1. **INTRODUCTION**

Currently, approx 60 million individuals in the United States alone have some form of cardiovascular disease. More specifically, heart attacks continue to be an increasing problem in our society. Coronary bypass surgery, angioplasty, stenting, the implantation of pacemakers/defibrillators, and valve replacement are currently routine treatment procedures, with growing numbers of such procedures performed each year. However, such treatments often provide only temporary relief of the progressive symptoms of cardiac disease. Optimization of therapies and the development of new ones (e.g., coated vascular or coronary stents, left ventricular assist devices, and biventricular pacing) continue to dominate the cardiovascular biomedical industry.

The purpose of this chapter is to provide a general overview of the cardiovascular system as a quick reference as to the underlying physiological composition of this system. More details concerning the pathophysiology of the cardiovascular system and state-of-the-art treatments can be found in subsequent chapters. In addition, note that a list of sources and references is provided at the end of this chapter.

2. **COMPONENTS OF THE CARDIOVASCULAR SYSTEM**

The principal components considered to make up the cardiovascular system include the blood, blood vessels, heart, and lymphatic system.

2.1. **Blood**

Blood is composed of formed elements (cells and cell fragments) suspended in the liquid (plasma) fraction. Blood, considered the only liquid connective tissue in the body, has three general functions: (1) transportation (e.g., \(O_2\), \(CO_2\), nutrients, wastes, hormones); (2) regulation (e.g., pH, temperature, osmotic pressures); and (3) protection (e.g., against foreign molecules and diseases, as well as for clotting to prevent excessive loss of blood). Dissolved within the plasma are many proteins, nutrients, metabolic waste products, and various other molecules traveling between the organ systems.

The formed elements in blood include red blood cells (erythrocytes), white blood cells (leukocytes), and the cell fragments known as platelets. All are formed in bone marrow from a common stem cell. In a healthy individual, the majority (~99%) of blood cells are red cells, which have a primary role in \(O_2\) exchange. Hemoglobin, the iron-containing heme protein that binds oxygen, is concentrated within the red cells; hemoglobin allows blood to transport 40 to 50 times the amount of oxygen that plasma alone could carry.

The white cells are required for the immune process to protect against infections and cancers. The platelets play a primary role in blood clotting. In a healthy cardiovascular system, the constant movement of blood helps keep these cells well dispersed throughout the plasma of the larger diameter vessels.

The **hematocrit** is defined as the percentage of blood volume occupied by the red cells (erythrocytes). It can be easily measured by centrifuging (spinning at high speed) a sample of blood, which forces these cells to the bottom of the centrifuge tube. The leukocytes remain on the top, and the platelets form a very
thin layer between the cell fractions (other, more sophisticated methods are also available to do such analyses). Normal hematocrit is approx 45% in men and 42% in women.

The total volume of blood in an average-size individual (70 kg) is approx 5.5 L; hence, the average red cell volume would be roughly 2.5 L. Because the fraction containing both leukocytes and platelets is normally relatively small or negligible, in such an individual the plasma volume can be estimated as 3.0 L. Approximately 90% of plasma is water, which acts: (1) as a solvent, (2) to suspend the components of blood, (3) in absorption of molecules and their transport, and (4) in the transport of thermal energy. Proteins make up 7% of the plasma (by weight) and exert a colloid osmotic pressure.

Protein types include albumins, globulins (antibodies and immunoglobulins), and fibrinogen. To date, more than 100 distinct plasma proteins have been identified, and each presumably serves a specific function. The other main solutes in plasma include electrolytes, nutrients, gases (some O2, large amounts of CO2 and N2), regulatory substances (enzymes and hormones), and waste products (urea, uric acid, creatine, creatinine, bilirubin, and ammonia).

2.2. Blood Vessels

Blood flows throughout the body tissues in blood vessels via bulk flow (i.e., all constituents together and in one direction). An extraordinary degree of branching of blood vessels exists within the human body, which ensures that nearly every cell in the body lies within a short distance from at least one of the smallest branches of this system—a capillary. Nutrients and metabolic end products move between the capillary vessels and the surroundings of the cell through the interstitial fluid by diffusion. Subsequent movement of these molecules into a cell is accomplished by both diffusion and mediated transport. Nevertheless, blood flow through all organs can be considered as passive and occurs only because arterial pressure is kept higher than venous pressure via the pumping action of the heart.

In an individual at rest at a given moment, approx 5% of the total circulating blood is actually in capillaries. Yet, this volume of blood can be considered to perform the primary functions of the entire cardiovascular system, specifically the supply of nutrients and removal of metabolic end products. The cardiovascular system, as reported by the British physiologist William Harvey in 1628, is a closed-loop system, such that blood is pumped out of the heart through one set of vessels (arteries) and then returns to the heart in another (veins).

More specifically, it can be considered that there are two closed-loop systems that both originate and return to the heart—the pulmonary and systemic circulations (Fig. 1). The pulmonary circulation is composed of the right heart pump and the lungs, whereas the systemic circulation includes the left heart pump, which supplies blood to the systemic organs (i.e., all tissues and organs except the gas exchange portion of the lungs). Because the right and left heart pumps function in a series arrangement, both will circulate an identical volume of blood in a given minute (cardiac output, normally expressed in liters per minute).

In the systemic circuit, blood is ejected out of the left ventricle via a single large artery—the aorta. All arteries of the systemic circulation branch from the aorta (this is the largest artery of the body, with a diameter of 2–3 cm) and divide into progressively smaller vessels. The aorta’s four principal divisions are: the ascending aorta (begins at the aortic valve, where, close by, the two coronary artery branches have their origin), the arch of the aorta, the thoracic aorta, and the abdominal aorta.

The smallest of the arteries eventually branch into arterioles. They, in turn, branch into an extremely large number (estimated at 10 billion in the average human body) of vessels with the smallest diameter, the capillaries. Next, blood exits the capillaries and begins its return to the heart via the venules. Microcirculation is a term coined to describe collectively the flow of blood through arterioles, capillaries, and venules (Fig. 2).

Importantly, blood flow through an individual vascular bed is profoundly regulated by changes in activity of the sympathetic nerves innervating the arterioles. In addition, arterial smooth muscle is very responsive to changes in local chemical conditions (i.e., those changes associated with increases or decreases in the metabolic rate of that given organ) within an organ.