cardiovascular system; without getting oxygen into the body through breathing (ventilation), diffusion, and gas exchange in the lungs, there is no oxygen to transport to the body's tissues. Thus, the body's systems must work together in order to function most efficiently.

Because cardiovascular function is so vital to our existence, it is important to be aware of the advantages that can result from training, and their implications for health. Exercise offers numerous benefits, and enhanced cardiovascular function is one of them. Understanding the changes that occur during exercise will enable you to train more effectively for performance and will improve your cardiovascular health. How are blood flow and blood volume controlled? What is actually involved in the transport of oxygen? And what role does hemoglobin play in oxygen transport? The answers to these and other questions will be presented in this chapter; this material will provide the foundation you will need to attain and maintain optimal cardiovascular health.

Cardiovascular Anatomy

The primary role of the cardiovascular system is supplying muscles and organs with the oxygen and nutrients they need to function properly, and removing metabolic by-products from areas of activity. Optimal functioning of this system is critical for human performance. The anatomy and physiology of the heart and blood vessels are described in this section.

The Heart

Structure

The heart is an organ that pumps blood through the human body. It is made up of specialized muscle cells that form three distinct layers of tissue: the endocardium, the myocardium, and the epicardium. The **endocardium** is the innermost layer of smooth muscle that lines the chambers of the heart and allows blood to flow smoothly; the **myocardium** is the thick and muscular middle layer that is responsible for physically pumping the blood; and the **epicardium** is the thin outer layer that helps protect the heart. Just outside the epicardium lies the **pericardium**, a protective sac that loosely surrounds the entire heart, allowing it to expand and contract freely.

Terminology A!ert

Like most anatomical terms, the layers of the heart can be figured out by identifying the root words involved: *endo-* (within), *myo-* (muscle), *epi-* (upon), *peri-* (around), and *-cardium* (heart).

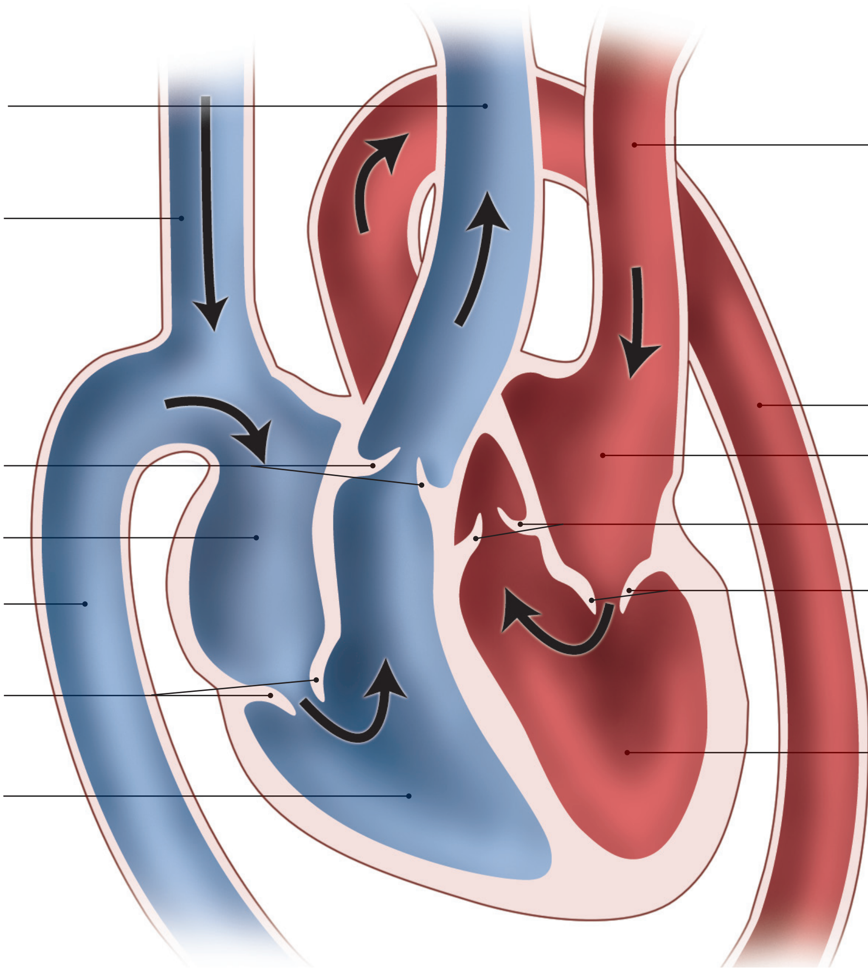
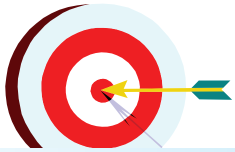


Figure 8.1 The chambers, vessels, and valves of the heart work together efficiently to supply all parts of the body with blood and oxygen.

Heart Chambers and Vessels The heart pumps blood through the body by using two different pumps called ventricles (Figure 8.1). The **right ventricle** pumps deoxygenated blood to the lungs via the **pulmonary artery** (the only artery in the body that carries deoxygenated blood), and the **left ventricle** pumps oxygenated blood to the rest of the body through the **aorta** – the largest artery in the human body. Since the left ventricle has to pump blood through the entire body, it is larger and its muscle walls are stronger than that of the right ventricle, which has to pump blood only a short distance to the lungs.

The heart also has two smaller chambers called atria (singular = *atrium*), which pump blood into the ventricles for distribution to the lungs and other areas of the body. Deoxygenated blood from the peripheral organs and tissues enters the **right atrium** of the heart through two large veins called the **superior vena cava** (from the upper part of the body) and the **inferior vena cava** (from the lower part of the body). From here, the blood passes into the right ventricle, which then pumps the blood to the lungs. Once oxygenated, the blood returns to the **left atrium** of the heart via the **pulmonary vein** (the only vein in the body that carries oxygenated blood) before continuing on its path into the left ventricle and to the rest of the body.



The human heart has four separate chambers: two upper atria and two lower ventricles, with one atrium and one ventricle on each side of the heart. Each of the four chambers has a specific function that keeps this life-sustaining organ pumping efficiently.

Heart Valves Blood in the heart flows from one chamber to another through two sets of valves, which open and close to ensure that blood flows in the proper direction. The two **semilunar valves** allow blood to flow into the arteries during ventricular contraction and prevent backflow

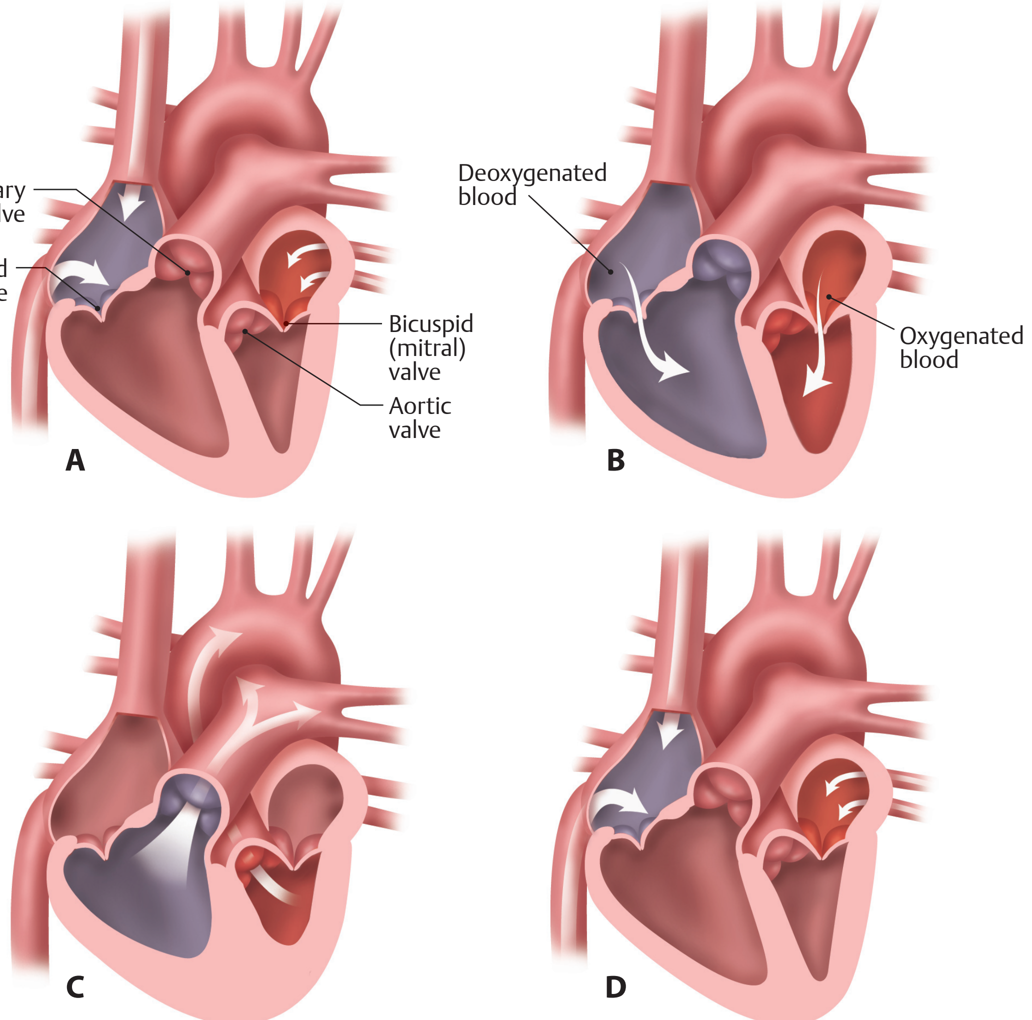


Figure 8.2 The finely tuned cardiac cycle. **(A)** As the heart relaxes in diastole, both atria and ventricles simultaneously fill with blood. **(B)** The atria, squeezing into systole, force blood into the ventricles. **(C)** As the ventricle compartments fill with blood, they contract, thereby ejecting blood to the lungs and body. **(D)** The atria and ventricles relax as the cycle begins anew.

during ventricular relaxation. Blood flow from the right ventricle into the pulmonary artery is regulated by the **pulmonary valve**, while the **aortic valve** controls blood flow from the left ventricle into the aorta.

Similarly, the two **atrioventricular valves** regulate blood flow between the atria and ventricles, allowing blood to flow from the right atrium into the right ventricle (**tricuspid valve**) and from the left atrium into the left ventricle (**bicuspid** or **mitral valve**), but not in the opposite direction.

Function

The heart contracts in a constant rhythm that may speed up or slow down depending on the need for blood (and oxygen) in the body. For example, if you start running, your leg muscles will need more oxygen to do the work. The heart needs to pump more oxygen-carrying blood to those working muscles and will have to beat more rapidly in order to supply that blood.

Located in the right atrium, the sinus node generates the electrical impulse that controls the rate of beating of the heart.

The beating of the heart is governed by an automatic electrical impulse that is generated by the **sinus node** – a small bundle of nerve fibers that are found in the wall of the right atrium near the opening of the superior vena cava. The sinus node generates an electrical charge called an **action potential** that causes the muscle walls of the heart to contract. The atria contract before the ventricles contract, which allows for the blood to be quickly pumped into the ventricles from the atria and then from the ventricles to the lungs and the rest of the body (Figure 8.2). The sinus node determines the rate of beating of the entire heart.

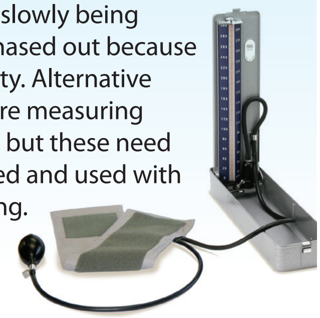
Blood Pressure

There are two components to the measure of blood pressure, which is an important measure of cardiac function. The first component is the pressure in the ventricles when they are contracting and pushing blood out into the body. This is called systole. Systolic pressure provides an estimate of how hard the heart is working and the strain against the arterial walls during the contraction. In healthy young adults, systolic pressure is normally around 120 mm Hg.

The second component of blood pressure is used to describe the pressure in the heart when it is in the relaxation phase of the cardiac cycle (the ventricles are relaxed and being filled with blood), called diastole. Diastolic pressure is used as an indicator of peripheral blood pressure (the blood pressure in the body outside the heart). It provides an indication of the ease with which the blood flows from the arterioles into the capillaries. The normal diastolic pressure in healthy young adults is about 70 to 80 mm Hg.

DID YOU KNOW?

Mercury **sphygmomanometers** have been routinely used in medicine as the gold standard for measuring blood pressure, but mercury-containing products are slowly being banned or phased out because of their toxicity. Alternative blood pressure measuring devices exist, but these need to be validated and used with proper training.



SILENT BUT DEADLY

Often referred to as the "silent killer" because it shows no early warning signs or symptoms, high blood pressure (**hypertension**) increases the risk of heart disease and stroke – two leading causes of death in North America. The problem is many people don't realize they have it, which is why it is so important to get your blood pressure checked regularly. The good news is that you can do many things to help control high blood pressure, including changes to your diet and exercise habits.

Getting regular blood pressure checks is key to maintaining cardiovascular health.

Cardiac Output

The amount of blood that is pumped into the aorta each minute by the heart is known as the cardiac output (measured in liters per minute). Cardiac output is the product of stroke volume (measured in milliliters per beat) and heart rate (measured in beats per minute) and is therefore representative of the quantity of blood that flows to the peripheral circulation. Cardiac output can be described by the simple equation presented below:

Cardiac output = Stroke volume x Heart rate

Stroke Volume The amount of blood that is pumped out of the left ventricle with each heartbeat is the stroke volume. The stroke volume of the heart is measured in milliliters (1 liter = 1,000 ml). A typical stroke volume for a normal heart is about 70 ml of blood. Regular exercise and sports training can increase stroke volume.

Figure 8.3 Measuring the carotid pulse in the neck (A) or the radial pulse in the wrist (B) can provide you with a good estimate of your work or exercise intensity.

Heart Rate The rhythmical contraction of the walls of the heart is commonly known as a **heartbeat**. **Heart rate** is the number of times the heart beats in one minute and is measured in beats per minute (bpm). At rest the normal heart rate of an adult can range from 40 bpm in a highly trained athlete to 70 bpm in a normal healthy person. During intense exercise, the heart rate may increase to up to 200 bpm and occasionally even higher. The maximum expected heart rate for most people can be estimated by using the following equation:

Maximum heart rate = 220 – Age (in years)

Intensity of Work The intensity of aerobic exercise can be estimated by measuring heart rate as the two are highly related. The higher the intensity of exercise the higher the heart rate per minute. Since heart rate is a measure that is easily obtained, it becomes very practical for estimation of intensity of work and/or exercise. The heart rate can easily be measured by feeling the **carotid** or **radial pulses** with the middle three fingers as in Figure 8.3. By placing two or three fingers and applying light pressure between the trachea and the sternocleidomastoid muscle in the neck you can feel the carotid pulse. Then count the number of beats in 10 seconds and multiply the figure by 6 to get the number of beats per minute.

For example, a count of 17 beats in 10 seconds multiplied by 6 would result in a heart rate of 102 beats per minute. This elementary procedure allows you to quickly determine how hard you are working without any specialized equipment.

The Peripheral Circulatory System

All of the blood vessels in the human body are made up of multiple layers of tissue. Smooth muscle cells allow these vessels to contract, which allows the peripheral circulatory system to regulate blood flow and alter the pattern of circulation throughout the body.

The peripheral circulatory system includes the vessels that carry blood away from the heart to the muscles and organs (lungs, brain, stomach, intestines) and those that return the blood to the heart (Figure 8.4). The vessels that carry blood away from the heart are called arteries and the vessels that return blood to the heart are called veins. These are discussed in the following sections.

Arteries

As the **arteries** carry blood away from the heart they branch into smaller and smaller vessels called **arterioles**. The arterioles also branch into smaller and smaller vessels until they are made up of vessels that are about the width of one red blood cell (Figure 8.5). At this point they are called **capillaries**. The capillaries are small vessels composed of only endothelial cells that allow for the exchange of oxygen and nutrients from the blood to muscles and organs and also allow blood to pick up the waste products and carbon dioxide from metabolism.

Arteries branch into smaller and smaller vessels called arterioles, which branch into even smaller vessels called capillaries.

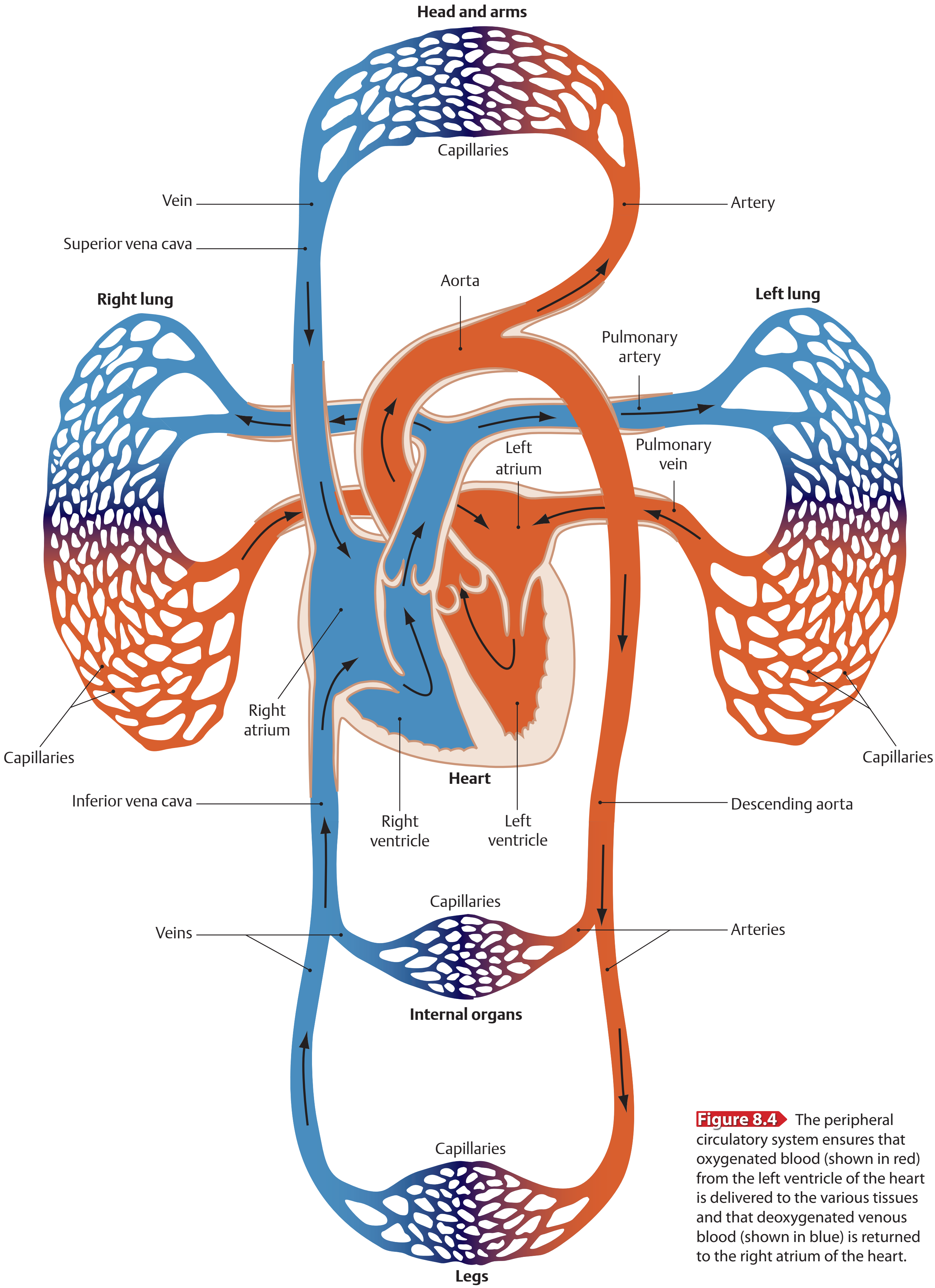


Figure 8.4 The peripheral circulatory system ensures that oxygenated blood (shown in red) from the left ventricle of the heart is delivered to the various tissues and that deoxygenated venous blood (shown in blue) is returned to the right atrium of the heart.