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Overview of the Circulation and Blood

OBJECTIVES

1. Describe the general structure of the cardiovascular system.
2. Compare the compositions and functions of the blood vessels.
3. Compare the relationship of the vascular cross-sectional area to the velocity of blood flow in the various vascular segments.
4. Indicate the pressure changes and pathways of blood flow throughout the vasculature.
5. Describe the constituents of the blood and explain the functions of the cellular elements of blood.
6. Know the importance of blood group matching before blood transfusions.

The circulatory, endocrine, and nervous systems constitute the principal coordinating and integrating systems of the body. Whereas the nervous system is primarily concerned with communication and the endocrine glands with regulation of certain body functions, the circulatory system serves to transport and distribute essential substances to the tissues and to remove metabolic byproducts. The circulatory system also shares in such homeostatic mechanisms as regulation of body temperature, humoral communication throughout the body, and adjustments of O_2 and nutrient supply in different physiological states.

THE CIRCULATORY SYSTEM

The cardiovascular system accomplishes these functions with a pump (see Chapter 4), a series of distributing and collecting tubes (see Chapter 7), and an extensive system of thin vessels that permit rapid exchange between the tissues and the vascular channels (see Chapter 8). The primary purpose of this text is to discuss the function of the components of the vascular system and the control mechanisms (with their checks and balances) that are responsible for alteration of blood distribution necessary to meet the changing requirements of different tissues in response to a wide spectrum of physiological (see Chapters 9 and 10) and pathological (see Chapter 13) conditions.

Before one considers the function of the parts of the circulatory system in detail, it is useful to consider it as a whole in a purely descriptive sense (Fig. 1.1). The heart

consists of two pumps in series: the right ventricle to propel blood through the lungs for exchange of O_2 and CO_2 (the **pulmonary circulation**) and the left ventricle to propel blood to all other tissues of the body (the **systemic circulation**). The total flow of blood out of the left ventricle is known as the cardiac output (CO). The rhythmic contraction of the heart is an intrinsic property of the heart whose sinoatrial node pacemaker generates action potentials spontaneously (see Chapter 3). These action potentials are propagated in an orderly manner through the organ to trigger contraction and to produce the currents detected in the electrocardiogram (see Chapter 3).

Unidirectional flow through the heart is achieved by the appropriate arrangement of effective flap valves. Although the cardiac output is intermittent, continuous flow to the periphery occurs by distention of the aorta and its branches during ventricular contraction (**systole**) and elastic recoil of the walls of the large arteries that propel the blood forward during ventricular relaxation (**diastole**). Blood moves rapidly through the aorta and its arterial branches (see Chapter 7). The branches become narrower and their walls become thinner and change histologically toward the periphery. From the aorta, a predominantly elastic structure, the peripheral arteries become more muscular until the muscular layer predominates at the arterioles (Fig. 1.2).

In the large arteries, frictional resistance is relatively small, and mean pressure throughout the system of large arteries is only slightly less than in the aorta. The small

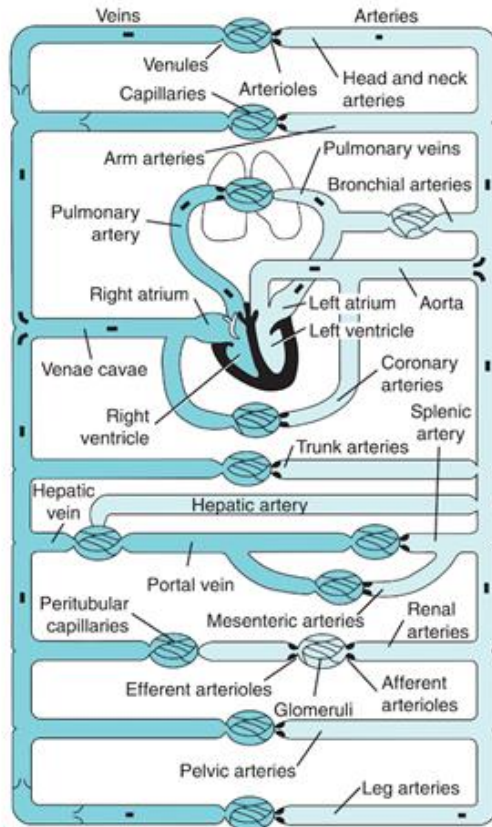


Fig. 1.1 Schematic diagram of the parallel and series arrangement of the vessels composing the circulatory system. The capillary beds are represented by *thin lines* connecting the arteries (on the *right*) with the veins (on the *left*). The crescent-shaped thickenings proximal to the capillary beds represent the arterioles (resistance vessels). (Redrawn from Green, H. D. (1944). In O. Glasser (Ed.). *Medical physics* (Vol 1); Chicago: Mosby-Year Book.)

arteries and arterioles serve to regulate flow to individual tissues by varying their resistance to flow. The small arteries offer moderate resistance to blood flow, and this resistance reaches a maximal level in the arterioles, sometimes referred to as the stopcocks of the vascular system. Hence the *pressure drop is significant and is greatest in the small arteries and in the arterioles* (Fig. 1.3). Adjustments in the degree of contraction of the circular muscle of these small vessels permit regulation of tissue blood flow and aid in the control of arterial blood pressure (see Chapter 9).

In addition to a sharp reduction in pressure across the arterioles, there is also a change from pulsatile to steady flow as pressure continues to decline from the arterial to the venous end of the capillaries (see Fig. 1.3). The *pulsatile arterial blood flow*, caused by the phasic cardiac ejection, is damped at the capillaries by the combination of distensibility of the large arteries and frictional resistance in the arterioles.

CLINICAL BOX

In a patient with hyperthyroidism (*Graves disease*), the basal metabolism is elevated and is often associated with arteriolar vasodilation. This reduction in arteriolar resistance diminishes the dampening effect on the pulsatile arterial pressure and is manifested as pulsatile flow in the capillaries, as observed in the fingernail beds of patients with this ailment.

Many capillaries arise from each arteriole to form the microcirculation (see Chapter 8), so that the total cross-sectional area of the capillary bed is very large, despite the fact that the cross-sectional area of each capillary is less than that of each arteriole. As a result, blood flow velocity becomes quite slow in the capillaries (see Fig. 1.3), analogous to the decrease in velocity of flow seen at the wide regions of a river. Conditions in the capillaries are ideal for the exchange of diffusible substances between blood and tissue, because the capillaries are short tubes whose walls are only one cell thick and because flow velocity is low.

On its return to the heart from the capillaries, blood passes through venules and then through veins of increasing size with a progressive decrease in pressure until the blood reaches the vena cava (see Fig. 1.3). As the heart is approached, the number of veins decreases, the thickness and composition of the vein walls change (see Fig. 1.2), the total cross-sectional area of the venous channels diminishes, and the velocity of blood flow increases (see Fig. 1.3). Note that the velocity of blood flow and the cross-sectional area at each level of the vasculature are essentially mirror images of each other (see Fig. 1.3).

Data indicate that between the aorta and the capillaries the total cross-sectional area increases about 500-fold (see Fig. 1.3). The volume of blood in the systemic vascular system (Table 1.1) is greatest in the veins and small veins (64%). Of the total blood volume only about 6% is in the capillaries and 14% in the aorta, arteries, and arterioles. In contrast, blood volume in the pulmonary vascular bed is about equal between arteries and capillaries; venous vessels display a slightly larger percentage of pulmonary blood volume. The cross-sectional area of the venae cavae is larger than that of the aorta. Therefore the velocity of flow is slower in the venae cavae than that in the aorta (see Fig. 1.3).

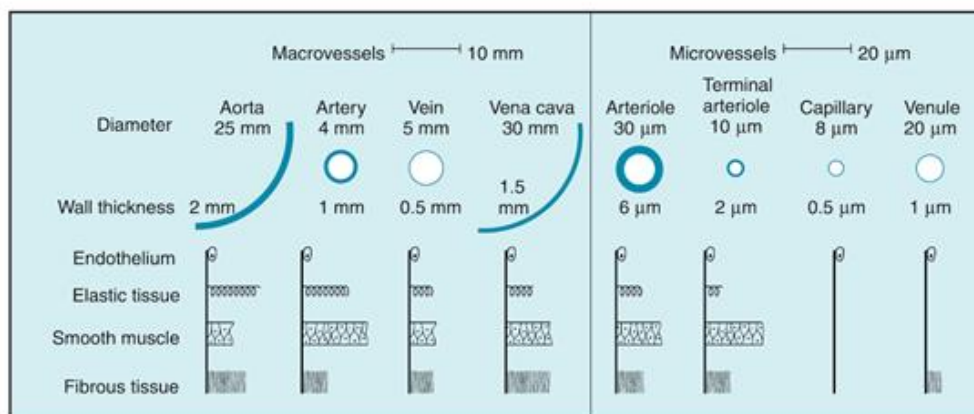


Fig. 1.2 Internal diameter, wall thickness, and relative amounts of the principal components of the vessel walls of the various blood vessels that compose the circulatory system. Cross sections of the vessels are not drawn to scale because of the huge range from aorta and venae cavae to capillary. (Redrawn from Burton, A. C. (1954). Relation of structure to function of the tissues of the wall of blood vessels. *Physiological Reviews*, 34(4), 619–642.)

Blood entering the right ventricle via the right atrium is pumped through the pulmonary arterial system at a mean pressure about one-seventh that in the systemic arteries. The blood then passes through the lung capillaries, where CO_2 is released and O_2 taken up. The O_2 -rich blood returns via the four pulmonary veins to the left atrium and ventricle to complete the cycle. Thus in the normal intact circulation the total volume of blood is constant, and an increase in the volume of blood in one area must be accompanied by a decrease in another. However, the *distribution* of the circulating blood to the different body organs is determined by the output of the left ventricle and by the contractile state of the arterioles (resistance vessels) of these organs (see Chapters 9 and 10). In turn, the *cardiac output* is controlled by the rate of heartbeat, cardiac contractility, venous return, and arterial resistance. The circulatory system is composed of conduits arranged in series and in parallel (see Fig. 1.1).

It is evident that the systemic and pulmonary vascular systems are composed of many blood vessels arranged in series and parallel, with respect to blood flow. The total resistance to blood flow of the systemic blood vessels is known as the total peripheral resistance (TPR), and the total resistance of the pulmonary vessels is known as the total pulmonary resistance. Total peripheral resistance and cardiac output determine the mean pressure in the large arteries, through the hydraulic resistance equation (see Chapter 7).

The main function of the circulating blood is to carry O_2 and nutrients to the various tissues in the body and to remove CO_2 and waste products from those tissues.

Furthermore, blood transports other substances, such as hormones, white blood cells, and platelets, from their sites of production to their sites of action. Blood also aids in the distribution of fluids, solutes, and heat. Hence blood contributes to **homeostasis**, the maintenance of a constant internal environment.

A fundamental characteristic of normal operation of the cardiovascular system is the maintenance of a relatively constant mean (average) blood pressure within the large arteries. The difference between mean arterial pressure (\bar{P}_a) and the pressure in the right atrium (P_{ra}) provides the driving force for flow through the resistance (R) of blood vessels of the individual tissues. Thus when the circulatory system is in steady-state, total flow of blood from the heart (cardiac output, CO) equals total flow of blood returning to the heart. The relation among these variables is described in the following hydraulic equation:

$$\bar{P}_a - P_{ra} = \text{CO} \times R \quad (1.1)$$

The cardiovascular system, together with neural, renal, and endocrine systems, maintains \bar{P}_a at a relatively constant level, despite the large variations in cardiac output and peripheral resistance that are required in daily life. *If the \bar{P}_a is maintained at its normal level under all circumstances, then each individual tissue will be able to obtain the necessary blood flow required to sustain its functions. Because blood flow to the brain and the heart cannot be interrupted for even a few seconds without endangering life, maintenance of the \bar{P}_a is a critical function of the cardiovascular system.*