chapter 19

Functions of the Blood Vessels

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Key Terms

baroreceptor reflex (p. 362)
blood pressure (p. 357)
capillary exchange (p. 364)
diastolic pressure (p. 358)
hypertension (p. 358)
hypotension (p. 358)
ischemia (p. 357)
Korotkoff sounds (p. 358)
oncotic pressure (p. 365)
pulse pressure (p. 358)
systemic vascular resistance (p. 360)
systolic pressure (p. 358)
vasoconstriction (p. 361)
vasodilation (p. 361)
vasopressor (p. 364)

Objective

1. List the five functions of the blood vessels.
2. Discuss blood pressure, including:
   - Describe the measurement of blood pressure.
   - Explain the variance of blood pressure in different blood vessels.
   - Describe the factors that determine blood pressure.
   - Explain the mechanisms involved in regulation of blood pressure, including the baroreceptor reflex.
3. Explain how blood vessels act as exchange vessels, including:
   - Describe the factors that determine capillary exchange.
   - Describe the mechanisms of edema formation.
4. Explain how the blood vessels respond to changing body needs.
5. Describe the role of the blood vessels in the regulation of body temperature.

As mentioned earlier in this text, it took seemingly forever for the ancients to "connect" the heart and the peripheral blood vessels. After that connection was made, scientists realized that blood was pumped out of the left heart, circulated around the body, and returned to the right side of the heart. However, we still had no real understanding of the functions (physiology) of the peripheral blood vessels.

Today, we know that the blood vessels do more than allow blood to run around in circles. The blood vessels perform five important functions:

1. Act as a delivery system
2. Regulate blood pressure
3. Engage in the exchange of nutrients and waste between the capillaries and cells
4. Redistribute blood in response to changing body needs
5. Help regulate body temperature

BLOOD VESSELS DELIVER

The primary purpose of the cardiovascular system is to deliver blood that is rich in oxygen, hormones, nutrients, and water to the cells; the blood also collects cellular waste and delivers it to organs of excretion, such as the kidneys. The delivery of oxygen is especially critical. All cells need oxygen; without oxygen, they die. Impaired blood flow and oxygen deprivation is called **ischemia**; the consequences of ischemia are tissue damage, pain, and gangrene.

BLOOD VESSELS REGULATE BLOOD PRESSURE

Why do you need a blood pressure? Blood pressure is needed to push blood through the blood vessels to an organ. No blood pressure means no organ perfusion! **Blood pressure** is the force that blood exerts against the walls of the blood vessels. Blood pressure is determined by the pumping action of the heart and the diameter of the blood vessels.

MEASUREMENT OF BLOOD PRESSURE

116/72 mm Hg: WHAT IT MEANS

You just had a physical examination. The physician nodded approvingly that your blood pressure is normal at 116/72 mm Hg. Although you are thrilled to be normotensive (normal blood pressure), what exactly does 116/72 mm Hg mean?

The blood pressure in the large arteries is caused by the heart's pumping activity. When the ventricles contract, blood is pumped out of the ventricle into the artery, thereby increasing pressure. The pressure in the arteries at the peak of ventricular contraction (systole) is called the **systolic pressure**; it is the top number (e.g., 116 mm Hg). The **diastolic pressure** is the pressure in the large arteries when the ventricles of the heart are relaxing (diastole). The diastolic reading is the bottom number (e.g., 72 mm Hg).

By measuring blood pressure, you can also calculate **pulse pressure**. The pulse pressure is the difference between the systolic and the diastolic pressure. For example, your blood pressure is 116/72 mm Hg. Your pulse pressure is 44 mm Hg (116 minus 72).

Do You Know...

About the MABP?

A blood pressure is expressed as 120/80 mm Hg. What is the mean arterial blood pressure (MABP)? MABP is calculated as follows:

$$\text{MABP} = 2/3 \text{ diastolic pressure} + 1/3 \text{ systolic pressure}$$

or

$$\text{MABP} = \text{diastolic pressure} + 1/3 \text{ pulse pressure}$$

For a blood pressure of 120/80 mm Hg, the MABP is 94 mm Hg. Why is the MABP important? It is important because the organs are perfused by or "feel" the MABP. Note that the MABP expresses more of the diastolic pressure than the systolic pressure. The dominance of the MABP by the diastolic pressure is the basis for the clinical concern for the diastolic reading.

NORMAL AND ABNORMAL

Blood pressure readings vary according to age, gender, and size (and don't discount your emotional state). For example, the normal blood pressure of a 2-year-old child is 95/65 mm Hg. The normal blood pressure for an adult is defined as a systolic pressure of less than 120 mm Hg and a diastolic pressure of less than 80 mm Hg. For many years, a blood pressure of 120/80 mm Hg was considered normal for an adult; today, it is classified as prehypertensive. The maintenance of normal blood pressure is extremely important. If blood pressure becomes too low (**hypotension**), blood flow to vital organs decreases, and the person is said to be in shock. Without immediate treatment, the person may die. If the blood pressure becomes elevated (**hypertension**), the blood vessels may burst, or rupture. A ruptured blood vessel in the brain, for example, is a major cause of stroke, resulting in loss of speech, paralysis, and possible death. Hypertension also puts added strain on the heart, damages the blood vessels in the kidneys, and damages the retina, causing loss of vision. Chronic hypertension is a major cause of heart failure. You will spend much time "taking" blood pressures and will be expected to interpret abnormal readings.

Do You Know...

About "White Coat Hypertension"?

Often a patient's blood pressure elevates in response to a health care worker (wearing a white coat) recording his or her blood pressure, hence the term *white coat hypertension*. In fact, the person's blood pressure should be recorded a second time after he or she has relaxed. Emotions matter! Diagnosis and treatment are never based on a single blood pressure recording. There are other considerations in recording blood pressure, including proper cuff size and the patient's position (sitting with feet on the floor). The person should not be talking. One study has indicated that over 90% of blood pressure recordings in a single clinic violate proper procedure.

"TAKING" A BLOOD PRESSURE

Measurement of blood pressure provides valuable information regarding a person's general health. Blood pressure is most commonly measured over the brachial artery in the arm. Blood pressure is expressed in millimeters of mercury (mm Hg). Unless otherwise stated, the term *blood pressure* refers to the blood pressure in the large arteries.

The instrument used to take a blood pressure recording is the sphygmomanometer (sfig-moh-mah-NOM-eh-ter), which is a device with two basic components: a dial indicating the pressure and an inflatable cuff. The cuff is wrapped around the patient's arm and inflated with air until the brachial artery is compressed and the flow of blood through the artery is stopped. Then, with a stethoscope placed over the brachial artery distal to, or below, the cuff, the examiner listens for "tap tap tap" sounds. These sounds, called **Korotkoff (kor-ROT-koff) sounds**, are caused by the turbulent flow of blood through the brachial artery. The measurement of blood pressure is further explained in Figure 19-1.

? Re-Think

1. Your patient's blood pressure is 145/88 mm Hg. To what do the top and bottom numbers refer?
2. Your patient's initial blood pressure was 145/88 mm Hg. After 10 minutes, his blood pressure had declined to 122/76 mm Hg. What is a likely explanation for this spontaneous decline in blood pressure?

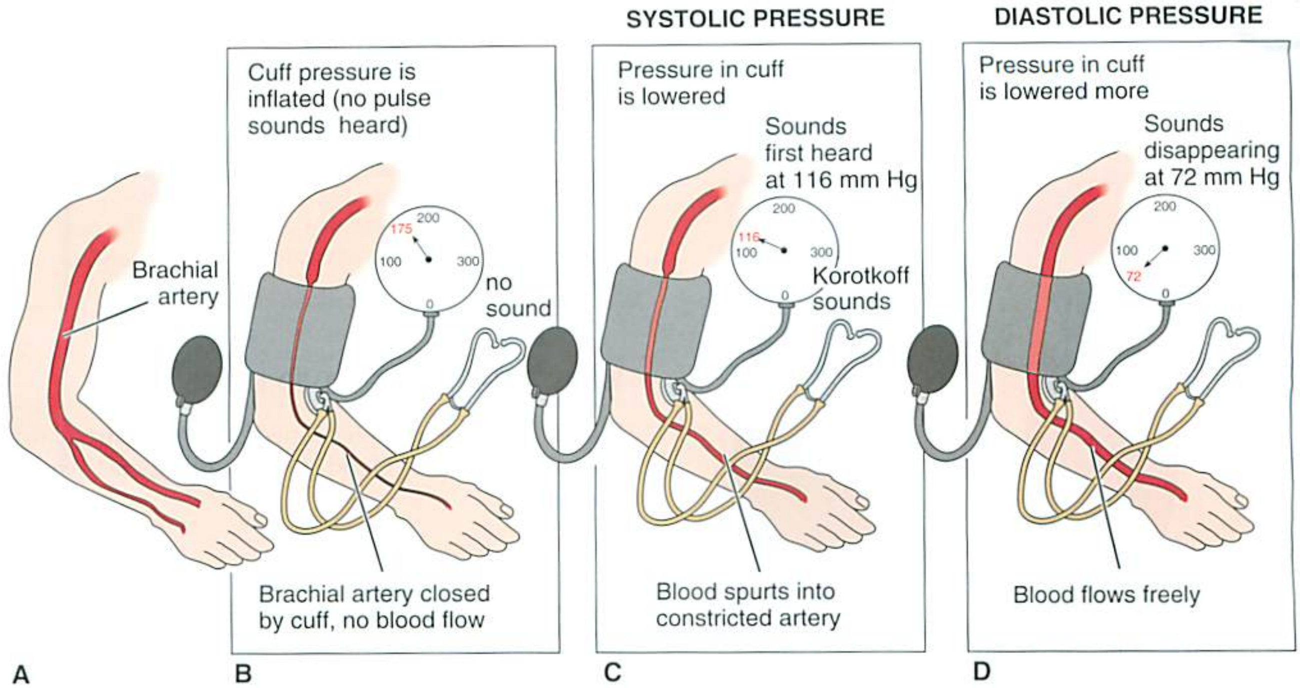


FIGURE 19-1 Taking a blood pressure. The measurement of blood pressure requires a sphygmomanometer and a stethoscope. Follow the panels for an explanation of the systolic (116 mm Hg) and diastolic (72 mm Hg) pressures. **A,** Identify the location of the brachial artery. **B,** Inflate the cuff, thereby squeezing the upper arm. At this point, the cuff pressure has become greater than the blood pressure in the brachial artery. The cuff pressure collapses the brachial artery, thereby stopping the flow of blood. No sound can be heard through the stethoscope. **C,** As the pressure in the cuff gradually diminishes, the artery opens slightly and blood spurts through the blood vessel in response to the pressure in the brachial artery. You can hear the spurting effect of the blood as soft tapping sounds. The number on the sphygmomanometer that corresponds to the tapping sounds is recorded as the systolic blood pressure (116 mm Hg). With further reduction in cuff pressure, the brachial artery opens wider and allows blood flow through the artery to increase. **D,** As cuff pressure declines even further, the brachial artery opens completely and normal blood flow through the artery resumes. At this point, the sounds heard through the stethoscope disappear or sound muffled. The pressure at which the sounds disappear is read as the diastolic blood pressure (72 mm Hg).

BLOOD PRESSURE IN DIFFERENT BLOOD VESSELS

Blood pressures vary from one type of blood vessel to the next (Figure 19-2). Note that the blood pressure is highest in the aorta because it is closest to the left ventricle; the left ventricle pumps blood with great force. The blood pressure gradually declines as the blood flows from the large arteries into the arterioles, into the capillaries, into the venules and, finally, into the veins. This difference in pressure causes blood to flow from the arterial side of the circulation to the venous side. Note that a blood pressure of 116/72 mm Hg is normal only for large blood vessels. Capillary pressure is generally much lower. Pressure within the large veins is around 0 mm Hg.

BLOOD PRESSURE AND VENOUS RETURN

Although blood pressure is very high in the arterial circulation, it decreases to almost 0 mm Hg in the veins. The blood pressure in the veins is so low, in fact, that it alone cannot return blood from the veins back to the heart. Three other mechanisms come to the rescue: skeletal muscle action, respiratory movements, and constriction of the veins.

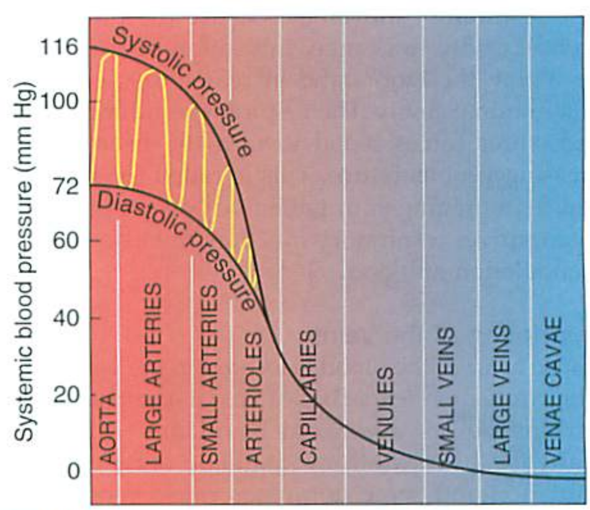


FIGURE 19-2 Blood pressure in the different blood vessels.

Skeletal Muscle Action

As Figure 19-3 shows, the large veins in the leg are surrounded by skeletal muscles. When the skeletal muscles are relaxed and blood flow slows, the valves close. As the skeletal muscles contract, they squeeze

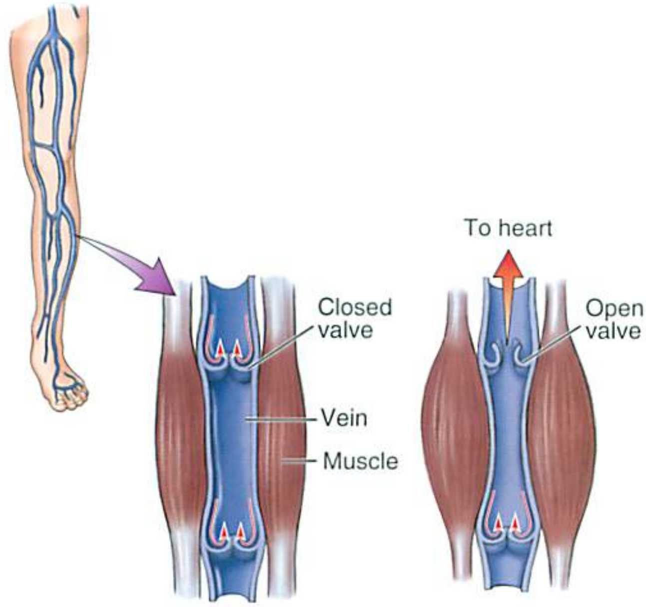


FIGURE 19-3 Skeletal muscle pump.

the large veins, thereby opening the valves and forcing blood toward the heart. This mechanism is called the *skeletal muscle pump*. The pump explains the beneficial effects of exercise for your patients. Exercise improves venous return of blood to the heart and prevents stagnation of blood and thrombosis (blood clot formation).

Respiratory Movements

The act of breathing is performed by the contraction and relaxation of the skeletal muscles of the chest. These respiratory movements cause the pressures in the chest cavity to change. Inhalation decreases pressure within the thorax and increases pressure within the abdominal cavity. The respiratory-induced change in pressures forces blood toward the heart, thereby increasing venous return. This is called the *respiratory pump*. Encouraging your patient to "deep breathe" not only improves respiratory function, but also improves the circulation of blood.

Constriction of the Veins

Because most of the blood is located in the venous side of the circulation (capacitance vessels), constriction of the veins pushes additional blood out of the veins toward the heart. Both sympathetic nervous system stimulation and some hormones cause venoconstriction (VEE-noh-kahn-STRIK-shun), thereby increasing venous return of blood to the heart.

? Re-Think

1. List three mechanisms that improve venous return of blood to the heart.
2. Why does walking prevent stagnation of blood in the legs?

2+2 Sum It Up!

The blood vessels deliver blood to every organ in the body. The driving force for the movement of blood through the blood vessels is the blood pressure. Blood pressure is highest in the large arteries and lowest in the veins, accounting for the flow of blood from arteries to veins. However, venous pressure is so low in the venae cavae that venous blood flow needs help; it is aided by the skeletal muscle pump, respiratory pump, and venoconstriction.

WHAT DETERMINES BLOOD PRESSURE?

Blood pressure is determined by the heart (cardiac output) and the blood vessels (**systemic vascular resistance**).

Blood Pressure = Cardiac Output × Systemic Vascular Resistance

HEART AND BLOOD PRESSURE

How does myocardial function affect blood pressure? You probably have watched enough television to know that when the heart stops beating, the blood pressure drops to 0 mm Hg and the person dies, indicating an obvious relationship between cardiac function and blood pressure.

What is the heart component of blood pressure? It is the cardiac output. Recall from Chapter 17 that cardiac output is determined by heart rate (HR) and stroke volume (SV). The stronger the force of contraction, the greater the stroke volume, the greater the cardiac output, and the higher the blood pressure. The faster the heart rate, the greater the cardiac output, and the higher the blood pressure. Conversely, a decline in heart rate and/or stroke volume decreases cardiac output and blood pressure.

BLOOD VESSELS AND BLOOD PRESSURE

How do the peripheral blood vessels affect blood pressure? A garden hose illustrates the blood vessels' effect on blood pressure. In Figure 19-4, *A*, the hose is hooked up to a faucet. When the faucet is turned on, water flows through the hose and falls to the ground in big droplets. In Figure 19-4, *B*, a nozzle has been attached to the end of the hose, thereby narrowing the end of the hose. The nozzle has increased the resistance to the flow of water. Because of the resistance of the nozzle, water does not fall out of the hose in big droplets, as in Figure 19-4, *A*; instead, water squirts out of the end of the hose. Notice how much further the squirted water travels. What is the reason for this difference? If you were to measure the pressures at point X, you would record a higher pressure in the hose with the nozzle on it. The nozzle increases resistance to the flow of water and causes the pressure behind the nozzle to

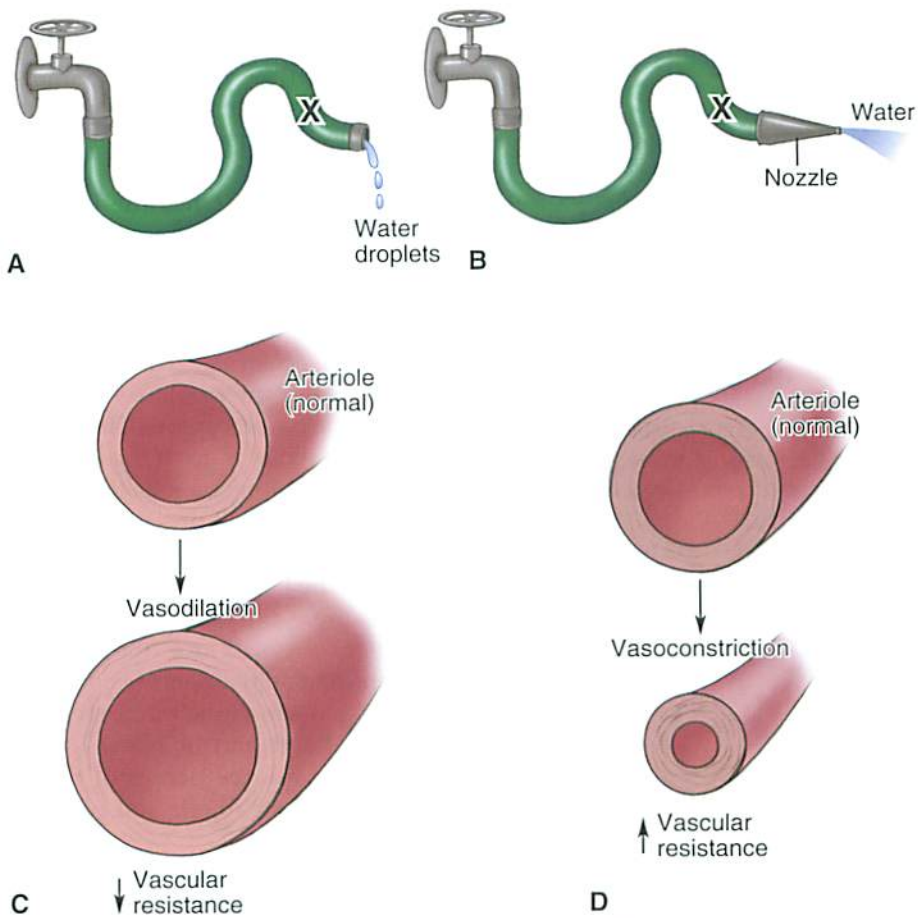


FIGURE 19-4 Effect of resistance on pressure. **A,** Low resistance and low pressure. **B,** High resistance and high pressure. **C,** Vasodilation, low resistance, and low pressure. **D,** Vasoconstriction, high resistance, and high pressure.

increase. The increased pressure in the nozzled hose simply pushes the water further.

How does the example of the hose apply to blood pressure? The large blood vessels are similar to the hose. The smaller vessels, especially the arterioles, act as nozzles. Because the arterioles are composed largely of smooth muscle, the contraction and relaxation of the muscle allow the arterioles to change their diameter and therefore their resistance to blood flow. *Systemic vascular resistance* (SVR) is the clinical term that refers to the resistance offered by all the peripheral blood vessels; it is the same as *total peripheral resistance* (TPR).

Arteriolar smooth muscle determines resistance. **Vasodilation** occurs when arteriolar smooth muscle relaxes and increases the diameter of the blood vessels. The process is comparable to removing the nozzle from the end of the hose (see Figure 19-4, *C*). Vasodilation decreases resistance in the blood vessels and decreases blood pressure. When the smooth muscle contracts, the diameter of the arteriole becomes smaller. This process is known as **vasoconstriction** and is comparable to adding a nozzle to the hose (see Figure 19-4, *D*). Vasoconstriction increases SVR and raises blood pressure. Thus, the arterioles' ability to dilate and constrict helps determine blood pressure.

Do You Know...

About Obesity and the Miles and Miles of New Blood Vessels?

Blood pressure is determined by cardiac output and SVR. SVR is usually determined by changes in the diameter of the arterioles. Other resistance terms such as *blood vessel length* and *blood viscosity* are normally ignored. However, the accumulation of excess fat tissue not only adds pounds; it also contributes miles of additional new blood vessels, making blood vessel length a significant contributor to SVR. Fat tissue also secretes hormones that narrow or constrict blood vessels. Excess fat therefore elevates SVR, making the person hypertensive. What to do to lower that blood pressure? Lose weight!

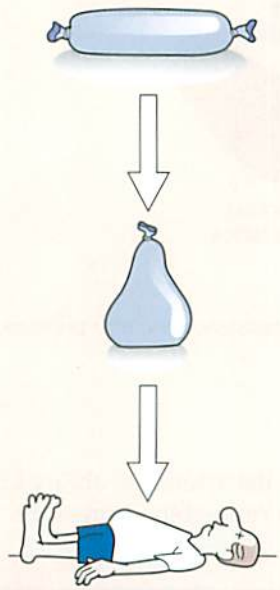
? Re-Think

1. What are the two determinants of blood pressure?
2. Why would peripheral vasodilation cause dizziness and possibly syncope (fainting)?

Do You Know...

About *Venodilation* and This "Fainting" Balloon?

If a patient takes a drug that causes venodilation, the following events occur: blood "pools" in the veins; less blood returns to the heart (decreased venous return); myocardial contraction decreases (Starling effect); cardiac output decreases; and blood pressure decreases (hypotension). If the patient attempts to change position quickly, as in rising from a supine (lying down) to a standing position, insufficient blood is pumped to the brain, causing dizziness, fainting, and falling. This series of events is called *postural hypotension*, because it usually occurs when the patient assumes an upright posture. The water-filled balloon illustrates venodilation and pooling when the position of the balloon changes from a lying (horizontal) to standing (vertical) position. Lesson? Advise your patients to get up slowly from lying to sitting to upright. Other common causes of postural hypotension are blood volume depletion (dehydration), an aging cardiovascular system, and autonomic dysfunction. Elderly persons are especially prone to postural hypotension.



HOW BLOOD PRESSURE STAYS WITHIN NORMAL LIMITS

Under normal conditions, blood pressure remains relatively constant, at slightly less than 120/80 mm Hg. Regulation of blood pressure involves rapidly acting and slowly acting mechanisms.

RAPIDLY ACTING MECHANISMS

The most important of the rapidly acting mechanisms is a nervous mechanism called the **baroreceptor reflex**. This reflex consists of the following structures: receptors, sensory nerves, medulla oblongata, and motor nerves. (Follow the arrows in Figure 19-5 as you read about the components of the baroreceptor reflex.)

- *Receptors.* The special receptors, called *baroreceptors* (bar-oh-ree-SEP-tors), or pressure receptors, are located in the walls of the aortic arch and carotid sinus, located in the lower part of the internal carotid arteries. The baroreceptors sense sudden change in blood pressure.
- *Sensory nerves.* Once the baroreceptors have been activated, the sensory information travels along the nerves to the brain. The nerves that carry the sensory information are cranial nerves (CNs) IX (glossopharyngeal) and X (vagus).
- *Medulla oblongata.* The medulla oblongata of the brain stem interprets sensory information coming from the baroreceptors. The medulla oblongata then decides what to do. If the blood pressure is low, the medulla oblongata tells the heart and blood vessels to increase blood pressure. If the medulla oblongata receives information that the blood pressure is high, it tells the heart and blood vessels to decrease blood pressure.
- *Motor nerves.* Once the medulla oblongata has identified adjustments needed to restore blood pressure to normal, the motor nerves carry information to the heart and blood vessels. The motor nerves involved are the nerves of the autonomic nervous system (sympathetic and parasympathetic nervous systems).

What happens if a person's blood pressure suddenly declines as in hemorrhage? The decline in blood pressure is sensed by the baroreceptors and the information carried by sensory nerves (CNs IX and X) to the medulla oblongata. The medulla oblongata then fires the sympathetic nervous system. Stimulation of the sympathetic nerves causes the sinoatrial (SA) node to fire more quickly, thereby increasing heart rate. Sympathetic firing also causes the ventricular myocardium to contract more forcefully, increasing stroke volume. Both of these responses increase cardiac output and blood pressure. Firing of the sympathetic nerves also causes vasoconstriction of the arterioles, thereby increasing systemic vascular resistance and blood pressure.

The same series of events occurs in a person who suddenly experiences a sudden, drug-induced (e.g., nitroglycerin) decline in blood pressure. Activation of the baroreceptors causes an increase in heart rate, or reflex tachycardia. The tachycardia can overburden a damaged heart, causing angina (chest pain) and additional myocardial damage. The effect of drugs on baroreceptor responses is huge!

What happens if a person's blood pressure suddenly increases? Parasympathetic (vagal) stimulation decreases heart rate and therefore decreases cardiac output and blood pressure. Blood pressure also decreases because the blood vessels dilate, thereby decreasing resistance. If the blood vessels do not contain parasympathetic nerves, why do they dilate? The vasodilation is not caused by parasympathetic

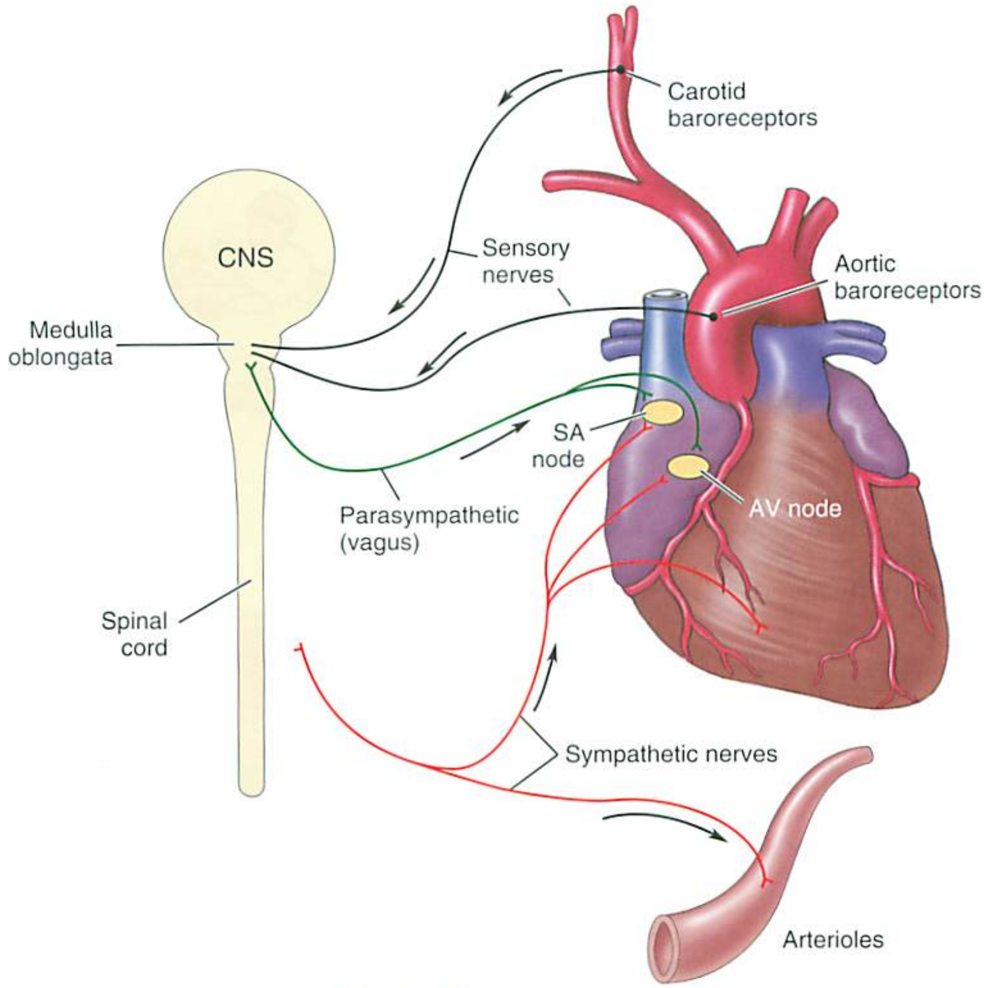


FIGURE 19-5 Baroreceptor reflex.

activity; it occurs because the sympathetic nerves become less active when the parasympathetic nerves fire.

Carotid sinus syncope also illustrates the baroreceptor response to a sudden increase in blood pressure. A tight collar exerts pressure over a hypersensitive carotid sinus, activating the baroreceptors. The medulla oblongata falsely interprets the blood pressure information as an elevation in blood pressure. Information sent from the brain to the heart and blood vessels lowers the blood pressure, so much so that the person faints (syncope). This response is called *carotid sinus syncope*. Other stimuli for carotid sinus syncope include shaving over the neck region, showering with strong spurts of water, and the use of shoulder strap seat belts.

? Re-Think

What is the baroreceptor response to excess vasodilation, as often occurs in the pharmacological treatment of hypertension?

A second, but less important, rapidly acting mechanism is the secretion of epinephrine and norepinephrine from the medulla of the adrenal gland. These hormones increase cardiac output and cause vasoconstriction, thus increasing blood pressure.

Do You Know...

About Val Salva's Most Embarrassing Medical Moment?

Val was constipated! Sounds like an insignificant problem, but in a person with a history of coronary artery disease (CAD), constipation can prove fatal. While "straining at stools," Val suffered a near-fatal heart attack. Straining at stools initiates the Valsalva maneuver, which occurs when a person tries to force an exhalation with the mouth and nose closed (as in having a bowel movement). The forced exhalation increases pressure in the chest, which in turn increases blood pressure. The sudden increase in blood pressure activates the baroreceptor reflex, causing a sudden burst of parasympathetic activity that not only slows heart rate, but triggers a fatal dysrhythmia, leading to cardiac arrest. Unfortunately, it is a rather common occurrence that someone with a history of CAD has a heart attack while on the "porcelain throne." How embarrassing—and to think it might have been prevented by a stool softener or laxative.

SLOWER ACTING MECHANISMS AND LONG-TERM REGULATION OF BLOOD PRESSURE

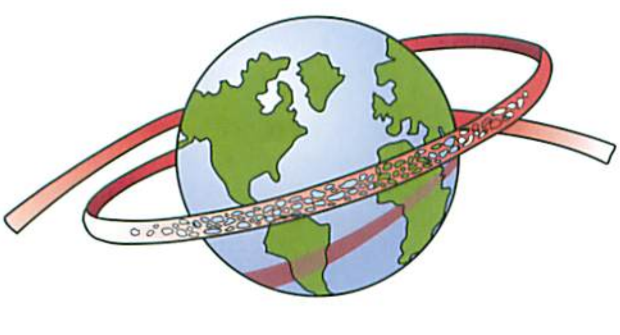
Several mechanisms act slowly to control blood pressure. These hormonally mediated mechanisms are more concerned with the long-term regulation of blood pressure. The most important of the slowly acting mechanisms is the renin-angiotensin-aldosterone mechanism. Activation of this mechanism increases blood volume and causes vasoconstriction. Both of these effects increase blood pressure (see Chapter 24). Other hormones that affect blood pressure include antidiuretic hormone (ADH). ADH is also called *vasopressin* because it exerts a **vasopressor** effect (increases blood pressure). Atrial natriuretic peptide (ANP) and brain natriuretic peptide (BNP), secreted by the distended walls of the heart, lower blood pressure by causing vasodilation and by decreasing blood volume through the renal (kidney) secretion of sodium and water.

2+2 Sum It Up!

Blood pressure is defined as the force that blood exerts against the walls of the blood vessels. Blood pressure is determined by the activity of the heart (cardiac output) and blood vessels, especially the arterioles (systemic vascular resistance). Remember: Blood pressure = cardiac output × systemic vascular resistance. Several mechanisms regulate blood pressure. The most important rapidly acting mechanism is the baroreceptor reflex; a sudden decline in blood pressure triggers a sympathetic discharge, whereas a sudden increase in blood pressure triggers parasympathetic or vagal discharge. The secretion of epinephrine and norepinephrine contributes to the rapid-response system. Long-term mechanisms are hormonal and include the renin-angiotensin-aldosterone system, antidiuretic hormone (ADH), and the natriuretic peptides.

BLOOD VESSELS ACT AS EXCHANGE VESSELS

The capillaries engage in the exchange of nutrients and waste between the blood and cells. Accordingly, the capillaries are called *exchange vessels*. The capillaries are the most numerous of the blood vessels. If all the capillaries in the body were lined up end to end, they would encircle the earth 2.5 times.



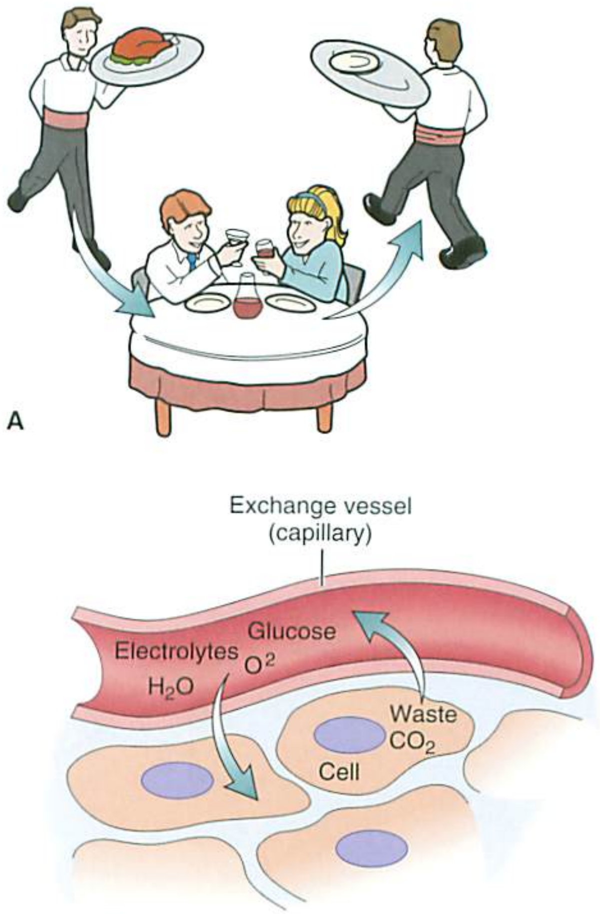


FIGURE 19-6 Capillary exchange: deliveries and pickup. **A,** Waiters delivering food and picking up empty trays. **B,** Capillary exchange.

WHAT IS AN EXCHANGE VESSEL?

An exchange vessel exchanges or swaps substances, much like a waiter (Figure 19-6, *A*). For example, a waiter delivers food to hungry guests. After some time has passed, the waiter picks up the waste—the empty trays, dirty dishes, and leftover food. Note the exchange part; food is dropped off and waste is picked up.

The capillaries work like the waiter (see Figure 19-6, *B*). As blood flows through the capillaries, substances move out of the capillary into the surrounding tissue spaces (interstitium). These substances include oxygen, water, electrolytes, and various nutrients such as glucose; they are the substances that the cell needs to live, work, and grow.

Oxygen and nutrients are taken up and used by the cells. As the cells carry on their work, they produce waste material such as carbon dioxide. The cellular waste diffuses out of the cell, into the interstitium, and then into the blood within the capillary. The blood carries the waste away from the capillary to the organs of excretion, such as the kidneys and the lungs.

WHY CAPILLARIES ARE GOOD EXCHANGE VESSELS

Three characteristics make the capillaries good exchange vessels: thin capillary walls, large numbers of capillaries, and slow blood flow through the capillaries.

THIN CAPILLARY WALLS

The capillary wall consists of a single layer of epithelium that sits on a delicate basement membrane. The epithelial layer has many holes, or pores, through which water and solute easily move.

MILLIONS OF CAPILLARIES

The millions of capillaries provide a huge surface for exchange; the larger the capillary surface, the greater the rate of exchange.

SLOW VELOCITY OF BLOOD FLOW

The large numbers of capillaries also affect the rate of blood flow. The greater the number of capillaries, the slower the flow of blood. The slow blood flow allows more time for exchange.

CAPILLARY FORCES: EXCHANGE

How do the nutrients and waste "know" where to go? There are forces that move water, nutrients, and waste in and out of the capillaries. These forces are diffusion and a filtration-osmosis balancing act.

EXCHANGE INVOLVING DIFFUSION

Diffusion is the primary process causing substances to move across the capillary wall. Diffusion means that a substance moves downhill from an area of high concentration to an area of low concentration. For example, the concentration of oxygen is higher in the capillary than in the tissue fluid. Thus, oxygen diffuses from the capillary into the interstitium and then into the cell. On the other hand, carbon dioxide concentration is higher in the interstitium than in the capillaries. Thus, carbon dioxide diffuses from the interstitium into the capillary.

EXCHANGE INVOLVING FILTRATION-OSMOSIS

A second process of exchange involves filtration-osmosis and is particularly important for water exchange. Filtration is illustrated in the syringe in Figure 19-7, *A*. A syringe is loaded with water. When the plunger is pushed, the pressure within the barrel of the syringe increases and water is forced out of the syringe through the needle. What would happen if you were to punch holes in the side of the syringe and push on the plunger? Not only would water flow through the needle end, it would also squirt out of the side of the syringe in response to the pressure.

The plunger and syringe are similar to the heart and capillaries (see Figure 19-7, *B*). The heart, like the plunger, creates a pressure that accomplishes two things. First, blood is pushed forward from the arterial end of the capillary to the venous end of the capillary. Second, because of the pores in the capillary wall, water and the smaller substances (electrolytes, glucose) squirt into the interstitium. Plasma proteins, such as albumin, are too large to fit through the capillary pores and therefore remain in the capillaries.

The pushing of the water and dissolved substances through the pores is filtration. Note that the cause of filtration is blood pressure. Note also the direction of filtration. In response to the pressure in the capillary, water and the dissolved substances are pushed out of the capillary into the interstitium.

What happens to all the substances pushed into the interstitium? The nutrients are used by the cells. What about the water that was filtered? The water is reabsorbed at the venous end of the capillary. The force that is responsible for the reabsorption of water is the oncotic pressure. The **oncotic pressure** is the plasma osmotic pressure that is due to the plasma proteins. Figure 19-7, *C*, shows that the oncotic pressure in the capillary is higher than in the interstitium. The capillary oncotic pressure is higher because of the plasma proteins trapped within the capillaries. The high oncotic pressure causes the water to diffuse from the interstitium into the capillary. Lymphatic drainage removes excess water from the interstitium (see Chapter 20).

What is the balancing act? The exact amount of water filtered at one end of the capillary is reabsorbed at the other end. The balancing act is important. If the amount of water filtered out of the capillary exceeds the amount reabsorbed from the tissue space, fluid collects in the tissue space. Excess fluid collection in the interstitium is called *edema*. If more water is reabsorbed from the tissue space than was filtered, the tissue space becomes depleted and the patient appears dehydrated. Fluid imbalances occur in many clinical conditions.

MECHANISMS OF EDEMA FORMATION

The forces that determine the movement of water across the capillary walls are disrupted in many clinical conditions. Some of the more common conditions are described here.

Heart Failure

A patient in heart failure retains water and develops excess blood volume (hypervolemia). The expanded blood volume, in turn, increases capillary filtration pressure, thereby increasing the amount of water filtered out of the capillaries into the interstitium. The excess filtration of water exceeds the ability of the capillaries to reabsorb water. Thus, the excess water remains in the interstitium, causing edema.

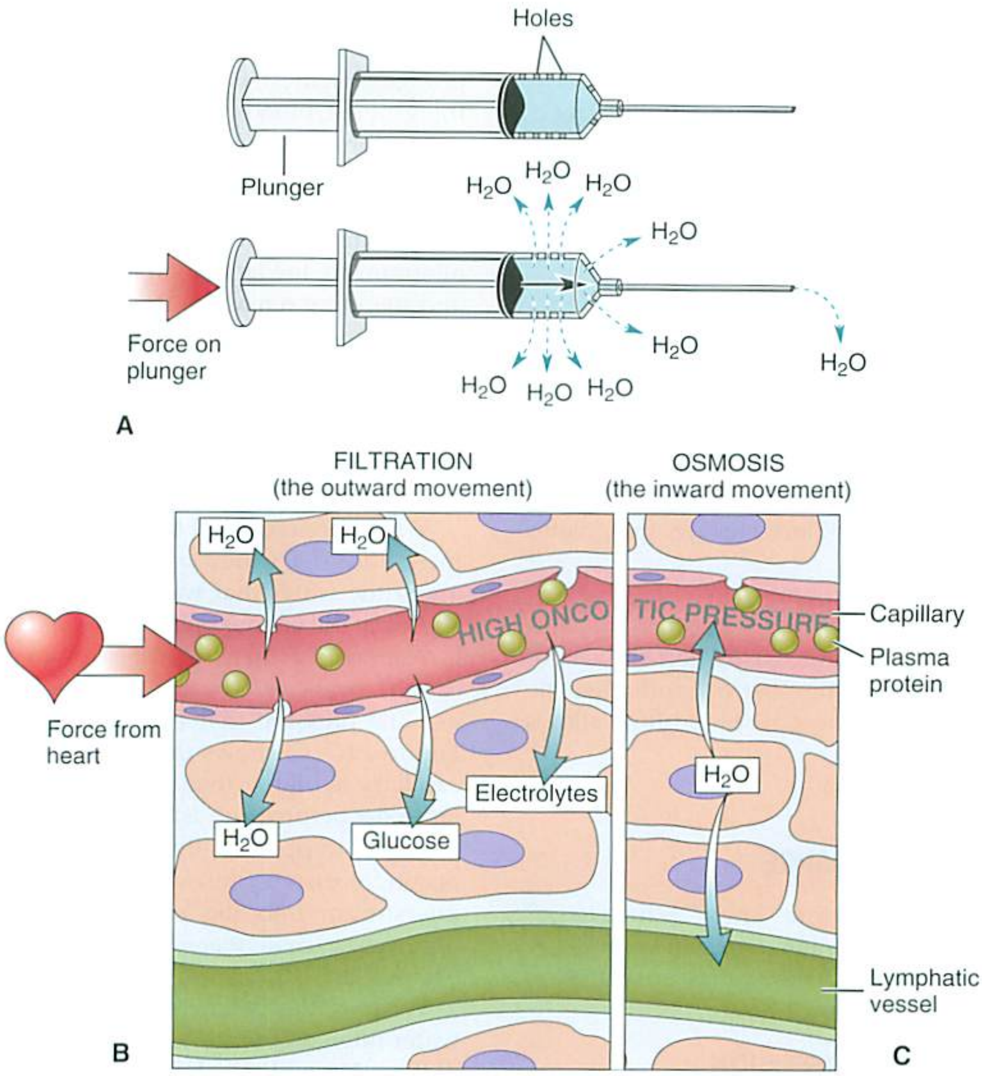


FIGURE 19-7 Filtration and osmosis. **A,** Syringe filled with water (H_2O). The plunger pushes the water out of the syringe. **B,** Capillary filled with blood. The heart pushes blood out of the capillary. **C,** Movement of water back into the capillary because of the oncotic pressure in the capillary.

Excess filtration of water into the lungs is called *pulmonary edema* and results in impaired oxygenation. Excess fluid accumulation in the feet is called *pedal edema*.

Severe Burn

A patient is admitted to the emergency room with severe burns on the lower extremities. In response to the thermal injury, the capillary pores dilate, thereby allowing the escape of excess water and plasma proteins into the interstitium. The "leaked" protein causes edema for two reasons. First, the reduction in plasma protein decreases oncotic pressure within the capillary; this decreases reabsorption of water. Second, the leaked protein "holds" the water in the interstitium by slowing its reabsorption.

Kidney Disease

A child is diagnosed with a kidney disease called *nephrotic syndrome*. The child's mother first noticed edema around his eyes (periorbital edema) and difficulty in fastening the waist of his pants. Nephrotic syndrome is characterized by the excretion of large amounts of the plasma protein, albumin, in the urine (albuminuria); this results in low plasma levels of albumin (hypoalbuminemia). The edema of nephrotic syndrome is caused in part by the hypoalbuminemia, resulting in a decreased plasma oncotic pressure.

Blocked Lymphatic Drainage

A woman goes to a clinic complaining of a grossly swollen leg and is eventually diagnosed with a large tumor in her lower pelvis. The tumor has compressed

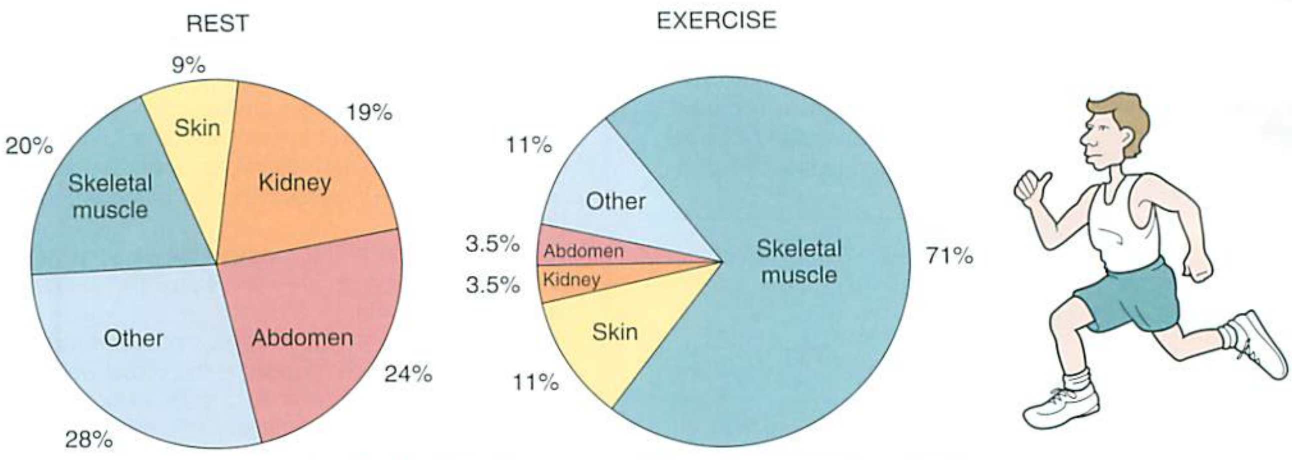


FIGURE 19-8 Distribution of blood flow at rest and during exercise.

the lymphatic vessels, thereby impairing the drainage of lymph; impaired lymph drainage causes the accumulation of fluid in the interstitium (edema). For this same reason, edema develops with the surgical removal of a breast (mastectomy) and lymph node dissection.

? Re-Think

1. Why are capillaries good exchange vessels?
2. Why is water filtered at the arterial end of the capillary? Why is water reabsorbed at the venous end of the capillary?
3. Explain how the body can "borrow" water from the interstitium in a dehydrated person?

2+2 Sum It Up!

The capillaries are well suited for exchange because of three characteristics: thin capillary wall, large surface area of capillaries, and slow velocity of capillary blood flow. Most solute exchanges by simple diffusion. Water (and some solute) exchange using the filtration-osmosis pressures (filtration at the arterial end and osmosis at the venous end of the capillary). Edema formation is due to an imbalance of the filtration-osmosis transport mechanisms at the capillary level.

BLOOD VESSELS DISTRIBUTE BLOOD

Blood vessels are also "in charge" of distributing blood according to changing body needs. As Figure 19-8 shows, blood flow to a particular area of the body can change. For example, in the resting state, the skeletal muscle receives 20% of the total blood flow, and the kidney and abdomen receive 19% and 24%, respectively. Note what happens during strenuous exercise. Blood flow is redirected; the percentage of blood flow pumped to skeletal muscle greatly increases (to 71% of total flow). Why? Exercising muscle needs more oxygen and nutrients. In addition, the increased blood flow carries heat and waste products away from the exercising muscles. At the same time, the percentage of blood that flows through the kidney and abdomen decreases (3.5% of total flow). In other words, the blood is directed to sites where it is most needed, such as the skeletal muscle. Note also that the blood flow to the skin increases from 9% to 11% of total flow. The increased blood flow to the skin helps lose the excess heat, thereby helping regulate body temperature.

BLOOD VESSELS REGULATE BODY TEMPERATURE

The regulation of body temperature is described in Chapter 7. In essence, the blood vessels help dissipate (get rid of) or conserve heat. For example, with exercise and temperature elevation, the blood vessels dilate, thereby allowing more blood to flow to the skin. This activity transfers heat from the deeper tissues to the surface of the body. The heat radiates from the flushed skin, thereby lowering body temperature. Conversely, heat is conserved when the blood vessels of the skin constrict, diverting the warm blood from surface blood vessels into deeper parts of the body.

2+2 Sum It Up!

The circulatory system does more than run around in circles. It acts as a delivery system, regulates blood pressure, engages in the exchange of nutrients and waste, redistributes blood in response to changing body needs, and helps in the regulation of body temperature.

As You Age

1. The circulatory system is one of the body systems most affected by age. The walls of the arteries thicken and become less elastic and stiffer. Two major consequences occur: blood flow to vital organs (e.g., the brain) decreases, and blood pressure increases, thereby increasing the work of the heart.
2. Changes occur in both the walls and the valves of the veins. As a result, older persons are more prone to the development of varicose veins.
3. The inner surface of the blood vessels becomes roughened because of age-related changes in the vessel wall and the development of fatty plaques. As a result, older persons are more prone to thrombus formation.
4. The baroreceptors become less sensitive. Cardiovascular adjustments to changes in position are slowed, and the person may become dizzy and tend to fall.
5. Permeability of the capillary membrane increases with age, thereby increasing edema formation in older persons.

MEDICAL TERMINOLOGY AND DISORDERS Disorders Involving the Peripheral Vasculature

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
Words			
angioplasty	angi/o-	vessel	An **angioplasty** is *the surgical repair of a blood vessel, either by the insertion of a balloon-tipped catheter or reconstruction of the vessel.* The widened blood vessel improves blood flow to the myocardium.
	-plasty	surgical repair of or reconstruction	
intravenous	intra-	within	Refers to *the space within a vein.* Access is achieved by a venipuncture, or the insertion of a needle into a vein. Fluids and drugs are often administered intravenously.
	-ven/o-	vein	
	-ous	pertaining to	
phlebotomy	phleb/o-	vein	A **phlebotomy** is *the entrance into a vein for the purpose of obtaining blood for analysis or treatment.*
	-otomy	incision into	
vascular	vascul/o-	vessel	A term that *refers to blood vessels,* as in vascular disease or vascular resistance.
	-ar	pertaining to	
Disorders			
aneurysm		From a Greek word meaning "dilation" or "wide"	An **aneurysm** is *an abnormal bulging or ballooning of the walls of blood vessels, especially the arteries.* Aneurysms have two shapes: fusiform and saccular. The **fusiform aneurysm** is a weakness along an extended section of the aorta and involves the entire circumference of the aorta. A **saccular aneurysm** is a small bulge or sac on one side of the aorta. There are three types of aneurysms based on location: aortic, cerebral (or berry), or peripheral aneurysm. The **aortic aneurysms** are classified as thoracic and abdominal. **Cerebral (or berry) aneurysms** occur in an artery of the brain and are often berry sized. **Peripheral aneurysms** are those that occur in arteries other than the aorta and brain. An aortic aneurysm can also occur with dissection **(dissecting aneurysm),** in which a small tear in the aortic wall allows the blood to flow through the layers, thereby extending the tear and occluding blood vessels supplying other organs.
angioma	angi/o-	blood vessel	An **angioma** is *a benign tumor composed of blood vessels or lymph vessels that usually appear at the surface of skin.* There are many types of angiomas: a **hemangioma,** such as a **port-wine stain,** is a proliferation of endothelial cells lining a blood vessel. The angioma often looks like a stain created by spilled red wine.
	-oma	tumor	

MEDICAL TERMINOLOGY AND DISORDERS Disorders Involving the Peripheral Vasculature—cont'd

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
claudication		From a Latin word, *claudicare*, meaning "limping"	**Claudication** is *a condition that usually occurs in the legs.* **Vascular claudication** refers to discomfort caused by poor circulation to the extremities and is common in persons with diabetes. **Spinal or neurogenic claudication** is due to nerve root compression (e.g., herniated disk, bone spurs, scar tissue) or stenosis of the spinal canal. Claudication usually presents as pain, discomfort, or tiredness in calf muscles while walking; it is often described in terms of city blocks. A "one-block claudication" refers to the onset of claudication when the person experiences discomfort after walking one city block. There is also two-block or three-block claudication. Claudication may occur intermittently with exercise or occur at rest. **Rest claudication** is usually indicative of more serious underlying pathology.
hypertension	hyper-	excessive	*High blood pressure* **(hypertension)** is defined as a blood pressure >140/90 mm Hg. Hypertension can cause blood vessels to rupture with catastrophic results, such as a hemorrhage into brain tissue. Chronic hypertension increases the workload of the heart, gradually causing the heart to enlarge (ventricular hypertrophy) and fail. Hypertension also causes damage to other organs such as the kidneys, eyes, and brain.
	-tension	From a Latin word, *tendere*, meaning "to stretch"	
hypotension	hypo-	below	*Low blood pressure* **(hypotension)** is a blood pressure <90/60 mm Hg. Hypotension reduces blood flow to vital organs. Very low blood flow to the brain causes a loss of consciousness (syncope). Low blood flow to the heart may cause ischemic chest pain and necrosis (myocardial infarction).
	-tension	From a Latin word, *tendere*, meaning "to stretch"	
ischemia	isch/o-	blockage	**Ischemia** means *insufficient blood supply to a tissue or an organ.* The ischemic tissue is deprived of oxygen and nutrients. Examples include myocardial ischemia and an ischemic gut.
	-emia	blood condition	
peripheral arterial disease			**Peripheral arterial disease (PAD)** involves *an atherosclerotic narrowing and deterioration of the arteries of the neck, abdomen, and periphery.* The most significant risk factors are hypertension, elevated cholesterol, diabetes mellitus, and, chiefly, cigarette smoking. Although any artery can be affected, PAD most often involves the coronary, carotid, distal abdominal aorta, iliac, and femoral arteries.
Raynaud's phenomenon		Named for French physician Dr. Maurice Raynaud (1834–1881)	**Raynaud's phenomenon** is *an episodic vasospasm (involuntary contraction of the blood vessels), most often of the cutaneous blood vessels of the fingers and toes (also ears and nose).* Vasospastic episodes cause the digits to change color: pallor (white) to cyanosis (bluish-purple) to rubor (red). Poor perfusion to the digits causes pain and tissue changes and damage, including gangrene.
shock			**Shock** is a general term used to characterize *a hypoperfusion of tissues and impairment of cellular metabolism. Shock is caused by low blood flow or maldistribution of blood flow.* Low blood flow is caused by poor cardiac function **(cardiogenic shock)** or low blood volume **(hypovolemic shock).** Hypovolemia is a consequence of hemorrhage, pooling of blood, and systemic vasodilation. Maldistribution of blood flow is caused by **neurogenic shock** (spinal cord injury), **septic shock** (infection), and **anaphylactic shock** (severe allergic response).

Continued

MEDICAL TERMINOLOGY AND DISORDERS Disorders Involving the Peripheral Vasculature—cont'd

Medical Term	Word Parts	Word Part Meaning or Derivation	Description
thrombophlebitis	thromb/o-	From the Greek word *thrombos*, meaning "clot or curdled milk"	**Thrombophlebitis** is *the most common disorder of the veins; it is the formation of a thrombus (blood clot) in association with inflammation of the vein.* Classifications include **superficial thrombophlebitis** and the more clinically significant **deep vein thrombosis (DVT).** DVT is characterized by **Virchow's triad:** venous stasis, damage of the venous endothelium, and hypercoagulability. The thrombus most often forms in the deep veins of the legs; a piece of the thrombus may break off, becoming an embolus that lodges in the pulmonary circulation **(pulmonary embolus). Phlebothrombosis** refers to the development of a thrombus in the veins without the associated inflammation. It is usually caused by sluggish circulation in the legs, caused by prolonged bed rest, long car trips, or extended air travel.
	-phleb/o-	vein	
	-itis	inflammation	
varices		From a Latin word meaning "raised area," a reference to the bulging area of the legs associated with varicose veins	**Varices** are *abnormally dilated and lengthened arteries, veins, or lymph nodes.* In the lower extremities, varices are known as **varicose veins.** These are large, tortuous veins; they are of cosmetic concern and cause discomfort and a feeling of heaviness while standing. Other veins throughout the body can be affected. In the digestive system, esophageal varices develop in the lower esophagus in response to elevated portal pressure caused by cirrhosis of the liver. The concern is that the varices will rupture and bleed. In the rectal area, varices are called *hemorrhoids.* **Hemorrhoids** may be external or internal. **External hemorrhoids** are often painful, are accompanied by irritation and itching, and are prone to thrombosis. **Internal hemorrhoids** are generally not painful, but may bleed when irritated. A scrotal varicosity is called a **varicocele. Telangiectasia** is an enlargement of superficial cutaneous blood vessels that are most visible on the face and thighs.

Get Ready for Exams!

Summary Outline

The blood vessels perform five main functions.

I. Functions as a Delivery System

A. The blood vessels deliver oxygen, nutrients, and hormones to the cells.

B. The blood vessels pick up waste from the cells and deliver it to the organs of excretion.

II. Regulates Blood Pressure

A. The blood vessels maintain a blood pressure to ensure an adequate flow of blood to the body.

B. The normal blood pressure is slightly less than 120/80 mm Hg; 116/72 mm Hg is a normal blood pressure—116 is the systolic reading, and 72 is the diastolic reading.

C. Blood pressure varies throughout the circulatory system; it is highest in the aorta and lowest in the venae cavae.

D. Blood pressure in the veins is so low that help is needed—via skeletal muscle pump, respiratory pump, and venoconstriction—in order to return blood to the right heart.

E. Blood pressure is determined by the action of the heart and blood vessels. The heart affects blood pressure by increasing or decreasing cardiac output. The blood vessels affect blood pressure by constricting or dilating the arterioles (systemic vascular resistance).

F. Blood pressure is regulated on a daily basis by the baroreceptor reflex. A sudden decline in blood pressure causes the sympathetic nerves to fire. A sudden increase in blood pressure causes the parasympathetic (vagus) nerves to fire.

G. Other mechanisms can correct blood pressure more slowly. The most important is the renin-angiotensin-aldosterone system.

III. Acts as Exchange Vessels

A. The capillaries are the site of exchange of nutrients and waste between the blood and tissue fluid.

B. Factors that make the capillaries ideal exchange vessels are the thin capillary walls with many pores, millions of capillaries, and a slow rate of blood flow through the capillaries.

C. Most exchange occurs by diffusion.

D. Water and dissolved substances exchange by filtration-osmosis. The capillary pressure pushes (filtration) water out of the capillary at its arterial end. Water and dissolved waste move from the tissue fluid into the capillaries in response to plasma oncotic pressure.

IV. Distributes Blood According to Need

A. Figure 19-8 compares the distribution of blood during rest and exercise.

B. Note the change in skeletal muscle blood flow during rest (20%) and exercise (71%).

V. Regulates Body Temperature

A. Vasodilation of the blood vessels of the skin encourages heat loss.

B. Vasoconstriction of the blood vessels of the skin decreases heat loss.

Review Your Knowledge

Matching: Blood Pressure Terms

Directions: Match the following words with their descriptions below. Some of the words may be used more than once.

a. systolic pressure
b. diastolic pressure
c. pulse pressure
d. mean arterial blood pressure (MABP)
e. reflex tachycardia
f. Korotkoff sounds
g. brachial artery
h. baroreceptors

1. ___ $\frac{2}{3}$ diastolic pressure + $\frac{1}{3}$ systolic pressure
2. ___ Silent…tap…tap…tap…tap…muffle
3. ___ Pressure reading that reflects myocardial contraction
4. ___ Cells in the carotid sinus and aortic arch that detect changes in blood pressure
5. ___ Usual site of blood pressure recording
6. ___ The top number of a blood pressure recording
7. ___ The bottom number of a blood pressure recording
8. ___ The difference between the systolic and diastolic pressures
9. ___ Pressure reading that reflects myocardial relaxation
10. ___ A cardiac consequence of a sudden drop in blood pressure

Matching: Blood Pressure Readings

Directions: Match the following blood pressure readings with their descriptions below.

a. 116/72 mm Hg
b. 70/40 mm Hg
c. 220/120 mm Hg

1. ___ Normal blood pressure recorded in the aorta
2. ___ Normal blood pressure recorded in the brachial artery
3. ___ A "shocky" blood pressure
4. ___ A hypertensive blood pressure
5. ___ A hypotensive blood pressure
6. ___ Normotensive reading
7. ___ A postoperative blood pressure that may require a vasopressor drug
8. ___ A blood pressure that requires immediate treatment with an antihypertensive drug
9. ___ Has a pulse pressure of 44
10. ___ Blood pressure that is most likely to cause a reflex tachycardia

Matching: Changes in Blood Pressure

Directions: Indicate if the following (a) increases blood pressure or (b) decreases blood pressure.

1. ___ Sympathetic nerve stimulation
2. ___ Vagal discharge
3. ___ Effects of a vasopressor agent
4. ___ Effects of epinephrine and angiotensin II
5. ___ Increased systemic vascular resistance (SVR)
6. ___ Decreased cardiac output
7. ___ Arteriolar constriction
8. ___ Administration of an $alpha_1$-adrenergic blocker
9. ___ IV infusion of Levophed (norepinephrine)
10. ___ Administration of a $beta_1$-adrenergic agonist

Multiple Choice

1. The ability of the arterioles to contract and relax allows them to
   a. regulate heart rate.
   b. prevent the backflow of venous blood.
   c. function as resistance vessels.
   d. function as exchange vessels.
2. Which of the following is not a consequence of sympathetic nerve stimulation?
   a. Increased cardiac output
   b. Peripheral vasoconstriction
   c. Elevation of blood pressure
   d. Decreased systemic vascular resistance
3. A sudden decrease in blood pressure is most likely to cause
   a. edema.
   b. reflex tachycardia.
   c. increase in the synthesis of albumin.
   d. arteriolar dilation.
4. Which of the following is true of an increase in systemic vascular resistance?
   a. Increases blood pressure
   b. Is caused by vagal discharge
   c. Is caused by peripheral vasodilation
   d. Is due to relaxation of the aorta
5. In which of the following vessels is blood flow slowest?
   a. Aorta
   b. Arterioles
   c. Capillaries
   d. Veins
6. Which of the following is most apt to lower plasma oncotic pressure?
   a. Dehydration
   b. Hypoalbuminemia
   c. Hypertension
   d. Blood transfusion
7. The skeletal muscle pump
   a. increases systemic vascular resistance.
   b. lowers blood pressure.
   c. enhances venous return of blood to the right heart.
   d. closes the valves within the large veins during exercise.
8. Which of the following is most apt to cause edema?
   a. Decreased filtration pressure as in dehydration
   b. Increased plasma oncotic pressure
   c. Accumulation of albumin in the interstitium (tissue space)
   d. Hypotension

9. Which of the following occurs in the dehydrated state?
   a. The capillary oncotic pressure decreases and fluid accumulates in the tissue spaces.
   b. The capillary filtration pressure decreases and tissue fluid is absorbed into the capillaries.
   c. The capillary filtration rate increases, thereby increasing lymph formation.
   d. Plasma protein is filtered into the tissue spaces, thereby causing edema.

Go Figure

1. **According to Figure 19-2**
   a. Pressure within the capillaries is less than the pressure within the venae cavae.
   b. The pulse pressure within the capillaries is equal to the pulse pressure within the large arteries.
   c. Arteriolar pressure is greater than venous pressure.
   d. Pressure is lowest in the arterioles.

2. **According to Figure 19-1, *B*, neither the systolic pressure nor diastolic pressure can be heard because**
   a. The cuff has not been inflated sufficiently.
   b. The brachial artery is compressed, thereby blocking any flow of blood.
   c. The stethoscope is in the wrong place; it should be proximal to the cuff.
   d. Korotkoff sounds can only be heard when the cuff is inflated to more than 200 mm Hg.

3. **According to Figure 19-3**
   a. Valves in the deep veins of the leg remain open when the person is in a sitting position.
   b. Leg movement, as in exercise, induces stagnation of blood in the deep veins of the legs.
   c. Contraction of the muscles of the leg compresses the veins and enhances the flow of blood toward the heart.
   d. Blood returns to the heart because the valves in the veins of the leg contract and force blood in a forward direction.

4. **According to Figure 19-4**
   a. Resistance is greater in panel *A* than in panel *B*.
   b. The radius of the arterioles in panels *C* and *D* determine resistance to flow (of blood).
   c. Vasoconstriction decreases resistance to flow.
   d. Vasodilation increases resistance to flow.

5. **According to Figure 19-5**
   a. The baroreceptors are located in the SA and AV nodes.
   b. Sensory neurons of cranial nerves IX and X carry pressure information from the SA and AV nodes to the aortic arch and the carotid sinus.
   c. Motor information regarding the adjustment of blood pressure is transmitted to the heart and blood vessels.
   d. Motor information regarding the adjustment of blood pressure is transmitted to the carotid sinus and the aortic arch.

6. **According to Figure 19-7**
   a. In panel *B*, water is oncotically reabsorbed into the capillary.
   b. In panel *B*, the plasma proteins (albumin) are filtered into the interstitium.
   c. In panel *C*, water is oncotically reabsorbed from the interstitium into the capillary.
   d. Oncotic pressure is primarily caused by the plasma electrolytes and glucose.

7. **According to Figure 19-7**
   a. Albumin is filtered at the arterial end of the capillary.
   b. Water is reabsorbed by both the venous end of the capillary and the lymphatic vessels.
   c. The capillary membrane is impermeable to water, electrolytes, and plasma protein.
   d. The lymphatic vessel is impermeable to albumin, electrolytes, and water.