

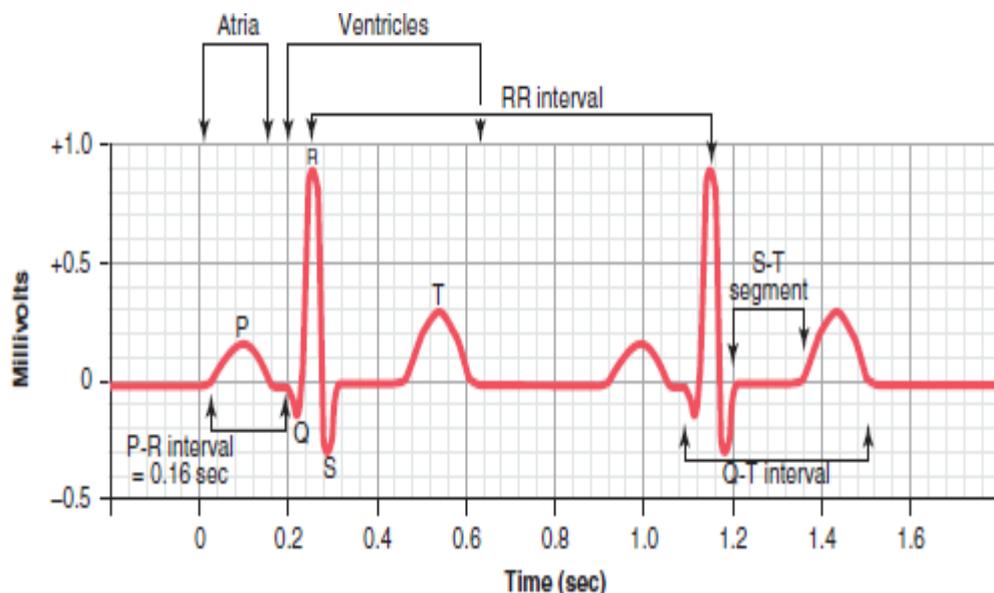
The Normal Electrocardiogram

When the cardiac impulse passes through the heart, electrical current also spreads from the heart into the adjacent tissues surrounding the heart. A small portion of the current spreads all the way to the surface of the body. If electrodes are placed on the skin on opposite sides of the heart, electrical potentials generated by the current can be recorded; the recording is known as an *electrocardiogram (ECG)*

The normal ECG is composed of a P wave, a QRS complex, and a T wave. The QRS complex is often, but not always, three separate waves: the Q wave, the R wave, and the S wave.

The *P wave* is caused by electrical potentials generated when the atria depolarize before atrial contraction begins. The *QRS complex* is caused by potentials generated when the ventricles depolarize before contraction, that is, as the depolarization wave spreads through the ventricles. Therefore, both the P wave and the components of the QRS complex are *depolarization waves*.

The *T wave* is caused by potentials generated as the ventricles recover from the state of depolarization. This process normally occurs in ventricular muscle 0.25 to 0.35 second after depolarization. The T wave is known as a *repolarization wave*.



Overview of the Circulation; Biophysics of Pressure, Flow, and Resistance

The function of the circulation is to serve the needs of the body tissues—to transport nutrients to the body tissues, to transport waste products away, to transport hormones from one part of the body to another and, in general, to maintain an appropriate environment in all the tissue fluids of the body for survival and optimal function of the cells. The rate of blood flow through many tissues is controlled mainly in response to their need for nutrients. In some organs, such as the kidneys, the circulation serves additional functions. Blood flow to the kidney, for example, is far in excess of its metabolic requirements and is related to its excretory function, which requires that a large volume of blood be filtered each minute.

The heart and blood vessels, in turn, are controlled to provide the necessary cardiac output and arterial pressure to cause the needed tissue blood flow.

The circulation is divided into the *systemic circulation* and the *pulmonary circulation*. Because the systemic circulation supplies blood flow to all the tissues of the body except the lungs, it is also called the *greater circulation* or *peripheral circulation*.

Functional Parts of the Circulation

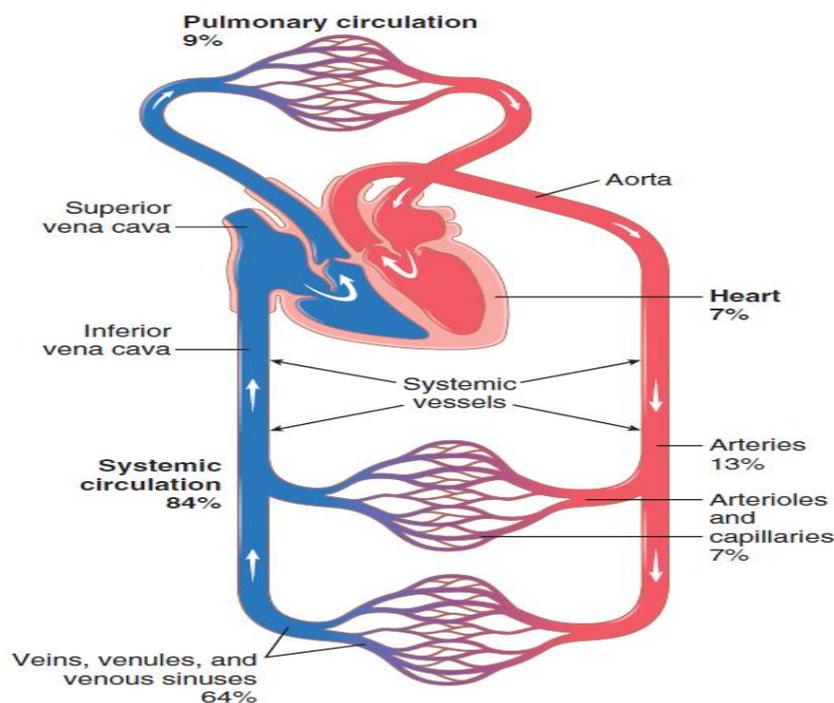
It is important to understand the role of each part of the circulation. The function of the *arteries* is to transport blood *under high pressure* to the tissues. For this reason, the arteries have strong vascular walls, and blood flows at a high velocity in the arteries.

The *arterioles* are the last small branches of the arterial system; they act as *control conduits* through which blood is released into the capillaries. Arterioles have strong muscular walls that can close the arterioles completely or can, by relaxing, dilate the vessels several fold, thus having the capability of vastly altering blood flow in each tissue in response to its needs.

The function of the *capillaries* is to exchange fluid, nutrients, electrolytes, hormones, and other substances between the blood and the interstitial fluid. To serve this role, the capillary walls are thin and have numerous minute *capillary pores* permeable to water and other small molecular substances.

The *venules* collect blood from the capillaries and gradually coalesce into progressively larger veins.

The *veins* function as conduits for transport of blood from the venules back to the heart; equally important, they serve as a major reservoir of extra blood. Because the pressure in the venous system is very low, the venous walls are thin. Even so, they are muscular enough to contract or expand and thereby serve as a controllable reservoir for the extra blood, either a small or a large amount, depending on the needs of the circulation.



Pressures in the Various Portions of the Circulation

Because the heart pumps blood continually into the aorta, the mean pressure in the aorta is high, averaging about 100 mm Hg. Also, because heart pumping is pulsatile, the arterial pressure alternates between a

systolic pressure level of 120 mm Hg and a *diastolic pressure level* of 80 mm Hg.

The pressure in the systemic capillaries varies from as high as 35 mm Hg near the arteriolar ends to as low as 10 mm Hg near the venous ends, but their average “functional” pressure in most vascular beds is about 17 mm Hg, a pressure low enough that little of the plasma leaks through the minute *pores* of the capillary walls, even though nutrients can *diffuse* easily through these same pores to the outlying tissue cells.

In the pulmonary arteries, the pressure is pulsatile, just as in the aorta, but the pressure is far less: *pulmonary artery systolic pressure* averages about 25 mm Hg and *diastolic pressure* averages about 8 mm Hg, with a mean pulmonary arterial pressure of only 16 mm Hg. The mean pulmonary capillary pressure averages only 7 mm Hg. Yet, the total blood flow through the lungs each minute is the same as through the systemic circulation. The low pressures of the pulmonary system are in accord with the needs of the lungs because all that is required is to expose the blood in the pulmonary capillaries to oxygen and other gases in the pulmonary alveoli.

Blood Flow

Blood flow through a blood vessel is determined by two factors: (1) *pressure difference* of the blood between the two ends of the vessel, also sometimes called “pressure gradient” along the vessel, which pushes the blood through the vessel, and (2) the impediment to blood flow through the vessel, which is called *vascular resistance* demonstrates these relationships, showing a blood vessel segment located anywhere in the circulatory system.

P1 represents the pressure at the origin of the vessel; at the other end, the pressure is P2. Resistance occurs as a result of friction between the flowing blood and the intravascular endothelium all along the inside of the vessel. The flow through the vessel can be calculated by the following formula, which is called *Ohm’s law*:

$$F = \frac{\Delta P}{R}$$

in which F is blood flow, ΔP is the pressure difference ($P_1 - P_2$) between the two ends of the vessel, and R is the resistance. This formula states that the blood flow is directly proportional to the pressure difference but inversely proportional to the resistance.

Note that it is the *difference* in pressure between the two ends of the vessel, not the absolute pressure in the vessel, that determines rate of flow. For example, if the pressure at both ends of a vessel is 100 mm Hg and yet no difference exists between the two ends, there will be no flow despite the presence of 100 mm Hg pressure.

BLOOD PRESSURE

Standard Units of Pressure. Blood pressure almost always is measured in millimeters of mercury (mm Hg) because the mercury manometer has been used as the standard reference for measuring pressure since its invention in 1846 by Poiseuille. Actually, blood pressure means the *force exerted by the blood against any unit area of the vessel wall*. When one says that the pressure in a vessel is 50 mm Hg, this means that the force exerted is sufficient to push a column of mercury against gravity up to a level 50 millimeters high. If the pressure is 100 mm Hg, it will push the column of mercury up to 100 millimeters.

RESISTANCE TO BLOOD FLOW

Units of Resistance. Resistance is the impediment to blood flow in a vessel, but it cannot be measured by any direct means. Instead, resistance must be calculated from measurements of blood flow and pressure difference between two points in the vessel. If the pressure difference between two points is 1 mm Hg and the flow is 1 ml/ sec, the resistance is said to be 1 *peripheral resistance unit*, usually abbreviated *PRU*.

VASCULAR DISTENSIBILITY

A valuable characteristic of the vascular system is that all blood vessels are *distensible*. The distensible nature of the arteries allows them to accommodate the pulsatile output of the heart and to average out the pressure pulsations. This capability provides smooth, continuous flow of blood through the very small blood vessels of the tissues.

The most distensible by far of all the vessels are the veins. Even slight increases in venous pressure cause the veins to store 0.5 to 1.0 liter of extra blood. Therefore, *the veins provide a reservoir* for storing large quantities of extra blood that can be called into use whenever blood is required elsewhere in the circulation.

The walls of the arteries are thicker and far stronger than those of the veins. Consequently, the veins, on average, are about eight times more distensible than the arteries. That is, a given increase in pressure causes about eight times as much increase in blood in a vein as in an artery of comparable size.

Effect of Sympathetic Stimulation or Sympathetic Inhibition on the Volume-Pressure Relations of the Arterial and Venous Systems

are the effects on the volume-pressure curves when the vascular sympathetic nerves are excited or inhibited. It is evident that an increase in vascular smooth muscle tone caused by sympathetic stimulation increases the pressure at each volume of the arteries or veins, whereas sympathetic inhibition decreases the pressure at each volume. Control of the vessels in this manner by the sympathetics is a valuable means for diminishing the dimensions of one segment of the circulation, thus transferring blood to other segments. For instance, an increase in vascular tone throughout the systemic circulation can cause large volumes of blood to shift into the heart, which is one of the principal methods that the body uses to rapidly increase heart pumping.

Sympathetic control of vascular capacitance is also highly important during hemorrhage. Enhancement of sympathetic tone, especially to the veins, reduces the vessel sizes enough that the circulation continues to

operate almost normally even when as much as 25 percent of the total blood volume has been lost.