The lymphatic system

Even under normal circumstances, slightly more fluid is filtered out of the capillaries into the interstitial fluid than is reabsorbed from the interstitial fluid back into the plasma. The extra fluid filtered out as a result of this filtration-reabsorption imbalance is picked up by the lymphatic system. This extensive network of one-way vessels provides an accessory route by which fluid can be returned from the interstitial fluid to the blood.

PICKUP AND FLOW OF LYMPH

Small, blind-ended terminal lymph vessels known as **initial lymphatics** permeate almost every tissue of the body (Figure 10-20a). The endothelial cells forming the walls of initial lymphatics slightly overlap like shingles on a roof, with their Overlapping edges being free instead of attached to the surrounding cells. This arrangement creates one-way, valve like openings in the vessel wall. Fluid pressure on the outside of the vessel pushes the innermost edge of a pair of overlapping edges inward, creating a gap between the edges (that is, opening the valve). This opening permits interstitial fluid to enter (Figure 10-20b). Once interstitial fluid enters a lymphatic vessel, it is cal1ed **lymph**. Fluid pressure on the inside forces the overlapping edges together, closing the valves so that lymph does not escape. These lymphatic valvelike openings are much larger than the pores in blood capillaries. Consequently, large particles in the interstitial fluid, such as escaped plasma proteins and bacteria, can gain access to initial lymphatics but are excluded from blood capillaries.

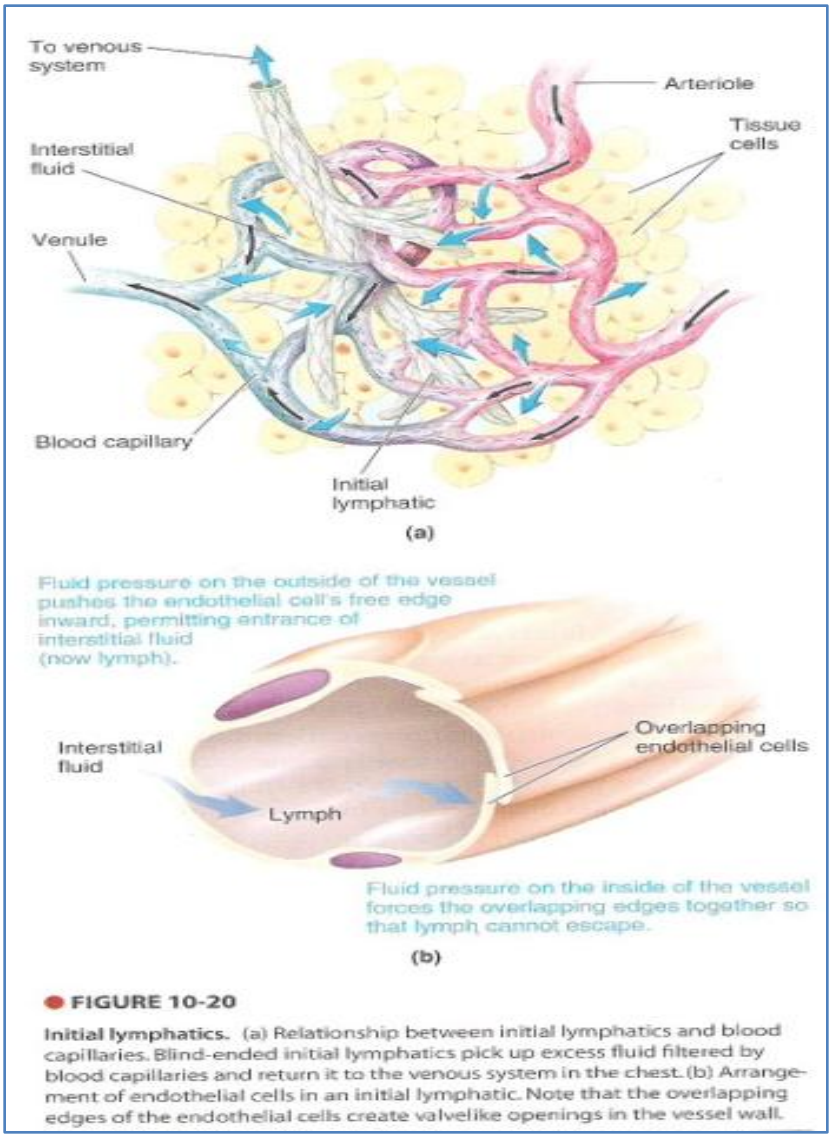


FIGURE 10-20

Initial lymphatics. (a) Relationship between initial lymphatics and blood capillaries. Blind-ended initial lymphatics pick up excess fluid filtered by blood capillaries and return it to the venous system in the chest. (b) Arrangement of endothelial cells in an initial lymphatic. Note that the overlapping edges of the endothelial cells create valvelike openings in the vessel wall.

Initial lymphatics converge to form larger and larger **lymph vessels**, which eventually empty into the venous system near where the blood enters the right atrium (Figure 10-21a). Lymph flow is accomplished by two mechanisms. First, lymph vessels beyond the initial lymphatics are surrounded by smooth muscle, which contracts rhythmically as a result of myogenic activity. When this muscle is stretched because the vessel is distended with lymph, the muscle inherently contracts more forcefully, pushing the lymph through the vessel. This intrinsic "lymph pump" is the major force for propelling lymph. Stimulation of lymphatic smooth muscle by the sympathetic nervous system further increases the pumping activity of the lymph vessels. Second, because lymph vessels lie between skeletal muscles, contraction of these muscles squeezes the lymph out of the vessels. One-way valves spaced at intervals within the lymph vessels direct the flow of lymph toward its venous outlet in the chest.

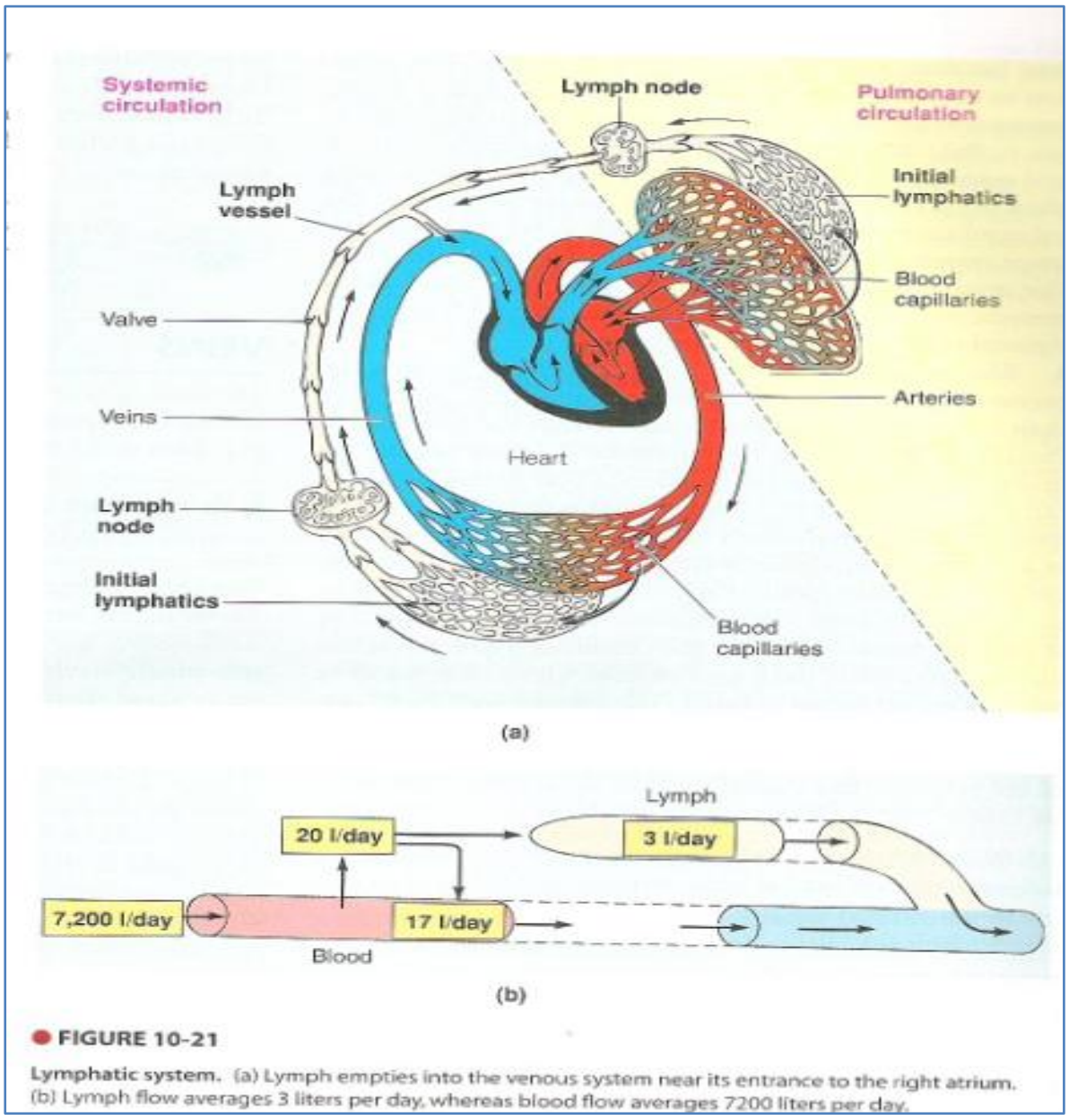


FIGURE 10-21

Lymphatic system. (a) Lymph empties into the venous system near its entrance to the right atrium. (b) Lymph flow averages 3 liters per day, whereas blood flow averages 7200 liters per day.

FUNCTIONS OF THE LYMPHATIC SYSTEM

The most important functions of the lymphatic system are:

- *Return of excess filtered fluid*. Even though only a small fraction of the filtered fluid is not reabsorbed by the blood capillaries, the cumulative effect of this process being repeated with every heartbeat results in the equivalent of more than the entire plasma volume being left behind in the interstitial fluid each day.
- *Defense against disease.* The lymph percolates through lymph nodes located en route within the lymphatic system. Passage of this fluid through the lymph nodes is an important aspect of the body's defense mechanism against disease. For example, bacteria picked up from the interstitial fluid are destroyed by special phagocytes within the lymph nodes.
- *Transport of absorbed fat.* The lymphatic system is important in the absorption of fat from the digestive tract. The end products of the digestion of dietary fats are packaged by cells lining the digestive tract into fatty particles that are too large to gain access to the blood capillaries but can easily enter the initial lymphatics.
- *Return of filtered protein.* Most capillaries permit leakage of some plasma proteins during filtration. These proteins cannot readily be reabsorbed back into the blood capillaries but can easily gain access to the initial lymphatics. If the proteins were allowed to accumulate in the interstitial fluid rather than being returned to the circulation via the lymphatics, the interstitial fluid-colloid osmotic pressure (an outward pressure) would progressively increase while the plasma-colloid osmotic pressure (an inward pressure) would progressively fall. As a result, filtration forces would gradually increase and reabsorption forces would gradually decrease, resulting in progressive accumulation of fluid in the interstitial spaces at the expense of loss of plasma volume.

Edema occurs when too much interstitial fluid accumulates.

Occasionally, excessive interstitial fluid does accumulate when one of the physical forces acting across the capillary walls becomes abnormal for some reason. Swelling of the tissues because of excess interstitial fluid is known as edema. The causes of edema can be grouped into four general categories:

1. *A reduced concentration of plasma proteins* decreases plasma-colloid osmotic pressure. Such a drop in the major inward pressure lets excess fluid filter out, whereas less-than normal amounts of fluid are reabsorbed; hence extra fluid remains in the interstitial spaces. Edema can be caused by a decreased concentration of plasma proteins in several different ways: excessive loss of plasma proteins in the urine, from kidney disease; reduced synthesis of plasma proteins, from liver disease (the liver synthesizes almost all plasma proteins); a diet deficient in protein; or significant loss of plasma proteins from large burned surfaces.

2. *Increased permeability of the capillary walls* allows more plasma proteins than usual to pass from plasma into surrounding interstitial fluid-for example, via histamine-induced widening of the capillary pores during tissue injury or allergic reactions. The resultant fall in plasma-colloid osmotic pressure decreases the effective inward pressure, whereas the resultant rise in interstitial fluid-colloid osmotic pressure caused by excess protein in the interstitial fluid

increases the effective outward force. This imbalance contributes in part to the localized edema associated with injuries (for example, blisters) and allergic responses (for example, hives).

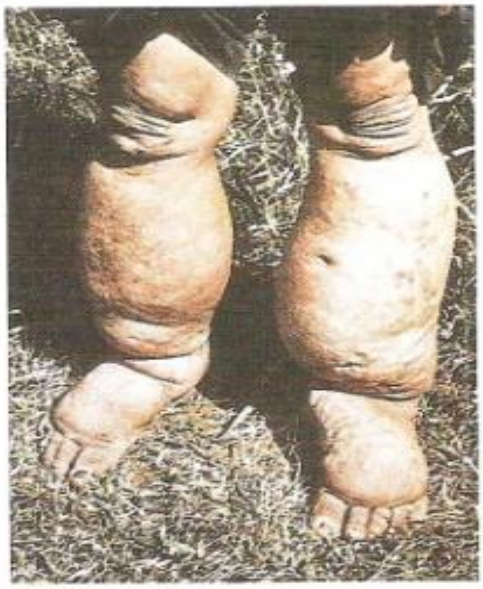
3. *Increased venous pressure,* as when blood dams up in the veins, is accompanied by an increased capillary blood pressure, because the capillaries drain into the veins. This elevation in outward pressure across the capillary walls is largely responsible for the edema seen with congestive heart failure. Regional edema can also occur because of localized restriction of venous return. An example is the swelling often occurring in the legs and feet during pregnancy. The enlarged uterus compresses the major veins that drain the lower extremities as these vessels enter the abdominal cavity. The resultant damming of blood in these veins raises blood pressure in the capillaries of the legs and feet, which promotes regional edema of the lower extremities.

4. *Blockage of lymph vessels* produces edema because the excess filtered fluid is retained in the interstitial fluid rather than being returned to the blood through the lymphatics. Protein accumulation in the interstitial fluid compounds the problem through its osmotic effect. Local lymph blockage can occur, for example, in the arms of women whose major lymphatic drainage channels from the arm have been blocked as a result of lymph node removal during surgery for breast cancer. More widespread lymph blockage occurs with *filariasis,* a mosquito-borne parasitic disease found predominantly in tropical coastal regions. In this condition, small, threadlike filaria worms infect the lymph vessels, where their presence prevents proper lymph drainage. The affected body parts, particularly the scrotum and extremities, become grossly edematous. The condition is often called elephantiasis because of the elephant-like appearance of the swollen extremities (Figure 10-22).

Whatever the cause or edema, an important consequence is a reduced exchange of materials between blood and cells. As excess interstitial fluid accumulates, the distance between blood and cells across which nutrients, O_2 and wastes must diffuse increases, so the rate of diffusion decreases. Therefore, cells within edematous tissues may not be adequately supplied.

FIGURE 10-22

Elephantiasis. This tropical condition is caused by a mosquito-borne parasitic worm that invades the lymph vessels. As a result of the interference with lymph drainage, the affected body parts, usually the extremities, become grossly edematous, appearing elephant-like.



VEINS

The venous system completes the circulatory circuit. Blood leaving the capillary beds enters the venous system for transport back to the heart.

Veins serve as a blood reservoir as well as passageways back to the heart.

Veins have a large radius, so they offer little resistance to flow. Furthermore, because the total cross-section area of the venous system gradually decreases as smaller veins converge into progressively fewer but larger vessels, blood flow speeds up as blood approaches the heart.

In addition to serving as low-resistance passageways to return blood from the tissues to the heart, systemic veins also serve as a *blood reservoir*. Because of their storage capacity, veins arc often called **capacitance vessels**. Veins have much thinner walls with less smooth muscle than arteries do. Also, in contrast to arteries, veins have very little elasticity, because venous connective tissue contains considerably more collagen fibers than elastin fibers. Unlike arteriolar smooth muscle, venous smooth muscle has little inherent myogenic tone. Because of these features, veins are highly distensible, or stretchable, and have little elastic recoil. They easily distend to accommodate additional volumes of blood with only a small increase in venous pressure. Arteries stretched by an excess volume of blood recoil because of the elastic fibers in their walls, driving the blood forward. Veins containing an extra volume of blood simply stretch to accommodate the additional blood without tending to recoil. In this way veins serve as a blood reservoir; that is, when demands for blood are low, the veins can store extra blood in reserve because of their passive distensibility. Under resting conditions, the veins contain more than 60% of the total blood volume (Figure 10-23).

When the stored blood is needed, such as during exercise, extrinsic factors reduce the capacity of the venous reservoir and drive the extra blood from the veins to the heart so it can be pumped to the tissues. Increased venous return leads to an increased cardiac stroke volume.

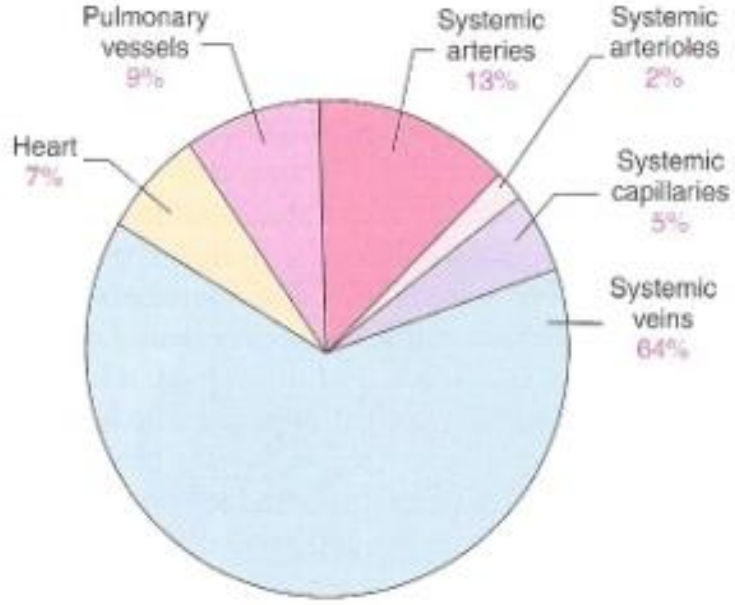


FIGURE 10-23

Percentage of total blood volume in different parts of the circulatory system

Venous return is enhanced by a number of extrinsic factors.

Venous capacity (the volume of blood that the veins can accommodate) depends on the distensibility of the vein walls (how much they can stretch to hold blood) and the influence of any externally applied pressure squeezing inwardly on the veins. Changes in venous capacity directly influence the magnitude of venous return,

The term **venous return** refers to the volume of blood entering each atrium per minute from the veins. By the time the blood enters the venous system, blood pressure averages only 17 mm Hg (Figure 10-8). However, because atrial pressure is near 0 mm Hg, a small but adequate driving pressure still exists to promote the flow of blood through the large-radius, low-resistance veins. If atrial pressure becomes pathologically elevated, as in the presence of a leaky AV va1ve, the venous-to-atrial pressure gradient is decreased, reducing venous return and causing blood to dam up in the venous system. Elevated atrial pressure is thus one cause of congestive heart failure.

In addition to the driving pressure imparted by cardiac contraction, five other factors enhance venous return: sympathetically induced venous vasoconstriction, skeletal muscle activity, the effect of venous valves, respiratory activity and the effect of cardiac suction (Figure 10-24). Most of these secondary factors affect venous return by influencing the pressure gradient between the veins and the heart.

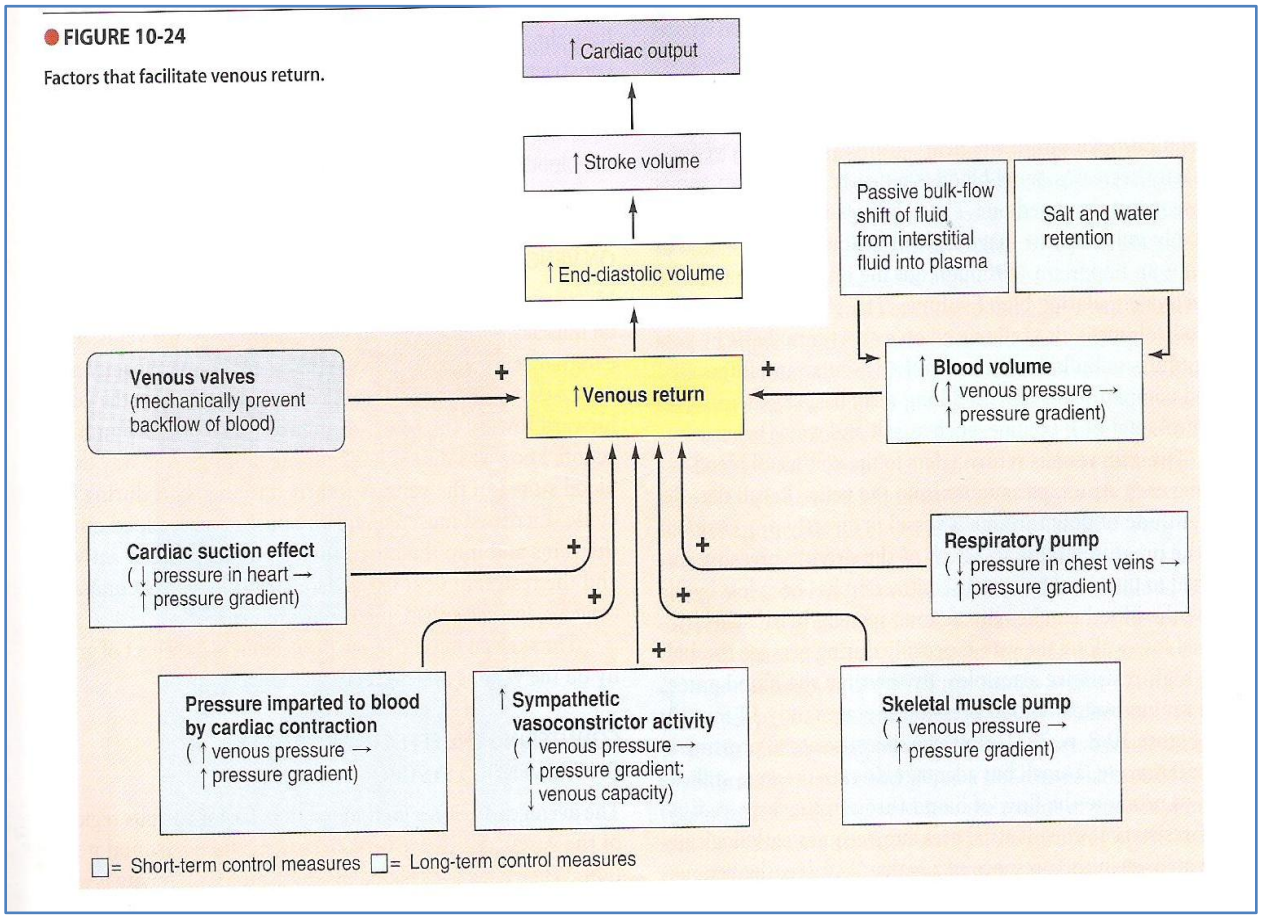


FIGURE 10-24
Factors that facilitate venous return.

EFFECT OF SYMPATHETIC ACTIVITY ON VENOUS RETURN

Veins are not very muscular and have little inherent tone. but venous smooth muscle is abundantly supplied with sympathetic nerve fibers. Sympathetic stimulation produces venous vasoconstriction, which modestly elevates venous pressure: this, in turn, increases the pressure gradient to drive more of the stored blood from the veins into the right atrium, thus enhancing venous return.

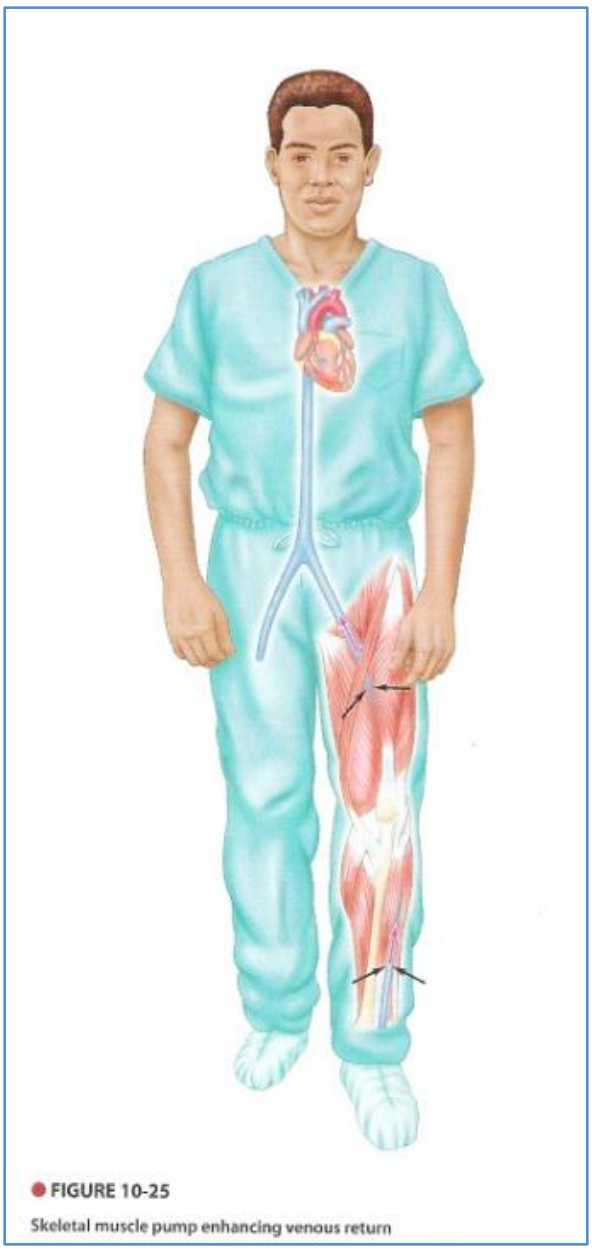
It is important to recognize the different outcomes of vasoconstriction in arterioles and veins. Arteriolar vasoconstriction immediately *reduces* flow through these vessels because of their increased resistance (less blood can enter and flow through a narrowed arteriole), whereas venous vasoconstriction immediately *increases* flow through these vessels because of their decreased capacity (narrowing of veins squeezes out more of the blood already in the veins, increasing blood flow through these vessels).

EFFECT OF SKELETAL MUSCLE ACTIVITY ON VENOUS RETURN

Many of the large veins in the extremities lie between skeletal muscles, so muscle contraction compresses the veins. This external venous compression decreases venous capacity and increases venous pressure, in effect squeezing fluid in the veins forward toward the heart (Figure 10-25). This pumping action, known as the skeletal muscle pump, is one way extra blood stored in the veins is returned to the heart during exercise. Increased muscular activity pushes more blood out of the veins and into the heart. Increased sympathetic activity and the resultant venous vasoconstriction also accompany exercise, further enhancing venous return. The skeletal muscle pump also counters the effect of gravity on the venous system

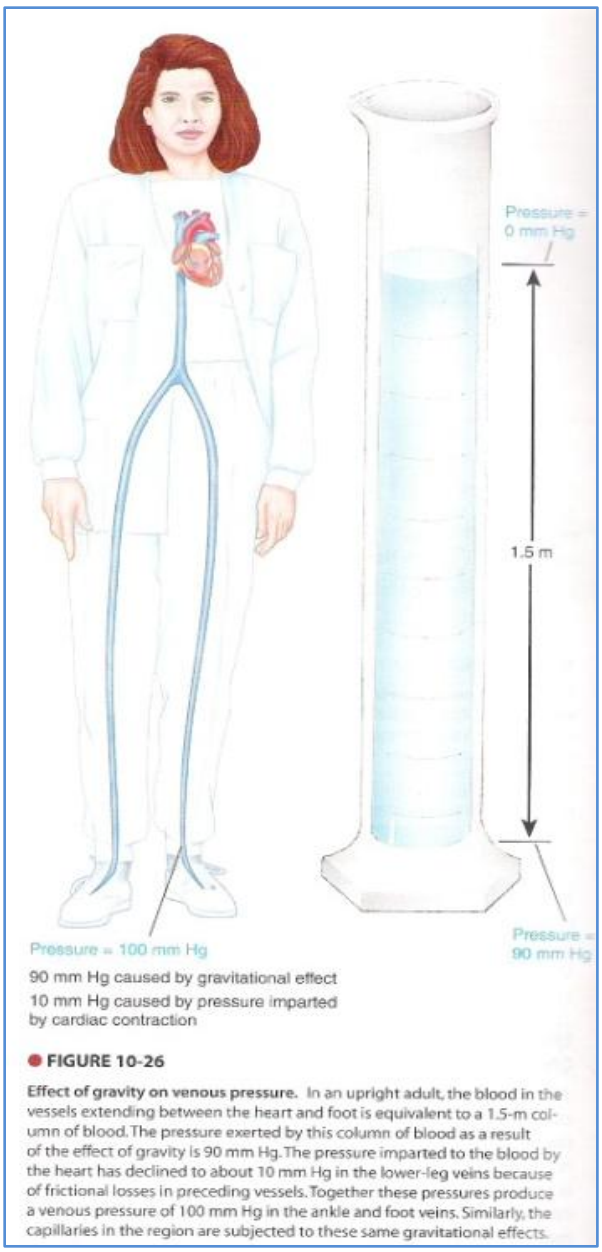
COUNTERING THE EFFECTS OF GRAVITY ON THE VENOUS SYSTEM

The average pressures mentioned thus far for various region of the vascular tree are for a person in the horizontal position. When a person is lying down, the force of gravity is uniformly applied, so it need not be considered. When a person stands up, however, gravitational effects are not uniform. In addition to the usual pressure from cardiac contraction, vessel below heart level are subject to pressure from the weight of the column of blood extending from the heart to the level of the vessel **(**Figure 10-26).



● FIGURE 10-25

Skeletal muscle pump enhancing venous return



● FIGURE 10-26

Effect of gravity on venous pressure. In an upright adult, the blood in the vessels extending between the heart and foot is equivalent to a 1.5-m column of blood. The pressure exerted by this column of blood as a result of the effect of gravity is 90 mm Hg. The pressure imparted to the blood by the heart has declined to about 10 mm Hg in the lower-leg veins because of frictional losses in preceding vessels. Together these pressures produce a venous pressure of 100 mm Hg in the ankle and foot veins. Similarly, the capillaries in the region are subjected to these same gravitational effects.

Two compensatory measures normally counteract these gravitational effects. First, the resultant fall in mean arterial pressure that occurs when a person moves from a lying-down to an upright position triggers sympathetically induced venous vasoconstriction, which drives some of the pooled blood forward. Second, the skeletal muscle pump "interrupts" the column of blood by completely emptying given vein segments intermittently so that a particular portion of a vein is not subjected to the weight of the entire venous column from the heart to that portion's level (Figure 10-27). Reflex venous vasoconstriction cannot completely compensate for gravitational effects without skeletal muscle activity.

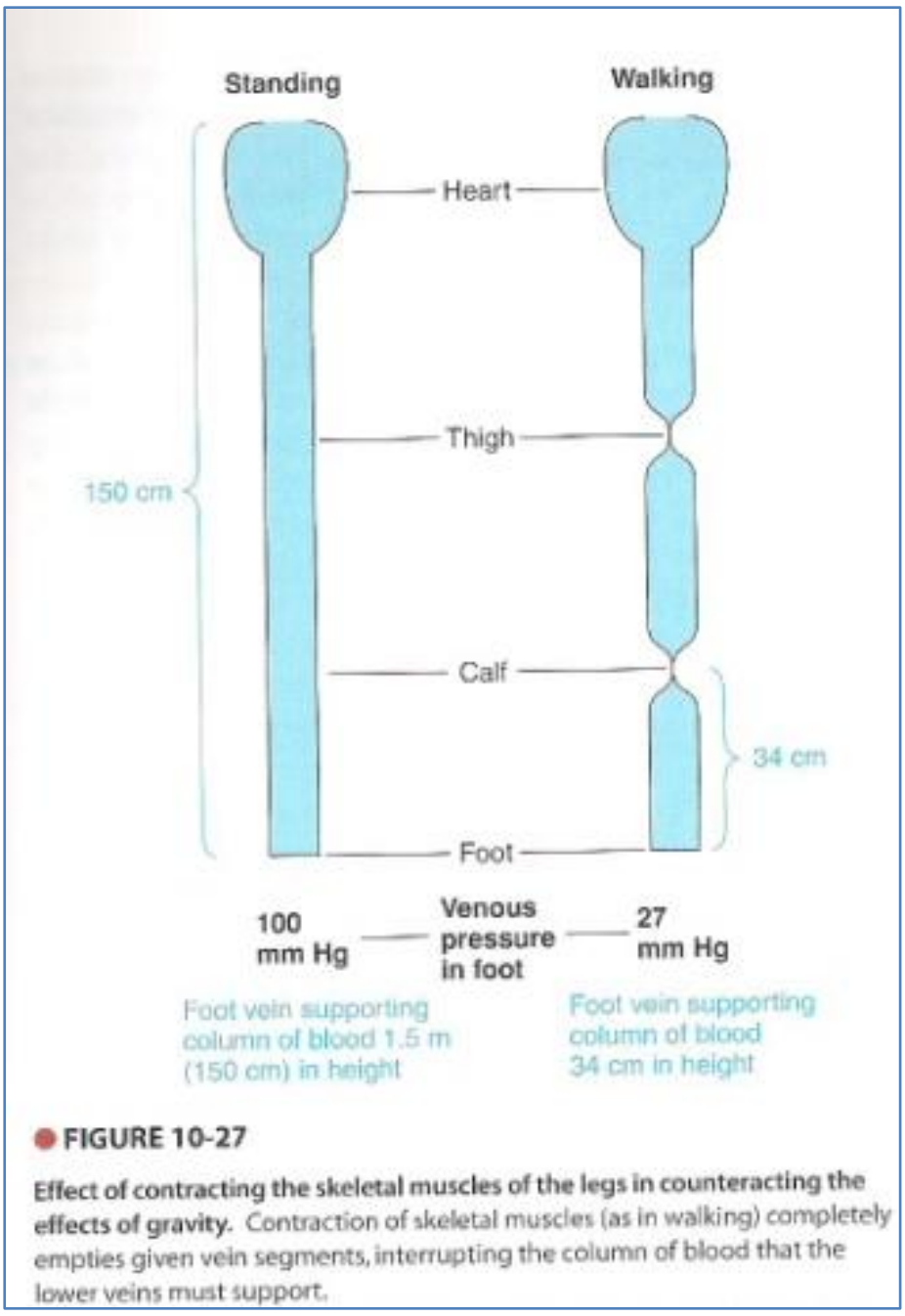
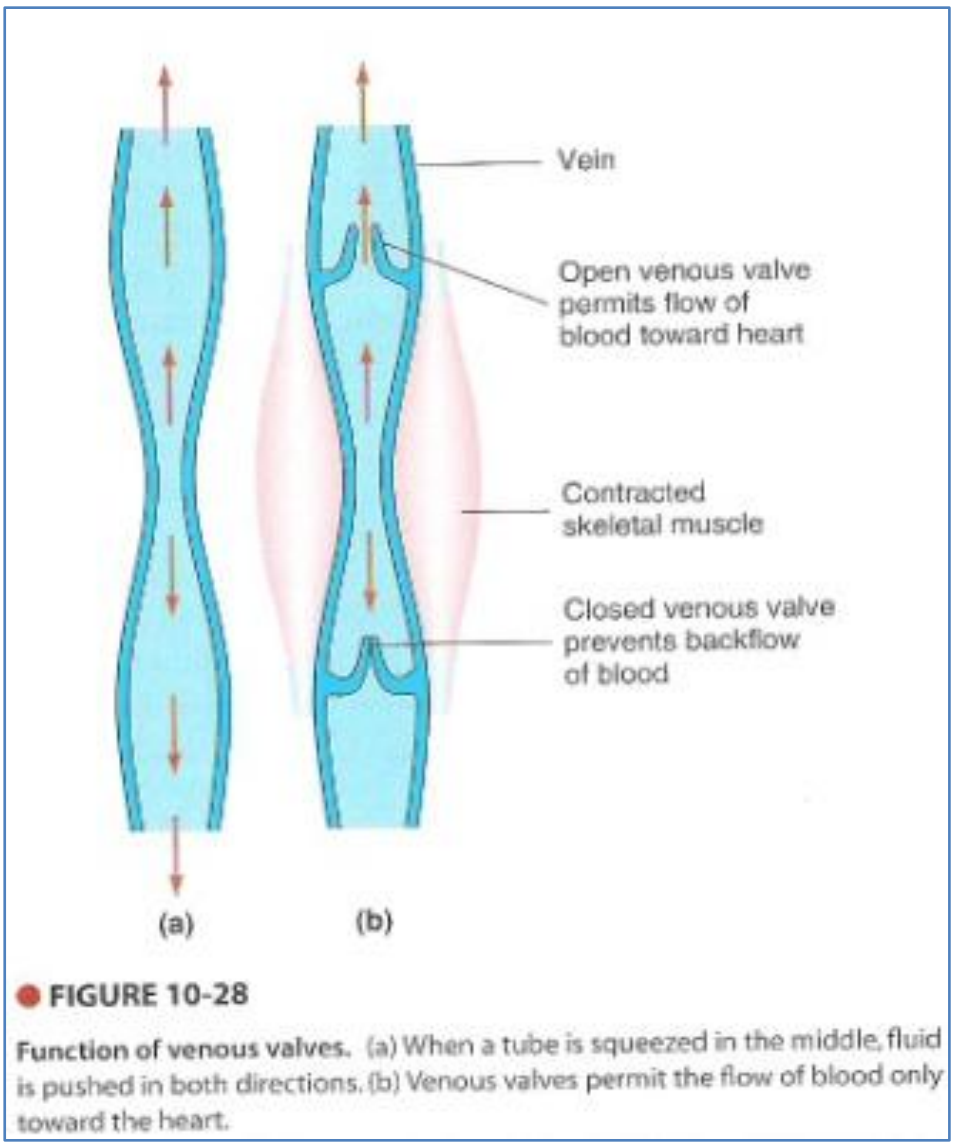


FIGURE 10-27

Effect of contracting the skeletal muscles of the legs in counteracting the effects of gravity. Contraction of skeletal muscles (as in walking) completely empties given vein segments, interrupting the column of blood that the lower veins must support.

EFFECT OF VENOUS VALVES ON VENOUS RETURN

Venous vasoconstriction and external venous compression both drive blood toward the heart. Blood can only be driven forward because the large veins are equipped with one-way valves spaced at 2- to 4-cm intervals; these valves let blood move forward toward the heart but keep it from moving back toward the tissues (Figure 10-28b).



● **FIGURE 10-28**

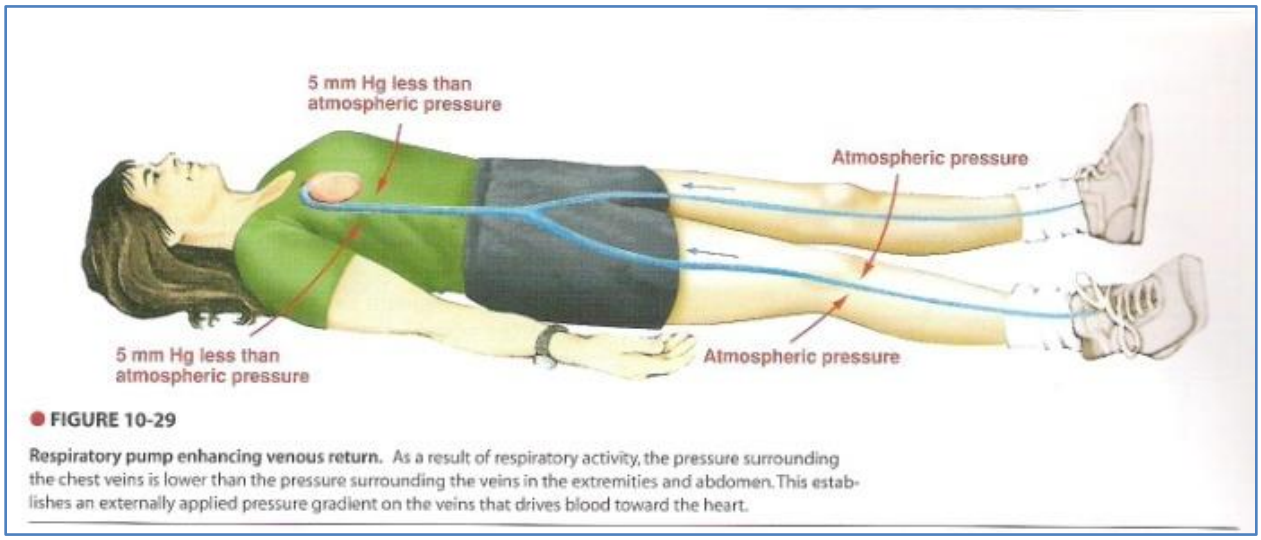
Function of venous valves. (a) When a tube is squeezed in the middle, fluid is pushed in both directions. (b) Venous valves permit the flow of blood only toward the heart.

Varicose veins occur when the venous valves become incompetent and can no longer support the column of blood above them. People predisposed to this condition usually have inherited an overdistensibility and weakness of their vein walls. Aggravated by frequent, prolonged standing, the veins become so distended as blood pools in them that the edges of the valves can no longer meet to form a seal. Varicosed superficial leg veins become visibly overdistended and tortuous (twisted). The most serious consequence of varicose veins is the possibility of abnormal clot formation in the sluggish, pooled blood.

EFFECT OF RESPIRATORY ACTIVITY ON VENOUS RETURN

As a result of respiratory activity, the pressure within the chest cavity averages 5 mm Hg less than atmospheric pressure. As the venous system returns blood to the heart from the lower regions of the body, it travels through the chest cavity, where it is exposed to this subatmospheric pressure. Because the venous system in the limbs and abdomen is subject to

normal atmospheric pressure, an externally applied pressure gradient exists between the lower veins (at atmospheric pressure) and the chest veins (at 5 mm Hg less than atmospheric pressure). This pressure difference squeezes blood from the lower veins to the chest veins, promoting increased venous return (Figure 10-29). This mechanism of facilitating venous return is called the **respiratory pump**.



● FIGURE 10-29

Respiratory pump enhancing venous return. As a result of respiratory activity, the pressure surrounding the chest veins is lower than the pressure surrounding the veins in the extremities and abdomen. This establishes an externally applied pressure gradient on the veins that drives blood toward the heart.

EFFECT OF CARDIAC SUCTION ON VENOUS RETURN

The extent of cardiac filling does not depend entirely on factors affecting the veins. The heart plays a role in its own filling. During ventricular contraction, the AV valves are drawn downward, enlarging the atrial cavities. As a result, the atrial pressure transiently drops below 0 mm Hg, thus increasing the vein-to-atria pressure gradient so that venous return is enhanced. In addition, the rapid expansion of the ventricular chambers during ventricular relaxation creates a transient negative pressure in the ventricles so that blood is "sucked in" from the atria and veins; that is, the negative ventricular pressure increases the vein-to-atria-to-ventricle pressure gradient, further enhancing venous return. Thus the heart functions as a "suction pump" to facilitate cardiac filling.

BLOOD PRESSURE

Mean arterial pressure is the blood pressure that is monitored and regulated in the body, not the arterial systolic or diastolic or pulse pressure nor the pressure in any other part of the vascular tree. Routine blood pressure measurements record the arterial systolic and diastolic pressures.

Blood pressure is regulated by controlling cardiac output, total peripheral resistance, and blood volume

Mean arterial pressure is the main driving force for propelling blood to the tissues. This pressure must be closely regulated for two reasons. First, it must be high enough to ensure sufficient driving pressure; without this pressure, the brain and other organs will not receive adequate flow,

no matter what local adjustments are made in the resistance of the arterio1es supplying them. Second, the pressure must not be so high that it creates extra work for the heart and increases the risk of vascular damage and possible rupture of small blood vessels.

DETERMINANTS OF MEAN ARTERIAL PRESSURE

Elaborate mechanisms involving the integrated action of the various components of the circulatory system and other body systems are vital in regulating this all-important mean arterial pressure (Figure 10-30). Remember that the determinants of mean arterial pressure are cardiac output and total peripheral resistance:

Mean arterial pressure = cardiac output X total peripheral resistance

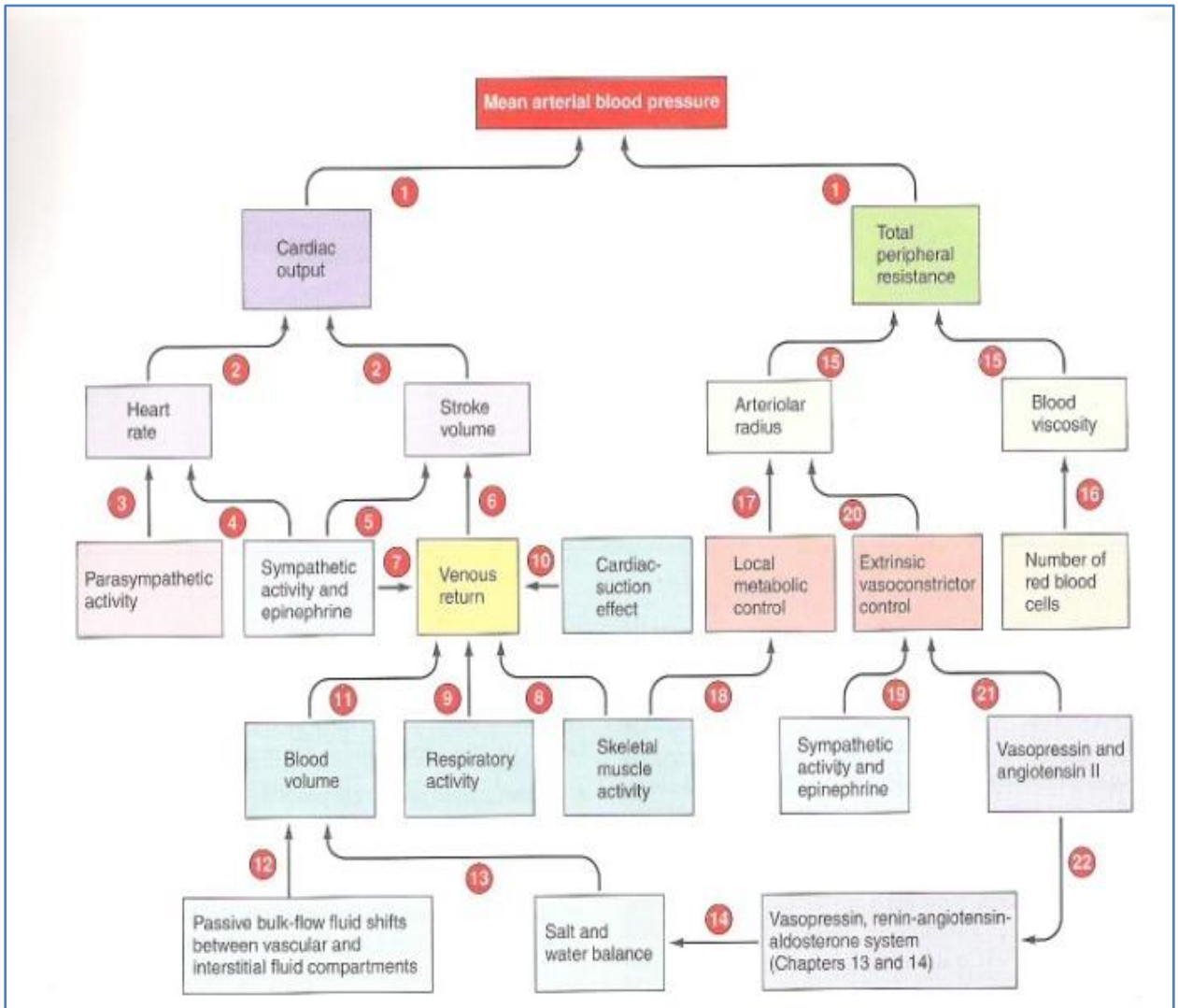


FIGURE 10-30

Determinants of mean arterial blood pressure. Note that this figure is basically a composite of Figure 9-23, p. 263, "Control of cardiac output"; Figure 10-12, p. 290, "Factors affecting total peripheral resistance"; and Figure 10-24, p. 300, "Factors that facilitate venous return." See the text for a discussion of the circled numbers.

- Mean arterial pressure depends on cardiac output and total peripheral resistance (1 on Figure 10-30). Cardiac output depends on heart rate and stroke volume 2.
- Heart rate depends on the relative balance of parasympathetic activity 3, which decreases heart rate, and sympathetic activity 4, which increases heart rate.
- Stroke volume increases in response to sympathetic activity 5 (extrinsic control of stroke volume).
- Stroke volume also increases as venous return increases 6 (intrinsic control of stroke volume).
- Venous return is enhanced by sympathetically induced venous vasoconstriction 7, the skeletal muscle pump 8, the respiratory pump 9, and cardiac suction 10.
- The effective circulating blood volume also influences how much blood is returned to the heart 11. The blood volume depends in the short term on the size of passive bulk flow fluid shifts between plasma and interstitial fluid across the capillary walls 12. In the long term, the blood volume depends on salt and water balance 13, which are hormonally controlled by the renin-angiotensin-aldosterone system and vasopressin, respectively 14.
- Urinary output is reduced, thereby conserving water that normally would have been lost from the body 15. This additional fluid retention helps expand the reduced plasma volume 16.
- Arteriolar radius is influenced by local (intrinsic) metabolic controls that match blood flow with metabolic needs 17. For example, local changes that take place in active skeletal muscles cause local arteriolar vasodilation and increased blood flow to these muscles 18.
- Arteriolar radius is also influenced by sympathetic activity 19, an extrinsic control mechanism that causes arteriolar vasoconstriction 20 to increase total peripheral resistance and mean arterial blood pressure.
- Arteriolar radius is also extrinsically controlled by the hormones vasopressin and angiotensin II, which are potent vasoconstrictors 21 as well as being important in salt and water balance 22.

Altering any of the relevant factors that influence blood pressure will change blood pressure, unless a compensatory change in another variable keeps the blood pressure constant.

SHORT-TERM AND LONG-TERM CONTROL MEASURES

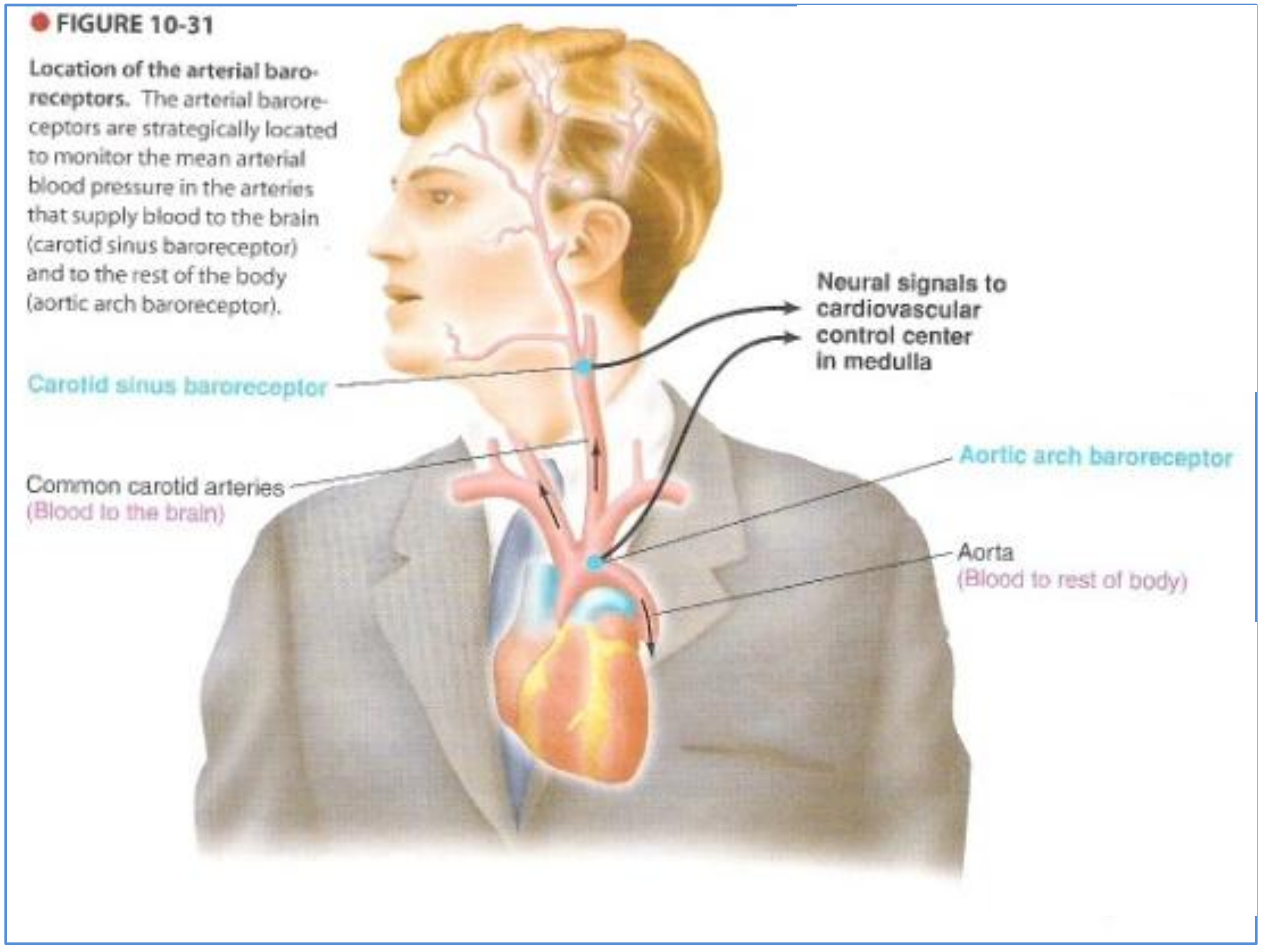
Mean arterial pressure is constantly monitored by baroreceptors (pressure sensors) within the circulatory system. When deviations from normal are detected, multiple reflex responses are initiated to return mean arterial pressure to its normal value. *Short-term* (within seconds) adjustments are made by alterations in cardiac output and total peripheral resistance, mediated by means of autonomic nervous system influences on the heart, veins, and arterioles. *Lang-term* (requiring minutes to days) control involves adjusting total blood volume by restoring normal salt and water balance through mechanisms that regulate urine output and thirst. The size of the total blood volume, in turn, has a profound effect on cardiac output and mean arterial pressure.

The baroreceptor reflex

Any change in mean arterial pressure triggers an autonomically mediated baroreceptor reflex that influences the heart and blood vessels to adjust cardiac output and total peripheral resistance in

an attempt to restore blood pressure to normal. Like any reflex, the baroreceptor reflex includes a receptor, an afferent pathway, an integrating center, an efferent pathway, and effector organs.

The most important receptors involved in moment-to-moment regulation of blood pressure, the carotid sinus and aortic arch baroreceptors, are mechanoreceptors sensitive to changes in mean arterial pressure. These baroreceptors are strategically located (Figure 10-31) to provide critical information about arterial blood pressure in the vessels leading to the brain (the carotid sinus baroreceptor) and in the major arterial trunk before it gives off branches that supply the rest of the body (the aortic arch baroreceptor).



The integrating center that receives the afferent impulses about the state of mean arterial pressure is the cardiovascular control center, located in the medulla within the brain stem. The efferent pathway is the autonomic nervous system. The cardiovascular control center alters the ratio between sympathetic and parasympathetic activity to the effector organs (the heart and blood vessels). To review how autonomic changes alter arterial blood pressure, Figure 10-33 summarizes the major effects of parasympathetic and sympathetic stimulation on the heart and blood vessels.

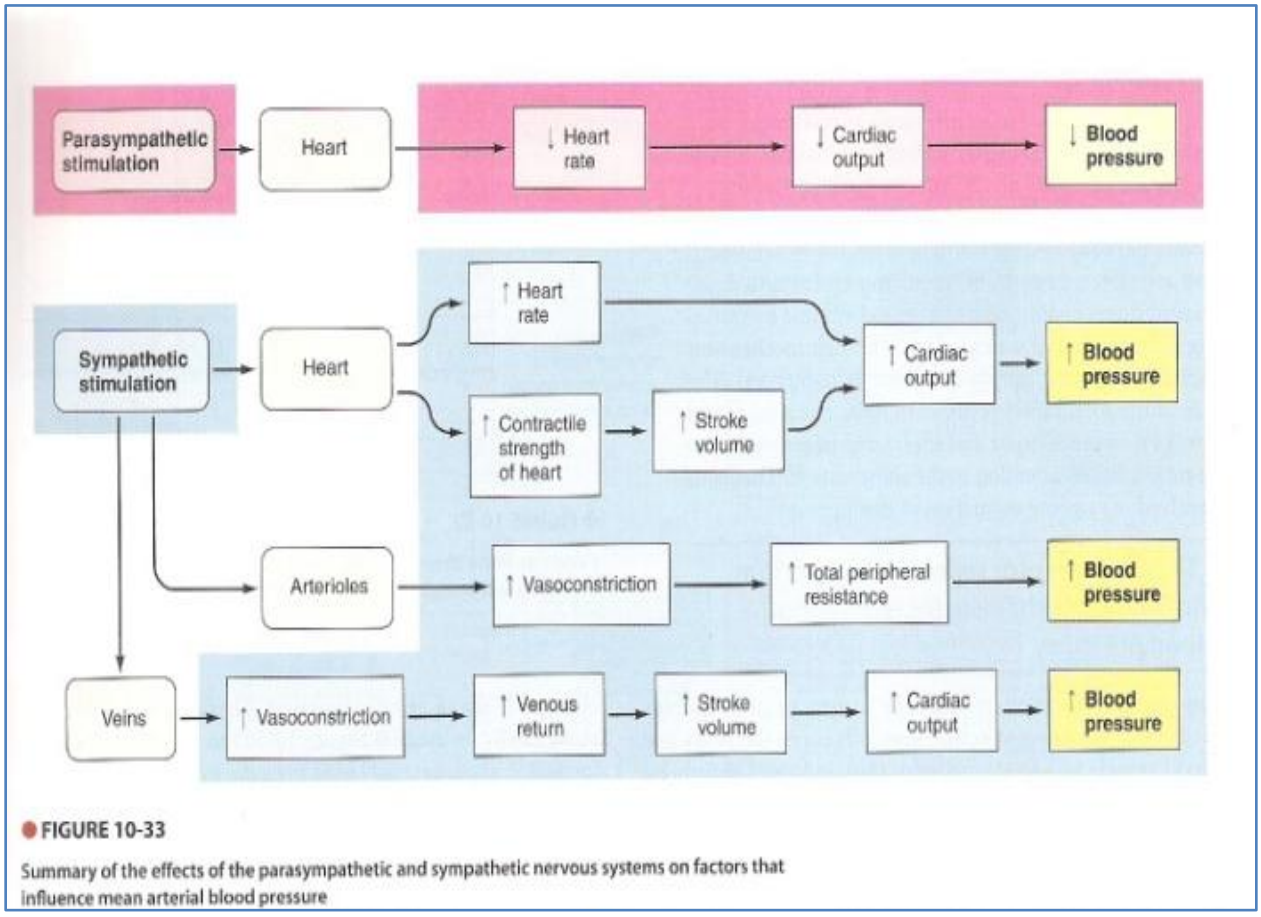


FIGURE 10-33

Summary of the effects of the parasympathetic and sympathetic nervous systems on factors that influence mean arterial blood pressure

If for any reason mean arterial pressure rises above normal (Figure 10-34a), the carotid sinus and aortic arch baroreceptors increase the rate of firing in their respective afferent neurons. On being informed by increased afferent firing that the blood pressure has become too high, the cardiovascular control center responds by decreasing sympathetic and increasing parasympathetic activity to the cardiovascular system. These efferent signals decrease heart rate, decrease stroke volume, and produce arteriolar and venous vasodilation, which in turn lead to a decrease in cardiac output and a decrease in total peripheral resistance, with a subsequent fall in blood pressure back toward normal.

Conversely, when blood pressure falls below normal (Figure 10-34b) baroreceptor activity decreases, inducing the cardiovascular center to increase sympathetic cardiac and vasoconstrictor nerve activity while decreasing its parasympathetic output. This efferent pattern of activity leads to an increase in heart rate and stroke volume, coupled with arteriolar and venous vasoconstriction. These changes increase both cardiac output and total peripheral resistance, raising blood pressure back toward normal. Despite these control measures, sometimes blood pressure is not maintained at the appropriate leve1.

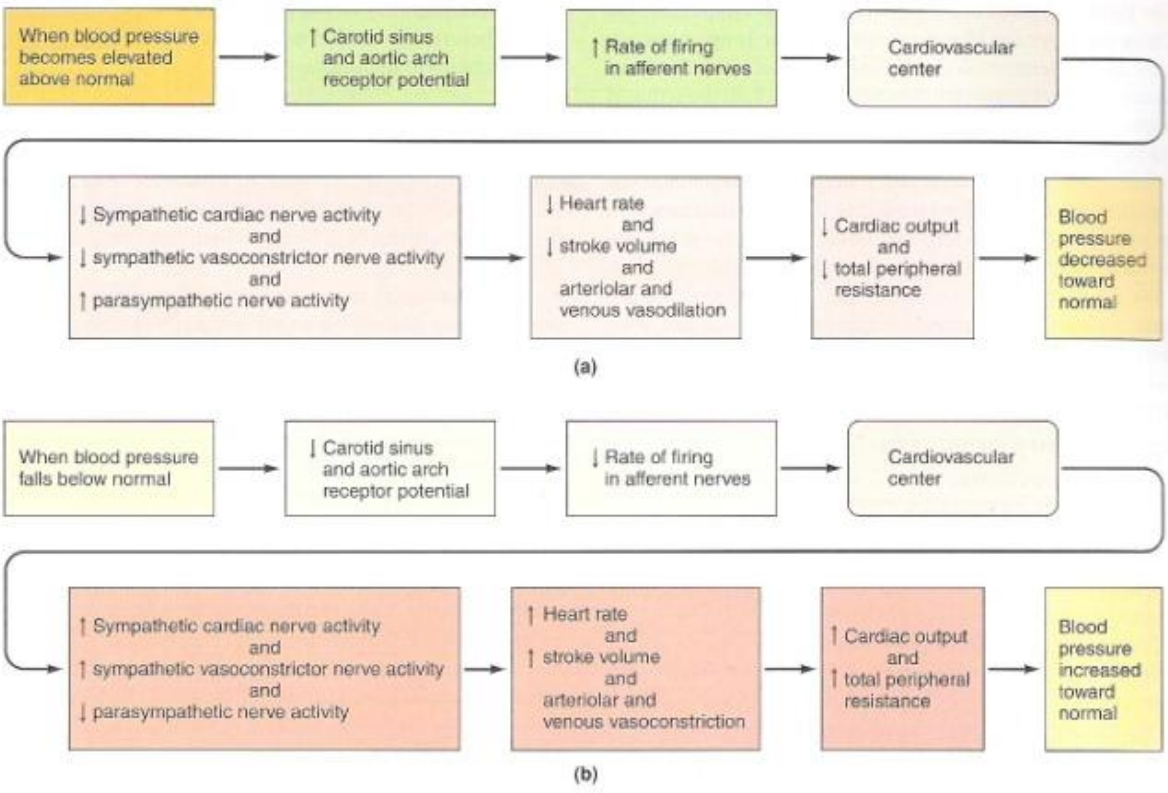


FIGURE 10-34

Baroreceptor reflexes to restore the blood pressure to normal. (a) Baroreceptor reflex in response to an elevation in blood pressure. (b) Baroreceptor reflex in response to a fall in blood pressure.

Hypertension

Sometimes blood-pressure control mechanisms do not function properly or are unable to completely compensate for, or too low (hypotension if below 100/60 mm Hg). Hypotension in its extreme form is *circulatory* shock

There are two broad classes of hypertension, secondary hypertension and primary hypertension, depending on the cause. A definite cause for hypertension can be established in only 10% of the cases. Hypertension that occurs secondary to another known primary problem is called *secondary hypertension.* For example, when the elasticity of the arteries is reduced by the loss of elastin fibers or the presence of calcified atherosclerotic plaques, arterial pressure is chronically increased by this "hardening of the arteries." Likewise, hypertension occurs if the kidneys are diseased and unable to eliminate the normal salt load. Salt retention induces water retention, which expands the plasma volume and leads to hypertension.

The underlying cause is unknown in the remaining 90% of hypertension cases. Such hypertension is known as *primary (essential* or *idiopathic) hypertension.* Primary hypertension is a catchall category for blood pressure elevated by a variety of unknown causes rather than by a single disease entity. People show a strong genetic tendency to develop primary hypertension,

which can be hastened or worsened by contributing factors such as obesity, stress, smoking, or dietary habits.

Whatever the underlying defect, once initiated, hypertension appears to be self-perpetuating. Constant exposure to elevated blood pressure predisposes vessel walls to the development of atherosclerosis, which further raises blood pressure.

ADAPTATION OF BARORECEPTORS DURING HYPERTENSION

The baroreceptors do not respond to bring the blood pressure back to normal during hypertension because they adapt, or are "reset," to operate at a higher level. In the presence of chronically elevated blood pressure, the baroreceptors still function to regulate blood pressure, but they maintain it at a higher mean pressure.

COMPLICATIONS OF HYPERTENSION

Hypertension imposes stresses on both the heart and the blood vessels. The heart has an increased workload because it is pumping against an increased total peripheral resistance, whereas blood vessels may be damaged by the high internal pressure, particularly when the vessel wall is weakened by the degenerative process of atherosclerosis. Complications of hypertension include congestive heart failure caused by the heart's inability to pump continuously against a sustained elevation in arterial pressure, strokes caused by rupture of brain vessels, and heart attacks caused by rupture of coronary vessels. Spontaneous hemorrhage caused by bursting of small vessels elsewhere in the body may also occur but with less serious consequences; an example is the rupture of blood vessels in the nose, resulting in nosebleeds. Another serious complication of hypertension is renal failure caused by progressive impairment of blood flow through damaged renal blood vessels. Furthermore, retinal damage from changes in the blood vessels supplying the eyes may result in progressive loss of vision.

Until complications occur, hypertension is symptomless because the tissues are adequately supplied with blood. Therefore, unless blood pressure measurements are made on a routine basis the condition can go undetected until a precipitous complicating event.

In its recent guidelines, a new category for blood pressures, prehypertension, is identified in the range between normal and hypertension (between *120/80 to 139/89).* Blood pressures in the prehypertension range can usually be reduced by appropriate dietary and exercise measures, whereas those in the hypertension range typically must be treated with blood pressure medication in addition to changing health habits. The goal in managing blood pressures in the prehypertension range is to take action before the pressure climbs into the hypertension range, where serious complications may develop.

Orthostatic hypotension

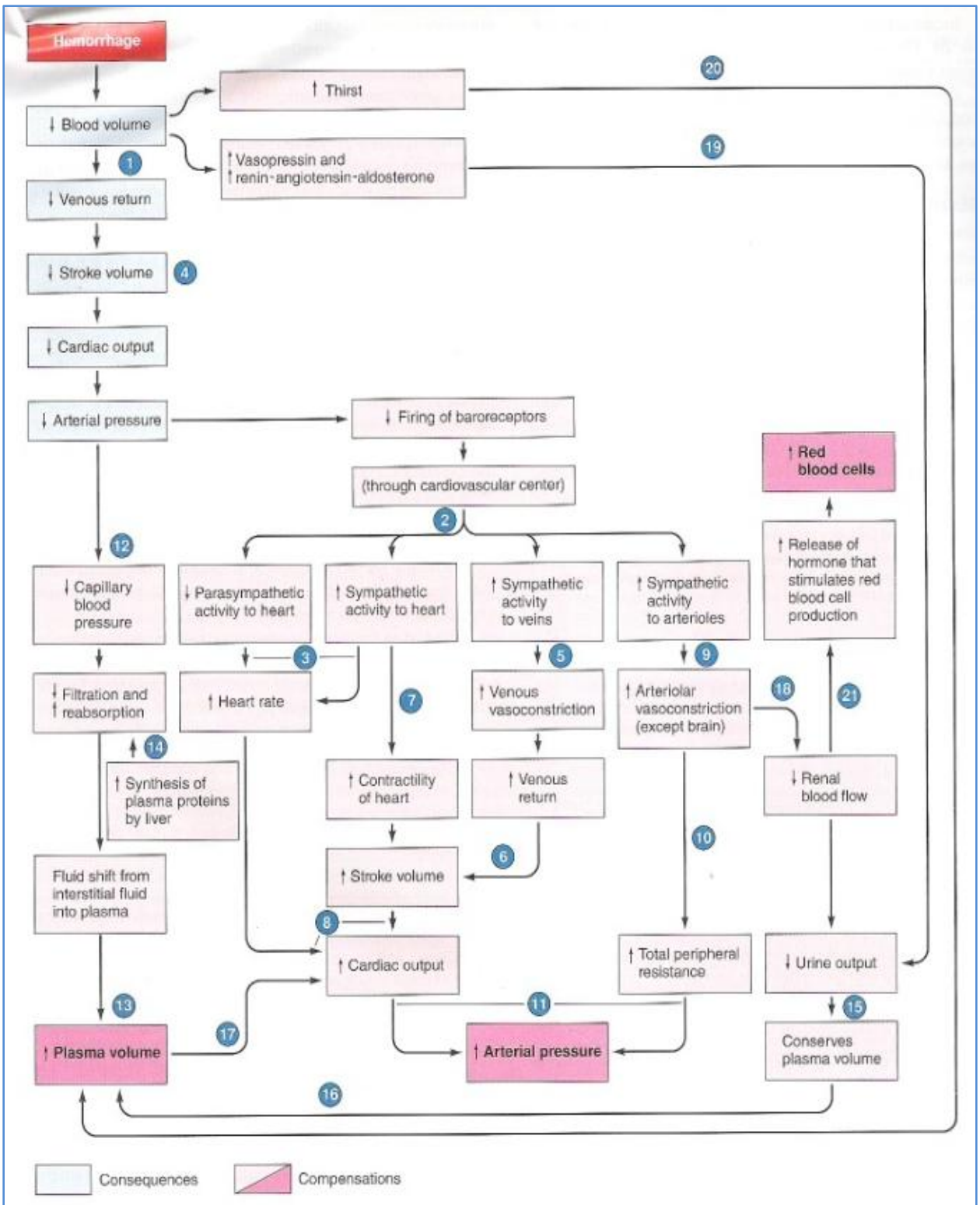
Hypotension, or low blood pressure, occurs either when there is a disproportion between vascular capacity and blood volume (in essence, too little blood to fill the vessels) or when the heart is too weak to drive the blood.

The most common situation in which hypotension occurs transiently is orthostatic hypotension. **Orthostatic (postural) hypotension** is a transient hypotensive condition resulting from insufficient compensatory responses to the gravitational shifts in blood when a person moves from a horizontal to a vertical position, especially after prolonged bed rest. Then a person moves from lying down to standing up, pooling of blood in the leg veins from gravity reduces venous return, decreasing stroke volume and thus lowering cardiac output and blood pressure. This fall in blood pressure is normally detected by the baroreceptors, which initiate immediate compensatory responses to restore blood pressure to its proper level. When a long-bedridden patient first starts to rise, however, these reflex compensatory adjustments are temporarily lost or reduced because of disuse. Sympathetic control of the leg veins is inadequate, so when the patient first stands up blood pools in the lower extremities. The resultant orthostatic hypotension and decrease in blood flow to the brain cause dizziness or actual fainting.

Circulatory shock can become irreversible

When blood pressure falls so low that adequate blood flow to the tissues can no longer be maintained, the condition known as **circulatory shock** occurs. Circulatory shock may result from (1) extensive loss of blood volume as through hemorrhage; (2) failure of a weakened heart to pump blood adequately; (3) widespread arteriolar vasodilation triggered by vasodilator substances (such as extensive histamine release in severe allergic reactions); or (4) neurally defective vasoconstrictor tone.

Figure 10-35 represents the consequences of and compensations for shock, using hemorrhage as an example.



● FIGURE 10-35

Consequences and compensations of hemorrhage. The reduction in blood volume resulting from hemorrhage leads to a fall in arterial pressure. (Note the *blue boxes*, representing consequences of hemorrhage.) A series of compensations ensue *(light pink boxes)* that ultimately restore plasma volume, arterial pressure, and the number of red blood cells toward normal *(dark pink boxes)*. Refer to the text (pp. 308 and 310) for an explanation of the circled numbers and a detailed discussion of the compensations.

CONSEQUENCES AND COMPENSATIONS OF SHOCK

- Following severe loss of blood, the resultant reduction in circulating blood volume leads to a decrease in venous return 1 and a subsequent fall in cardiac output and arterial blood pressure. (Note the blue boxes, which indicate consequences of hemorrhage.)
- Compensatory measures immediately attempt to maintain adequate blood flow to the brain. (Note the pink boxes, which indicate compensations for hemorrhage.)
- The baroreceptor reflex response to the fall in blood pressure brings about increased sympathetic and decreased parasympathetic activity to the heart 2. The result is an increase in heart rate 3 to offset the reduced stroke volume 4 brought about by the loss of blood volume. With severe fluid loss, the pulse is weak because of the reduced stroke volume but rapid because of the increased heart rate.
- Increased sympathetic activity to the veins produces generalized venous vasoconstriction 5, increasing venous return 6.
- Simultaneously, sympathetic stimulation of the heart increases the heart's contractility 7 so that it beats more forcefully and ejects a greater volume of blood, likewise increasing the stroke volume.
- The increase in heart rate and in stroke volume collectively increase cardiac output 8.
- Sympathetically induced generalized arteriolar vasoconstriction 9 leads to an increase in total peripheral resistance 10.
- Together, the increase in cardiac output and total peripheral resistance bring about a compensatory increase in arterial pressure 11.
- The original fall in arterial pressure is also accompanied by a fall in capillary blood pressure 12, which results in fluid shifts from the interstitial fluid into the capillaries to expand the plasma volume 13. This response is sometimes termed *autotransfusion,* because it restores the plasma volume as a transfusion does.
- This ECF fluid shift is enhanced by plasma protein synthesis by the liver during the next few days following hemorrhage 14. The plasma proteins exert a colloid osmotic pressure that helps retain extra fluid in the plasma.
- Urinary output is reduced, thereby conserving water that normally would have been lost from the body 15. This additional fluid retention helps expand the reduced plasma volume 16. Expansion of plasma volume further augments the increase in cardiac output brought about by the baroreceptor reflex 17. Reduction in urinary output results from decreased renal blood flow caused by compensatory renal arteriolar vasoconstriction 18. The reduced plasma volume also triggers increased secretion of the hormone vasopressin and activation of the salt- and water-conserving renin-angiotensin-aldosterone hormonal pathway, which further reduces urinary output 19.
- Increased thirst is also stimulated by a fall in plasma volume 20. The resultant increased fluid intake helps restore plasma volume.
- Over a longer course of time (a week or more), lost red blood cells are replaced through increased red blood cell production triggered by a reduction in O_2 delivery to the kidneys 21.

IRREVERSIBLE SHOCK

These compensatory mechanisms are often not enough to counteract substantial fluid loss. Even if they can maintain an adequate blood pressure level, the short-term measures cannot continue indefinitely. Ultimately, fluid volume must be replaced from the outside through drinking, transfusion, or a combination of both. Blood supply to kidneys, digestive tract, skin, and other organs can be compromised to maintain blood flow to the brain only so long before organ damage begins to occur. A point may be reached at which blood pressure continues to drop rapidly because of tissue damage, despite vigorous therapy. This condition is frequently termed *irreversible shock,* in contrast to *reversible shock,* which can be corrected by compensatory mechanisms and effective therapy.