General Anatomy of the Blood Vessels
Physiology of Circulation

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LEARNING OUTCOMES

As a result of the lesson you will be able to:

- *Describe the structure of a blood vessel;*
- *Compare and contrast arteries, capillaries, and veins;*
- *Explain how portal systems and anastomoses differ from the most common route in which blood flows from the heart and back again.*
- *Define blood pressure; and Explain the relationship between blood pressure, resistance, and flow;*
- *Describe three factors that determine resistance to blood flow;*
- *Discuss local, neural, and hormonal control of blood pressure;*
- *Explain how blood pressure and osmotic pressure interact in capillary fluid exchanges;*
- *Describe the mechanisms for returning venous blood to the heart.*

Anatomy of Blood Vessels

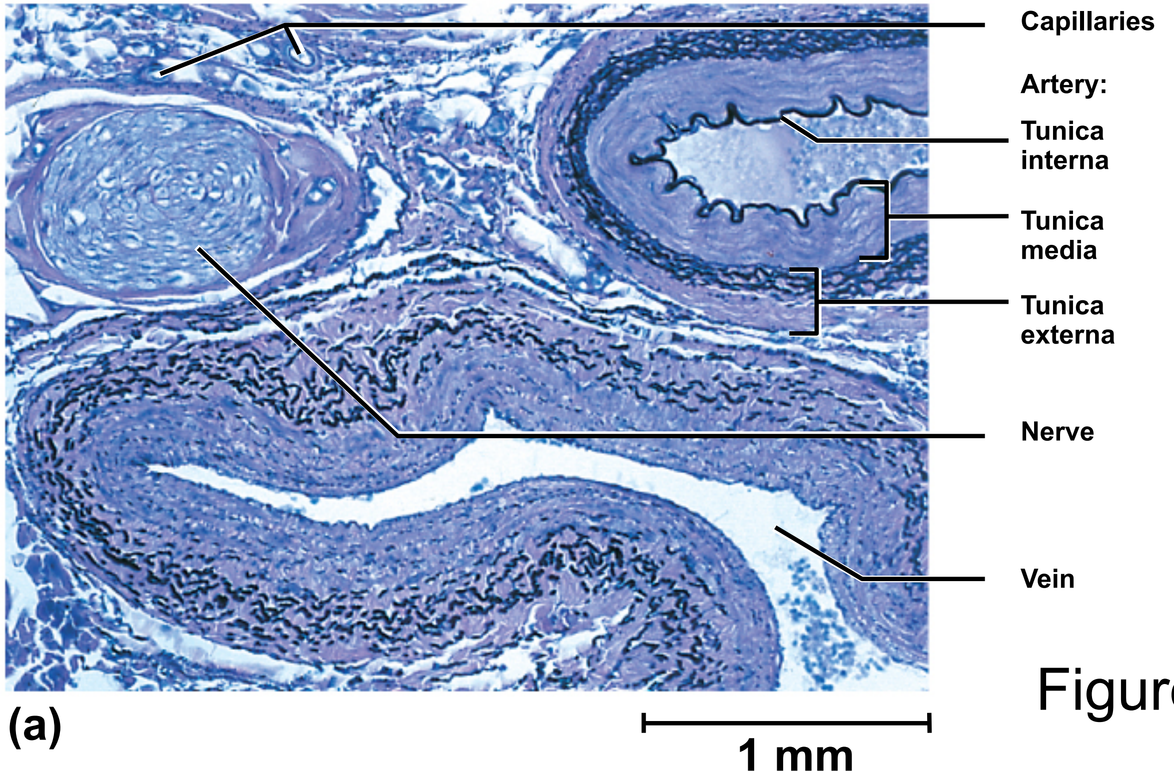


Figure 20.1a

- **arteries** carry blood away from heart
- **veins** carry blood back to heart
- **capillaries** connect smallest arteries to veins

Vessel Wall

- **tunica interna** (tunica intima)
  - lines the blood vessel and is exposed to blood
  - **endothelium** – simple squamous epithelium overlying a basement membrane and a sparse layer of loose connective tissue
    - acts as a **selectively permeable barrier**
    - **secrete chemicals** that stimulate dilation or constriction of the vessel
    - normally **repels blood cells and platelets** that may adhere to it and form a clot
    - when tissue around vessel is inflamed, the endothelial cells **produce cell-adhesion molecules** that induce leukocytes to adhere to the surface
      - causes leukocytes to congregate in tissues where their defensive actions are needed

Vessel Wall

- **tunica media**
  - middle layer
  - consists of **smooth muscle**, collagen, and elastic tissue
  - strengthens vessel and prevents blood pressure from rupturing them
  - **vasomotion** – changes in diameter of the blood vessel brought about by smooth muscle

Vessel Wall

- **tunica externa** (tunica adventitia)
  - outermost layer
  - consists of loose connective tissue that often merges with that of neighboring blood vessels, nerves, or other organs
  - anchors the vessel and provides passage for small nerves, lymphatic vessels
  - **vasa vasorum** – small vessels that supply blood to at least the outer half of the larger vessels
    - blood from the lumen is thought to nourish the inner half of the vessel by diffusion

Large Vessels

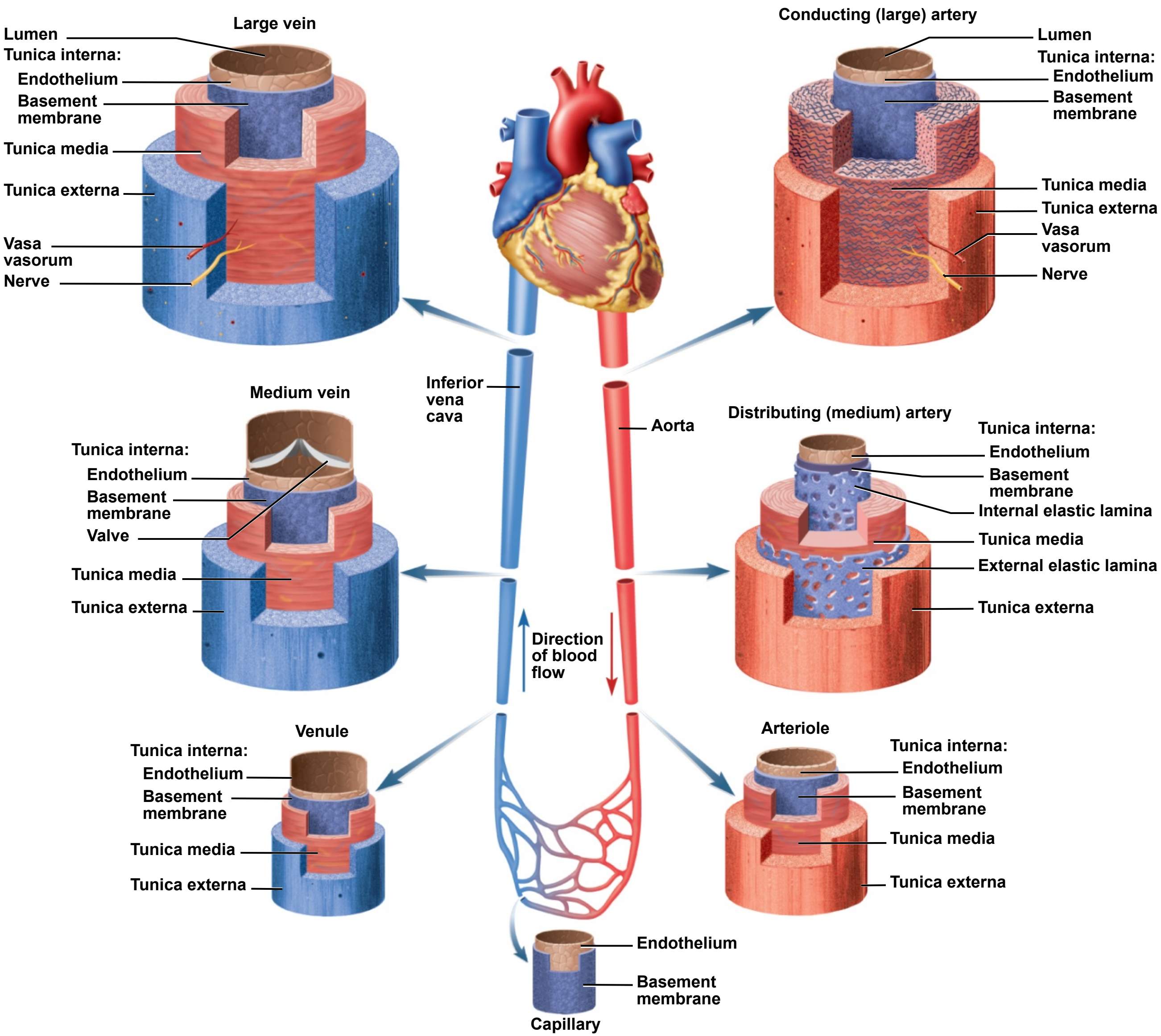


Figure 20.2

Arteries

- **arteries** are sometimes called **resistance vessels** because they have relatively strong, resilient tissue structure that resists high blood pressure
  - **conducting (elastic** or **large) arteries**
    - biggest arteries
    - aorta, common carotid, subclavian, pulmonary trunk, and common iliac arteries
    - have a layer of elastic tissue, internal elastic lamina, at the border between interna and media
    - **external elastic lamina** at the border between media and externa
    - expand during systole, recoil during diastole which lessens fluctuations in blood pressure
  - **distributing (muscular** or **medium) arteries**
    - distributes blood to specific organs
    - brachial, femoral, renal, and splenic arteries
    - smooth muscle layers constitute three-fourths of wall thickness

Medium Vessels

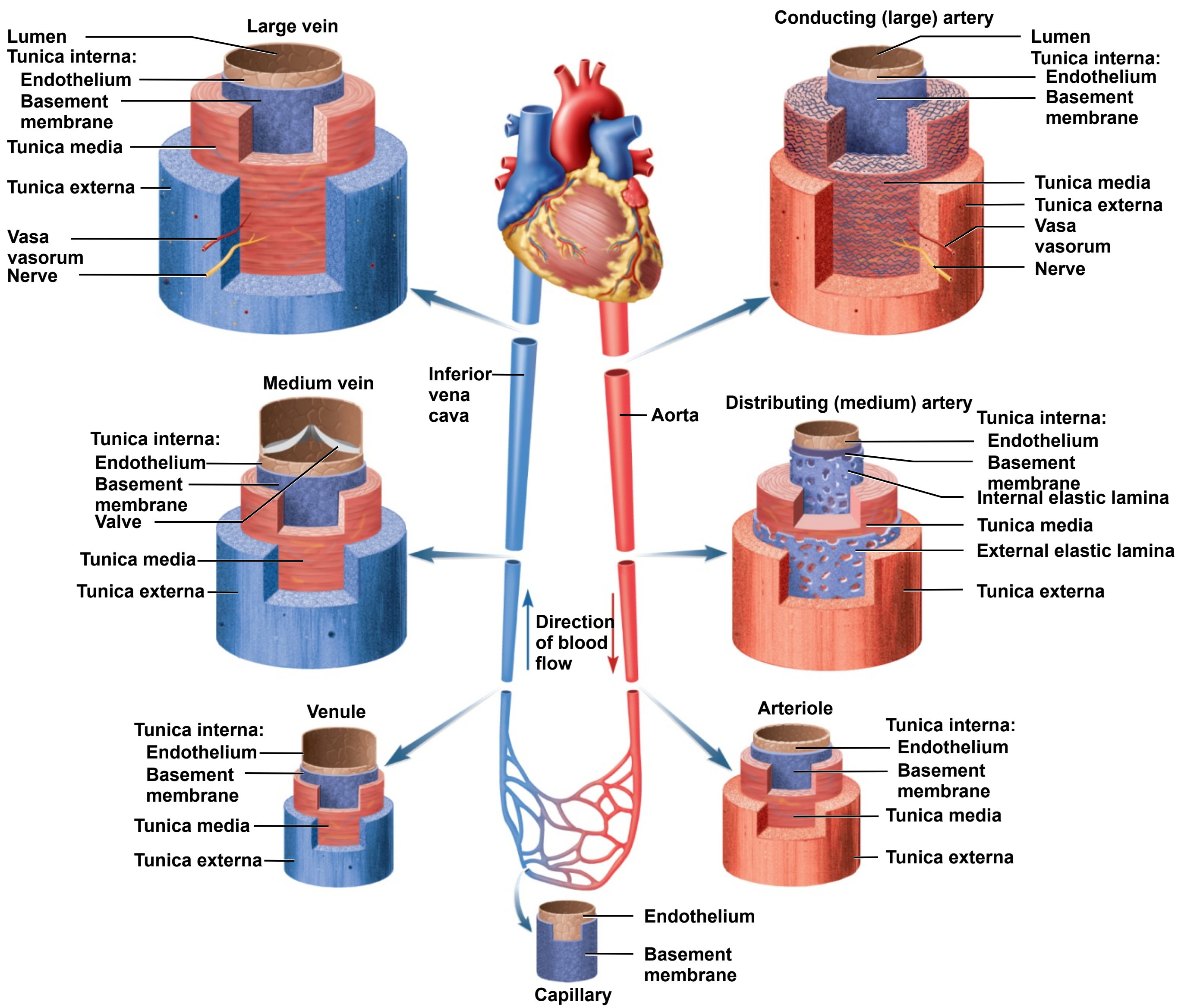


Figure 20.2

Aneurysm

- **aneurysm** - weak point in an artery or the heart wall
  - forms a thin-walled, bulging sac that pulsates with each heartbeat and may rupture at any time
  - **dissecting aneurysm -** blood accumulates between the tunics of the artery and separates them, usually because of degeneration of the tunica media
  - **most common sites**: abdominal aorta, renal arteries, and arterial circle at the base of the brain
  - can cause pain by putting pressure on other structures
  - can rupture causing hemorrhage
  - result from congenital weakness of the blood vessels or result of trauma or bacterial infections such as syphilis
    - most common cause is atherosclerosis and hypertension

Arteries and Metarterioles

- **resistance (small) arteries**
  - arterioles – smallest arteries
    - control amount of blood to various organs
  - thicker tunica media in proportion to their lumen than large arteries and very little tunica externa
- **metarterioles**
  - short vessels that link arterioles to capillaries
  - muscle cells form a **precapillary sphincter** about entrance to capillary
    - constriction of these sphincters reduces or shuts off blood flow through their respective capillaries
    - diverts blood to other tissues

Small Vessels

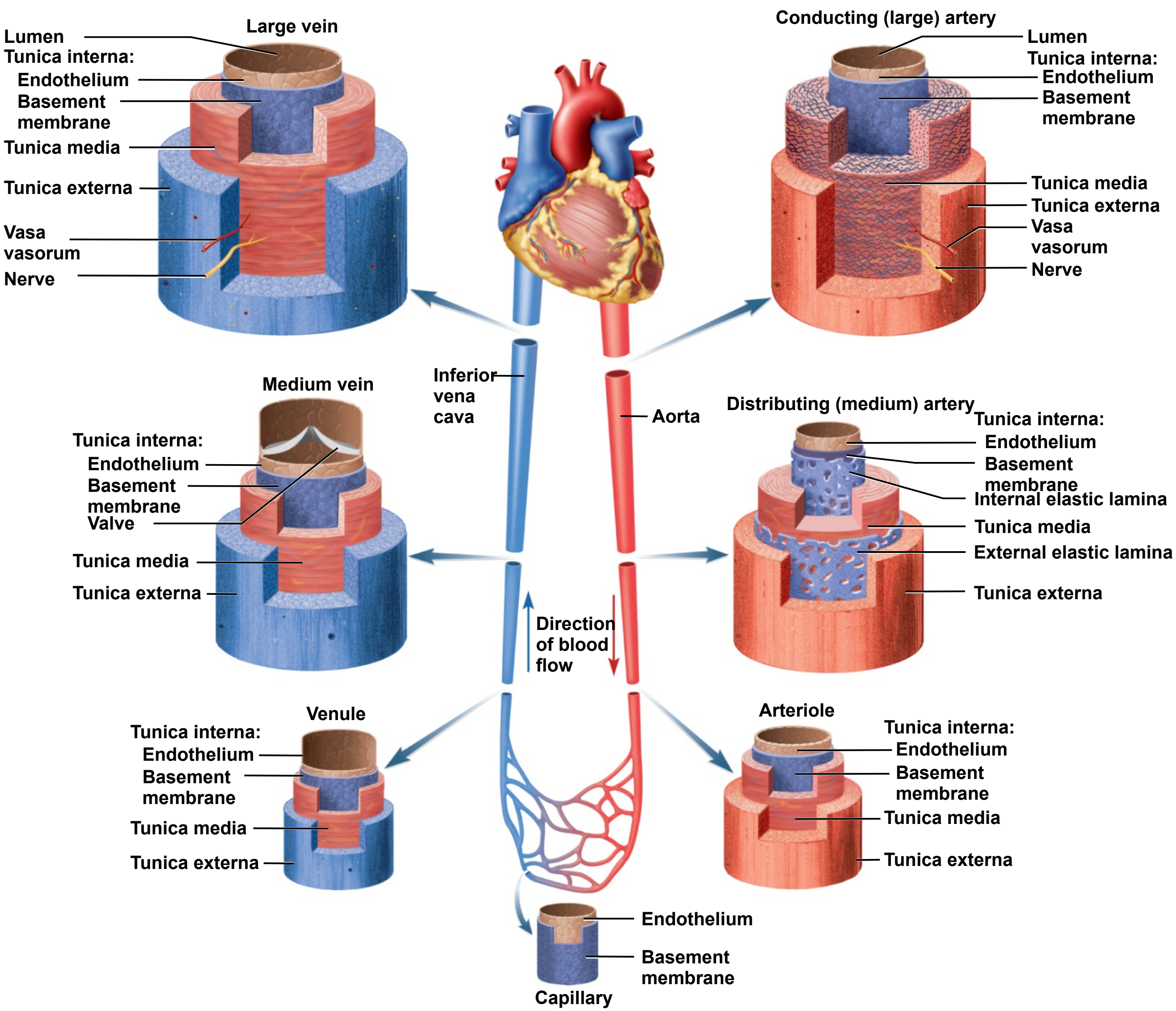
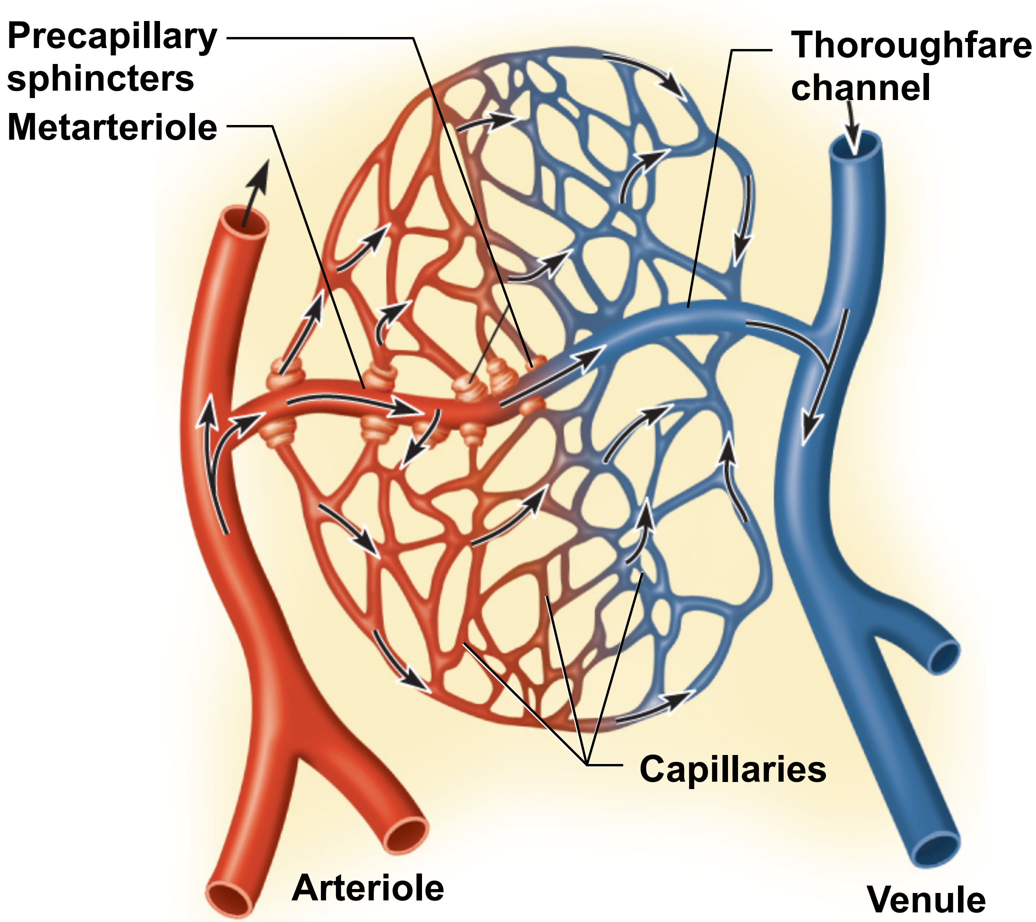


Figure 20.2

Baroreceptors and Chemoreceptors



(a) Sphincters open

Figure 20.3a

Arterial Sense Organs

- sensory structures in the walls of certain vessels that monitor blood pressure and chemistry
  - transmit information to brainstem that serves to regulate heart rate, vasomotion, and respiration
  - **carotid sinuses –** baroreceptors (pressure sensors)
    - in walls of internal carotid artery
    - monitors blood pressure – signaling brainstem
      - decreased heart rate and vessels dilation in response to high blood pressure
  - **carotid bodies** - chemoreceptors
    - oval bodies near branch of common carotids
    - monitor blood chemistry
    - mainly transmit signals to the brainstem respiratory centers
    - adjust respiratory rate to stabilize pH, CO_2, and O_2
  - **aortic bodies -** chemoreceptors
    - one to three in walls of aortic arch
    - same function as carotid bodies

Capillaries

- **capillaries** - site where nutrients, wastes, and hormones pass between the blood and tissue fluid through the walls of the vessels (exchange vessels)
  - the 'business end' of the cardiovascular system
  - composed of **endothelium and basal lamina**
  - absent or scarce in tendons, ligaments, epithelia, cornea and lens of the eye
- **three capillary types** distinguished by ease with which substances pass through their walls and by structural differences that account for their greater or lesser permeability

Three Types of Capillaries

- **continuous capillaries** - occur in most tissues
  - **endothelial cells** have **tight junctions** forming a continuous tube with **intercellular clefts**
    - allow passage of solutes such as glucose
  - **pericytes** wrap around the capillaries and contain the same contractile protein as muscle
    - contract and regulate blood flow

- **fenestrated capillaries** - kidneys, small intestine
  - organs that require rapid absorption or filtration
  - endothelial cells riddled with holes called **filtration pores (fenestrations)**
    - spanned by very thin glycoprotein layer
    - allows passage of only small molecules

- **sinusoids (discontinuous capillaries)** - liver, bone marrow, spleen
  - irregular blood-filled spaces with large fenestrations
  - allow proteins (albumin), clotting factors, and new blood cells to enter the circulation

Continuous Capillary

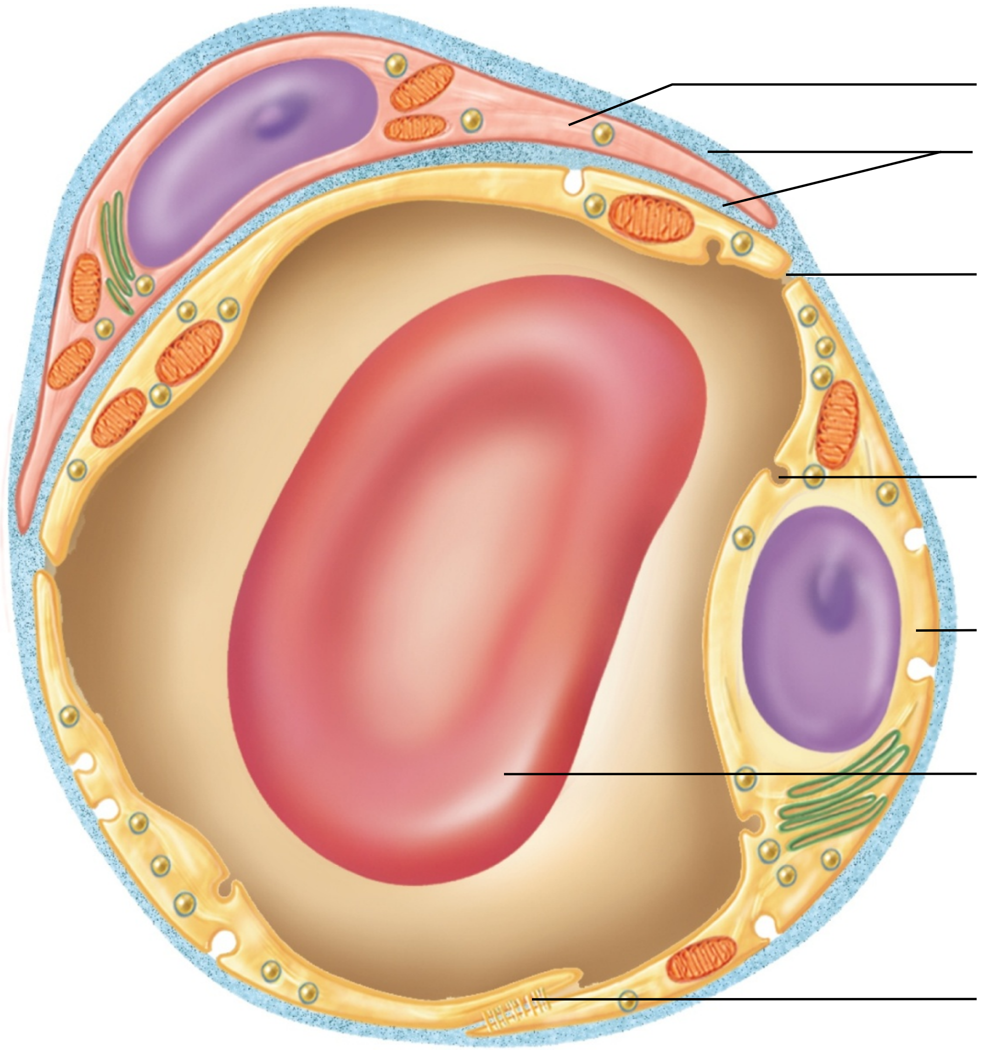
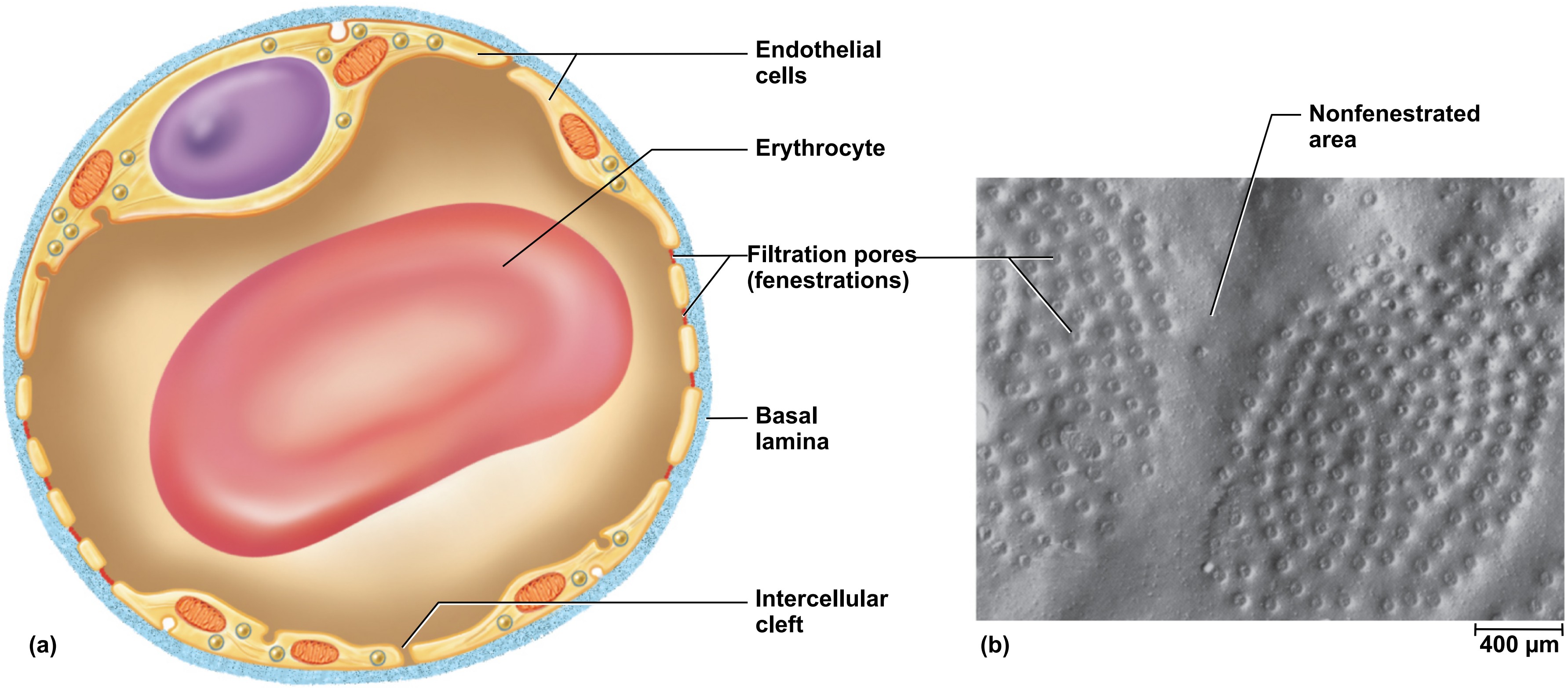


Figure 20.5

Fenestrated Capillary



b: Courtesy of S. McNutt

Figure 20.6a

Figure 20.6b

Sinusoid in Liver

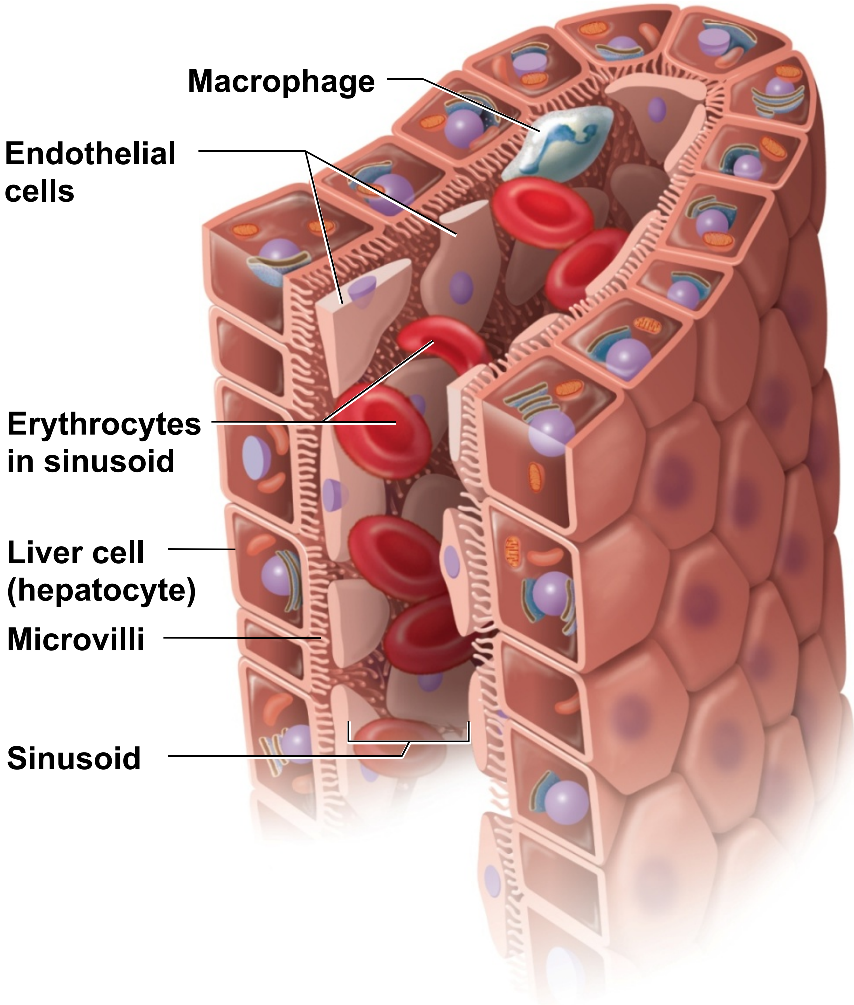
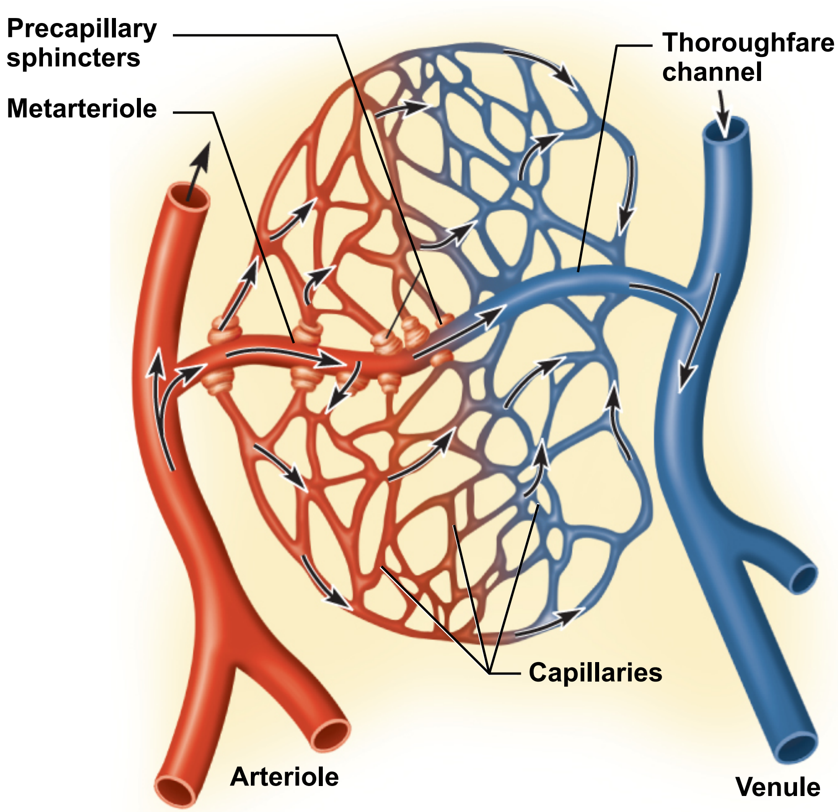


Figure 20.7

Capillary Beds

- capillaries organized into networks called **capillary beds**
  - usually supplied by a single **metarteriole**
- **thoroughfare channel** - metarteriole that continues through capillary bed to venule
- **precapillary sphincters** control which beds are well perfused
  - **when sphincters open**
    - capillaries are well perfused with blood and engage in exchanges with the tissue fluid
  - **when sphincters closed**
    - blood bypasses the capillaries
    - flows through thoroughfare channel to venule
- three-fourths of the bodies capillaries are shut down at a given time

Capillary Bed Sphincters Open

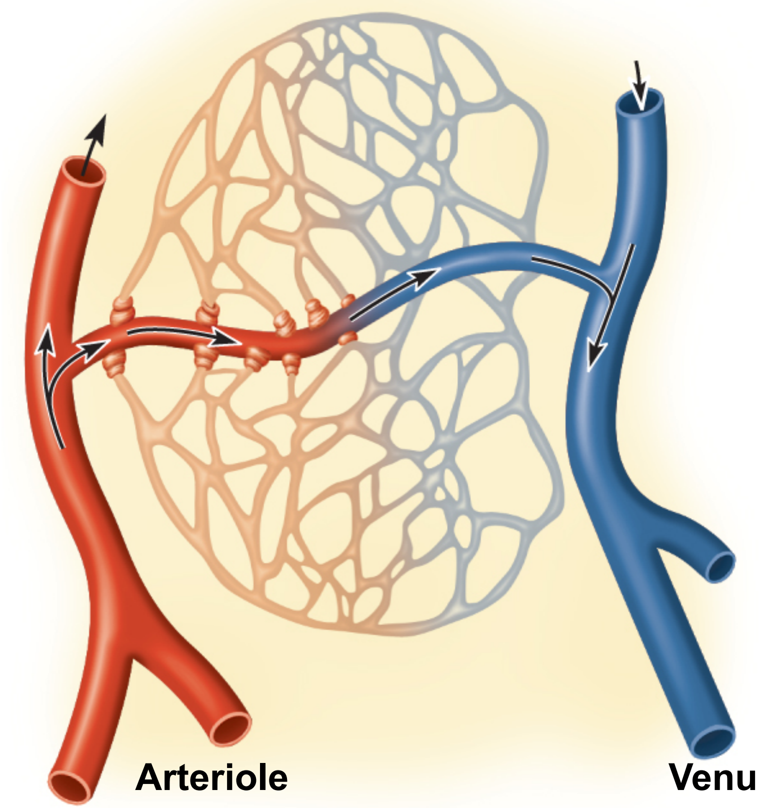


(a) Sphincters open

Figure 20.3a

when sphincters are open, the capillaries are well perfused
three-fourths of the capillaries of the body are shut down

Capillary Bed Sphincters Closed



(b) Sphincters closed

Figure 20.3b

when the sphincters are closed, little to no blood flow occurs (skeletal muscles at rest)

Veins (Capacitance Vessels)

- greater capacity for blood containment than arteries
- thinner walls, flaccid, less muscular and elastic tissue
- collapse when empty, expand easily
- have steady blood flow
- merge to form larger veins
- subjected to relatively low blood pressure
  - remains 10 mm Hg with little fluctuation

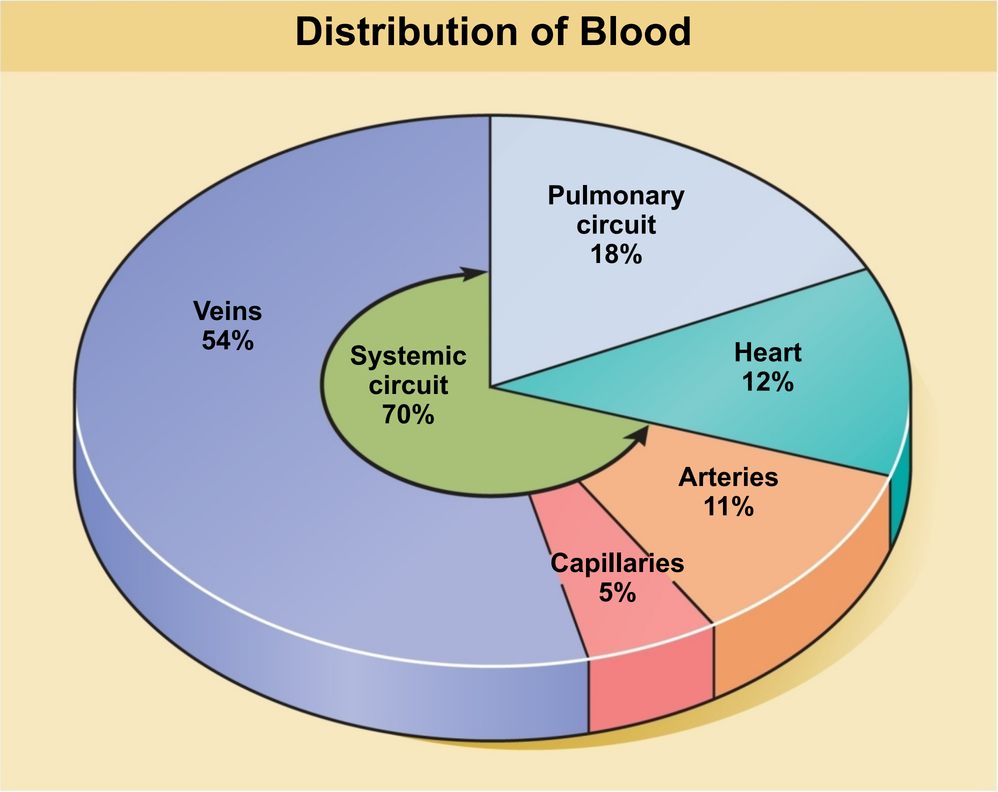


Figure 20.8

Blood Flow Pathway

- **postcapillary venules** – smallest veins
  - even more porous than capillaries so also exchange fluid with surrounding tissues
  - tunica interna with a few fibroblasts and no muscle fibers
  - most leukocytes emigrate from the bloodstream through venule walls
- **muscular venules** – up to 1 mm in diameter
  - 1 or 2 layers of smooth muscle in tunica media
  - have a thin tunica externa
- **medium veins** – up to 10 mm in diameter
  - thin tunica media and thick tunica externa
  - tunica interna forms **venous valves**
  - **varicose veins** result in part from the failure of these valves
  - skeletal muscle pump propels venous blood back toward the heart

Blood Flow Pathway

- **venous sinuses**
  - veins with especially thin walls, large lumens, and no smooth muscle
  - **dural venous sinus** and **coronary sinus** of the heart
  - not capable of vasomotion
- **large veins** – larger than 10 mm
  - some smooth muscle in all three tunics
  - thin tunica media with moderate amount of smooth muscle
  - tunica externa is thickest layer
    - contains longitudinal bundles of smooth muscle
  - venae cavae, pulmonary veins, internal jugular veins, and renal veins

Varicose Veins

- blood pools in the lower legs in people who stand for long periods stretching the veins
  - cusps of the valves pull apart in enlarged superficial veins further weakening vessels
  - blood backflows and further distends the vessels, their walls grow weak and develop into **varicose veins**
- hereditary weakness, obesity, and pregnancy also promote problems
- **hemorrhoids** are varicose veins of the anal canal

Circulatory Routes

- simplest and most common route
  - heart → arteries → arterioles → capillaries → venules → veins
  - passes through only **one network of capillaries** from the time it leaves the heart until the time it returns
- **portal system**
  - blood flows through **two consecutive capillary** networks before returning to heart
    - between hypothalamus and anterior pituitary
    - in kidneys
    - between intestines to liver

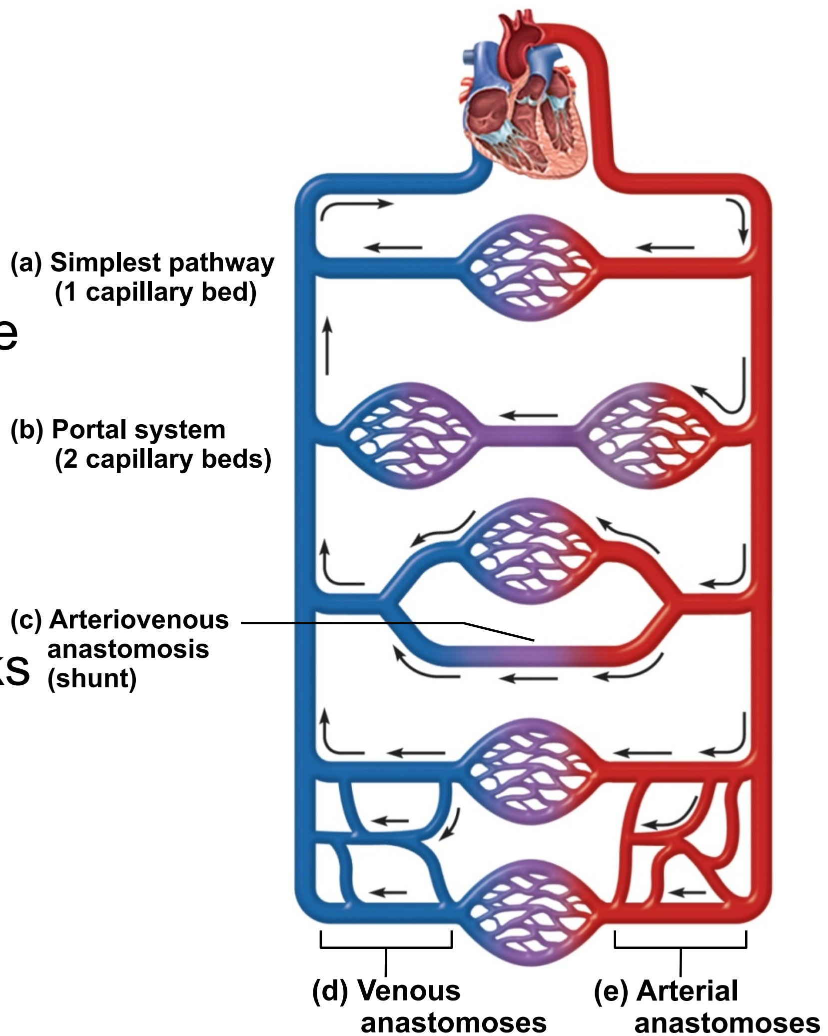


Figure 20.9

Anastomoses

- **anastomosis** – the point where two blood vessels merge
- **arteriovenous anastomosis** (shunt)
  - artery flows directly into vein bypassing capillaries
- **venous anastomosis**
  - most common
  - one vein empties directly into another
  - reason vein blockage less serious than an arterial blockage
- **arterial anastomosis**
  - two arteries merge
  - provides **collateral (alternative) routes** of blood supply to a tissue
  - coronary circulation and around joints

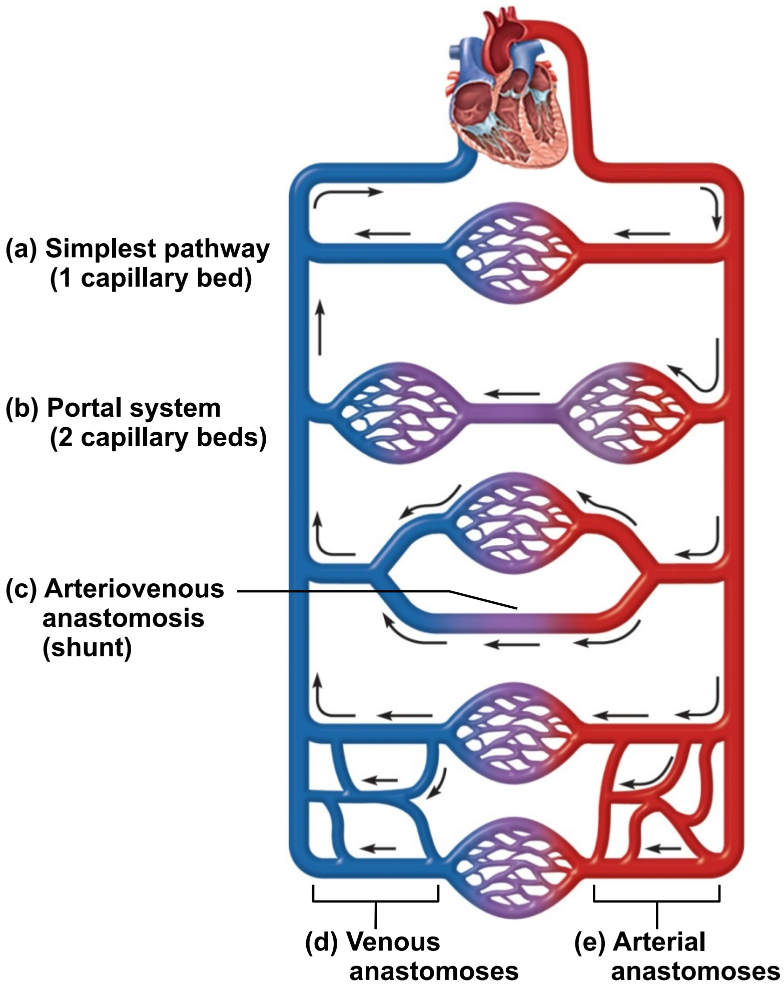


Figure 20.9

Principles of Blood Flow

- blood supply to a tissue can be expressed in terms of **flow** and **perfusion**
  - **blood flow** – the amount of blood flowing through an organ, tissue, or blood vessel in a given time (ml/min)
  - **perfusion** – the flow per given volume or mass of tissue in a given time (ml/min/g)
- at rest, total flow is quite constant, and is equal to the cardiac output (5.25 L/min)
- important for delivery of nutrients and oxygen, and removal of metabolic wastes
- **hemodynamics**
  - physical principles of blood flow based on **pressure** and **resistance**
    - F is proportional to $\Delta P/R$, (F = flow, ΔP = difference in pressure, R = resistance to flow)
    - the greater the pressure difference between two points, the greater the flow; the greater the resistance the less the flow

Blood Pressure

- blood pressure (bp) – the force that blood exerts against a vessel wall
- measured at **brachial artery** of arm using **sphygmomanometer**
- two pressures are recorded:
  - **systolic pressure**: peak arterial BP taken during ventricular contraction (ventricular systole)
  - **diastolic pressure**: minimum arterial BP taken during ventricular relaxation (diastole) between heart beats
- normal value, young adult: **120/75 mm Hg**
- **pulse pressure** – difference between systolic and diastolic pressure
  - important measure of stress exerted on small arteries by pressure surges generated by the heart
- **mean arterial pressure (MAP)** – the mean pressure one would obtain by taking measurements at several intervals throughout the cardiac cycle
  - diastolic pressure + (1/3 of pulse pressure)
  - average blood pressure that most influences risk level for edema, fainting (syncope), atherosclerosis, kidney failure, and aneurysm

Abnormalities of Blood Pressure

- **hypertension** – high blood pressure
  - chronic is resting BP > 140/90
  - consequences
    - can weaken small arteries and cause aneurysms
- **hypotension** – chronic low resting BP
  - caused by blood loss, dehydration, anemia

Blood Pressure

- one of the body's chief mechanisms in preventing excessive blood pressure is the ability of the arteries to **stretch and recoil** during the cardiac cycle
- importance of arterial elasticity
  – expansion and recoil maintains steady flow of blood throughout cardiac cycle, smoothes out pressure fluctuations and decreases stress on small arteries
- BP rises with age
  – arteries less distensible and absorb less systolic force
- BP determined by **cardiac output, blood volume** and **peripheral resistance**
  – resistance hinges on blood viscosity, vessel length, and vessel radius

BP Changes With Distance

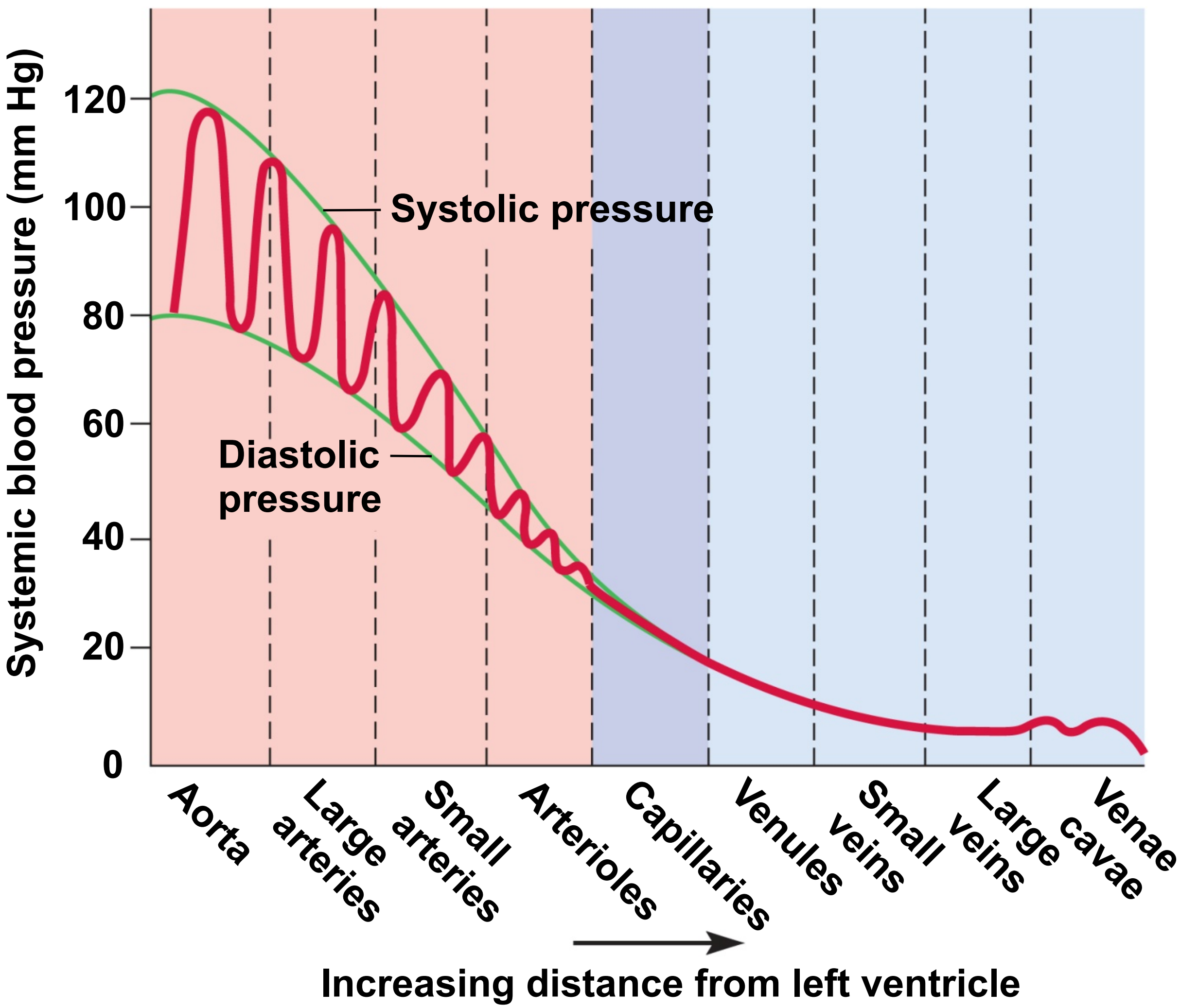


Figure 20.10

Peripheral Resistance

- **peripheral resistance** – the opposition to flow that blood encounters in vessels away from the heart
- resistance hinges on three variables
  - **blood viscosity "thickness"**
    - RBC count and albumin concentration elevate viscosity the most
    - decreased viscosity with anemia and hypoproteinemia speed flow
    - increased viscosity with polycythemia and dehydration slow flow
  - **vessel length**
    - the farther liquid travels through a tube, the more cumulative friction it encounters
    - pressure and flow decline with distance
  - **vessel radius** - most powerful influence over flow
    - only significant way of controlling peripheral resistance.
    - **vasomotion** - change in vessel radius
      - **vasoconstriction** - by muscular effort that results in smooth muscle contraction
      - **vasodilation** - by relaxation of the smooth muscle

Peripheral Resistance

- vessel radius (cont.)
  - vessel radius markedly affects **blood velocity**
  - **laminar flow** - flows in layers, faster in center
  - blood flow (F) proportional to the fourth power of radius (r), $F \propto r^4$
    - arterioles can constrict to 1/3 of fully relaxed radius
      - if r = 3 mm, F = (3^4) = 81 mm/sec; if r = 1 mm, F = 1mm/sec
      - an increase of **three times** in the radius of a vessel results in **eighty one times** the flow

Laminar Flow and Vessel Radius

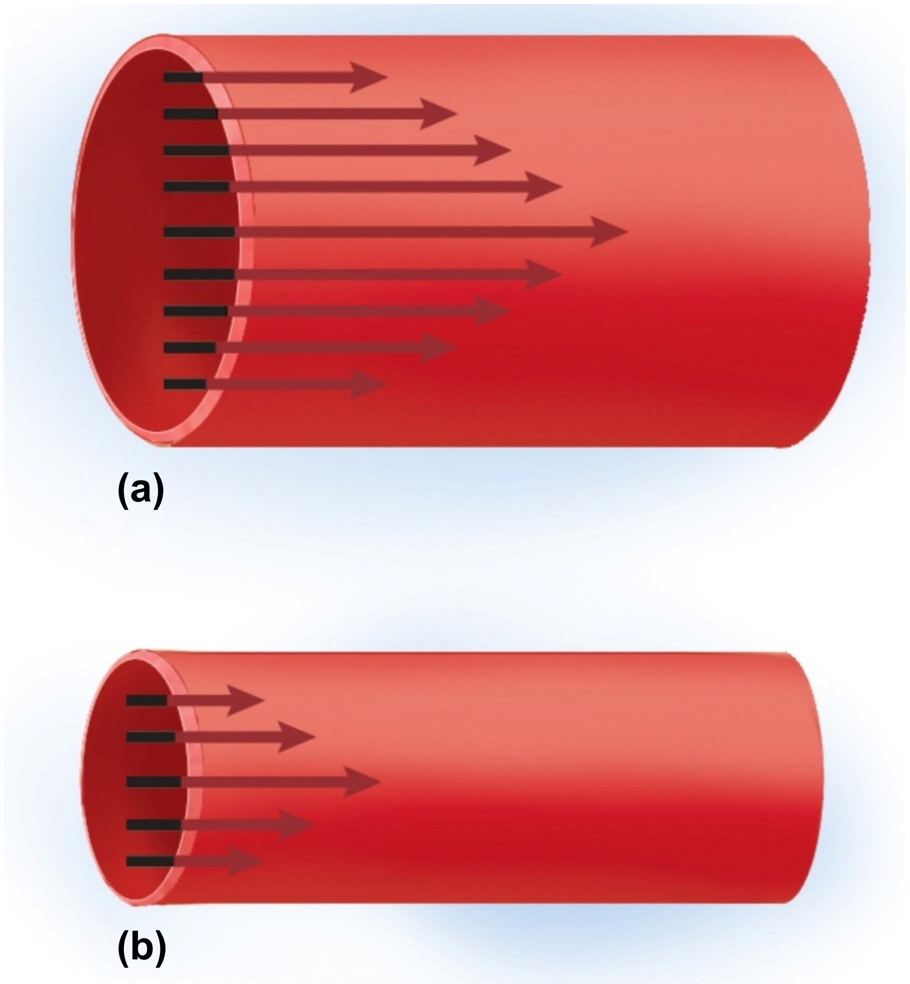


Figure 20.11

Flow at Different Points

- from **aorta** to **capillaries**, blood velocity (speed) decreases for three reasons:
  - greater distance, more friction to reduce speed
  - smaller radii of arterioles and capillaries offers more resistance
  - farther from heart, the number of vessels and their total cross-sectional area becomes greater and greater
- from **capillaries** to **vena cava**, flow increases again
  - decreased resistance going from capillaries to veins
  - large amount of blood forced into smaller channels
  - never regains velocity of large arteries

Control by Arterioles

- **arterioles** are most significant point of control over peripheral resistance and flow
  - on proximal side of capillary beds and best positioned to regulate flow into the capillaries
  - outnumber any other type of artery, providing the most numerous control points
  - more muscular in proportion to their diameter
    - highly capable of vasomotion
- arterioles produce half of the total peripheral resistance

Regulation of BP and Flow

- **vasomotion** is a quick and powerful way of altering blood pressure and flow
- three ways of controlling vasomotion:
  - local control
  - neural control
  - hormonal control

Local Control of BP and Flow

- **autoregulation** – the ability of tissues to regulate their own blood supply
  - metabolic theory of autoregulation – if tissue is inadequately perfused, wastes accumulate stimulating vasodilation which increases perfusion
  - bloodstream delivers oxygen and remove metabolites
  - when wastes are removed, vessels constrict

- **vasoactive chemicals** - substances secreted by platelets, endothelial cells, and perivascular tissue stimulate vasomotion
  - histamine, bradykinin, and prostaglandins stimulate vasodilation
  - endothelial cells secrete prostacyclin and nitric oxide (vasodilators) and endothelins (vasoconstrictor)

- **reactive hyperemia**
  - if blood supply cut off then restored, flow increases above normal

- **angiogenesis** - growth of new blood vessels
  - occurs in regrowth of uterine lining, around coronary artery obstructions, in exercised muscle, and malignant tumors
  - controlled by growth factors

Neural Control of Blood Vessels

- vessels under remote control by the central and autonomic nervous systems

- **vasomotor center** of medulla oblongata exerts **sympathetic control** over blood vessels throughout the body
  - stimulates most vessels to **constrict**, but dilates vessels in skeletal and cardiac muscle to meet demands of exercise
    - **precapillary sphincters** respond only to local and hormonal control due to lack of innervation
  - vasomotor center is the integrating center for three autonomic reflexes
    - **baroreflexes**
    - **chemoreflexes**
    - **medullary ischemic reflex**

Baroreflex

- **baroreflex** – an automatic, negative feedback response to changes in blood pressure
  - increases in BP detected by **carotid sinuses**
  - signals sent to brainstem by way of **glossopharyngeal nerve**
  - inhibit the sympathetic cardiac and vasomotor neurons reducing sympathetic tone, and excite vagal fibers to the slowing of heart rate and cardiac output – thus reducing BP
  - decreases in BP have the opposite effect
- baroreflexes important in **short-term regulation** of BP but not in cases of chronic hypertension
  - adjustments for rapid changes in posture

Negative Feedback Control of BP

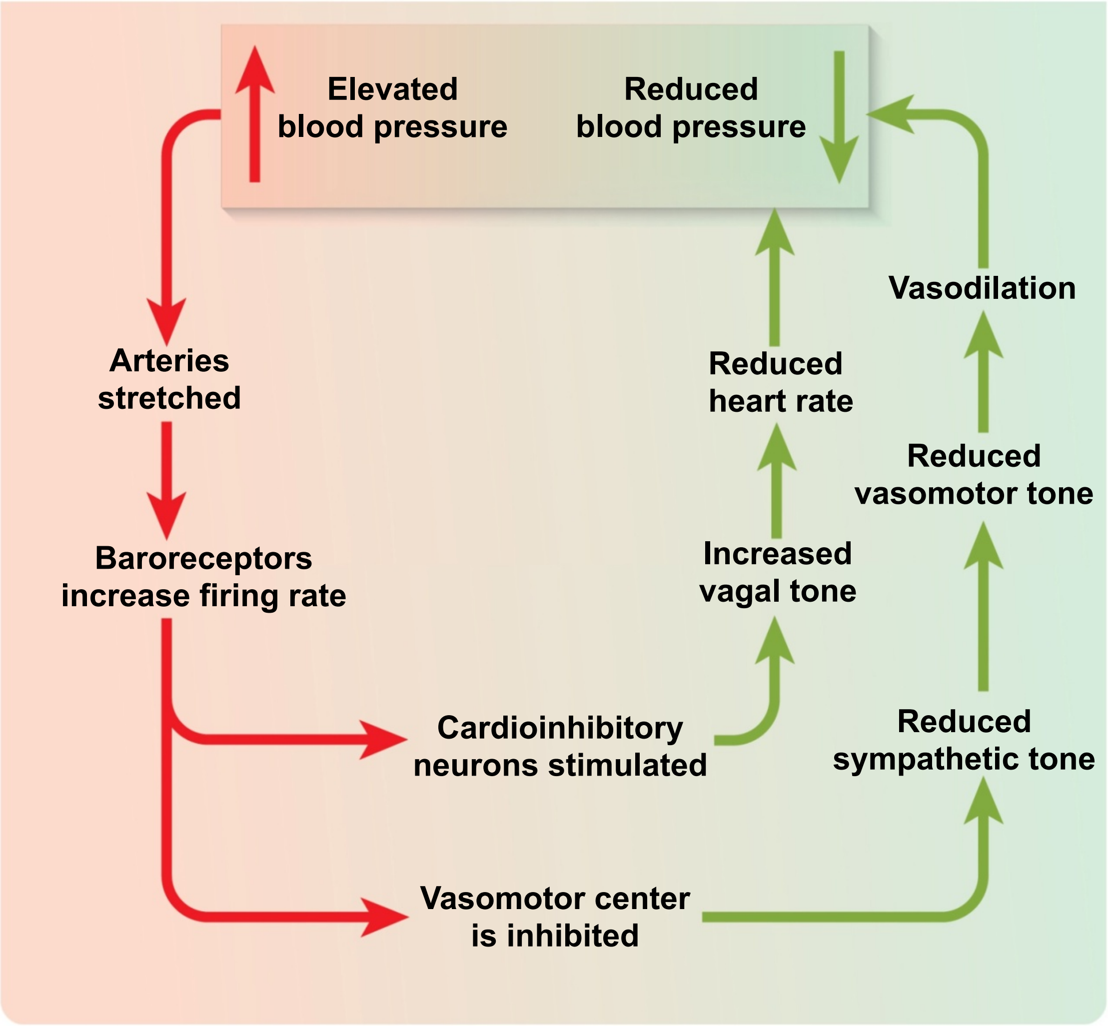


Figure 20.13

Chemoreflex

- **chemoreflex** – an automatic response to changes in blood chemistry
  - especially pH, and concentrations of O_2 and CO_2
- **chemoreceptors** called aortic bodies and carotid bodies
  - located in aortic arch, subclavian arteries, external carotid arteries
- **primary role**: adjust respiration to changes in blood chemistry
- **secondary role**: vasomotion
  - hypoxemia, hypercapnia, and acidosis stimulate chemoreceptors, acting through vasomotor center to cause widespread vasoconstriction, increasing BP, increasing lung perfusion and gas exchange
  - also stimulate breathing

Medullary Ischemic Reflex

- **medullary ischemic reflex** - automatic response to a drop in perfusion of the brain
  - medulla oblongata monitors its own blood supply
  - activates corrective reflexes when it senses ischemia (insufficient perfusion)
    - cardiac and vasomotor centers send sympathetic signals to heart and blood vessels
      - increases heart rate and contraction force
      - causes widespread vasoconstriction
      - raises BP and restores normal perfusion to the brain
- other brain centers can affect vasomotor center
  - stress, anger, arousal can also increase BP

Hormonal Control

- hormones influence blood pressure
  - some through their **vasoactive effects**
  - some by regulating **water balance**
- **angiotensin II** – potent vasoconstrictor
  - raises blood pressure
- **aldosterone**
  - promotes Na^+ and water retention by kidneys
  - increases blood volume and pressure
- **atrial natriuretic peptide** – increases urinary sodium excretion
  - reduces blood volume and promotes vasodilation
  - lowers blood pressure
- **ADH -** promotes water retention and raises BP
  - pathologically high concentrations - vasoconstrictor
- **epinephrine and norepinephrine** effects
  - most blood vessels
    - binds to α-adrenergic receptors - **vasoconstriction**
  - skeletal and cardiac muscle blood vessels
    - binds to β-adrenergic receptors - **vasodilation**

Two Purposes of Vasomotion

- general method of **raising or lowering BP throughout the whole body**
  - increasing BP requires medullary vasomotor center or widespread circulation of a hormone
    - important in supporting cerebral perfusion during a hemorrhage or dehydration
- method of **rerouting blood** from one region to another for perfusion of individual organs
  - either centrally or locally controlled
    - during exercise, sympathetic system reduces blood flow to kidneys and digestive tract and increases blood flow to skeletal muscles
    - metabolite accumulation in a tissue affects local circulation without affecting circulation elsewhere in the body

Routing of Blood Flow

- localized vasoconstriction
  - if a specific artery constricts, the pressure downstream drops, pressure upstream rises
  - enables routing blood to different organs as needed
- examples
  - vigorous exercise dilates arteries in lungs, heart and muscles
    - vasoconstriction occurs in kidneys and digestive tract
  - dozing in armchair after big meal
    - vasoconstriction in lower limbs raises BP above the limbs redirecting blood to intestinal arteries

Blood Flow in Response to Needs

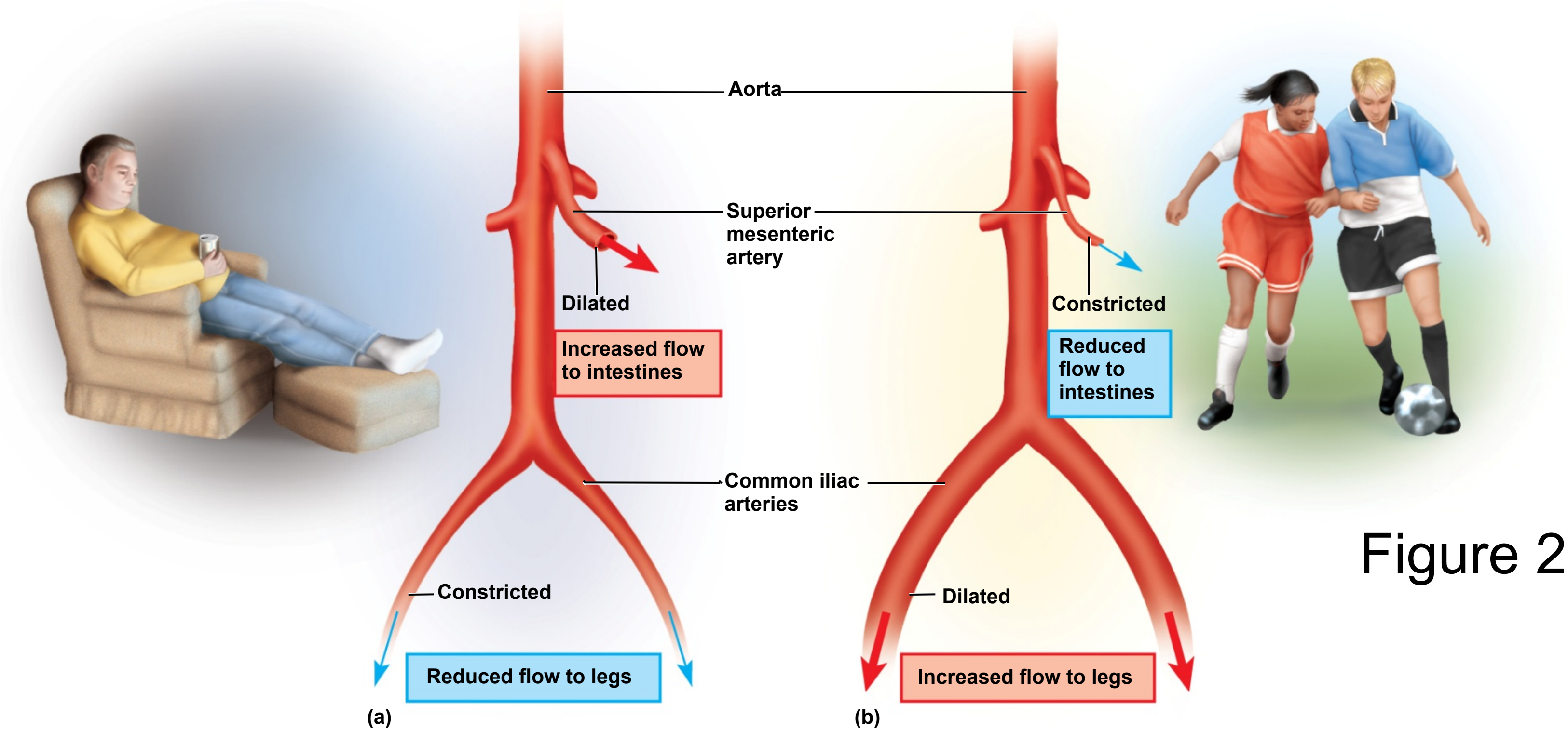


Figure 20.14

arterioles shift blood flow with changing priorities

Blood Flow Comparison

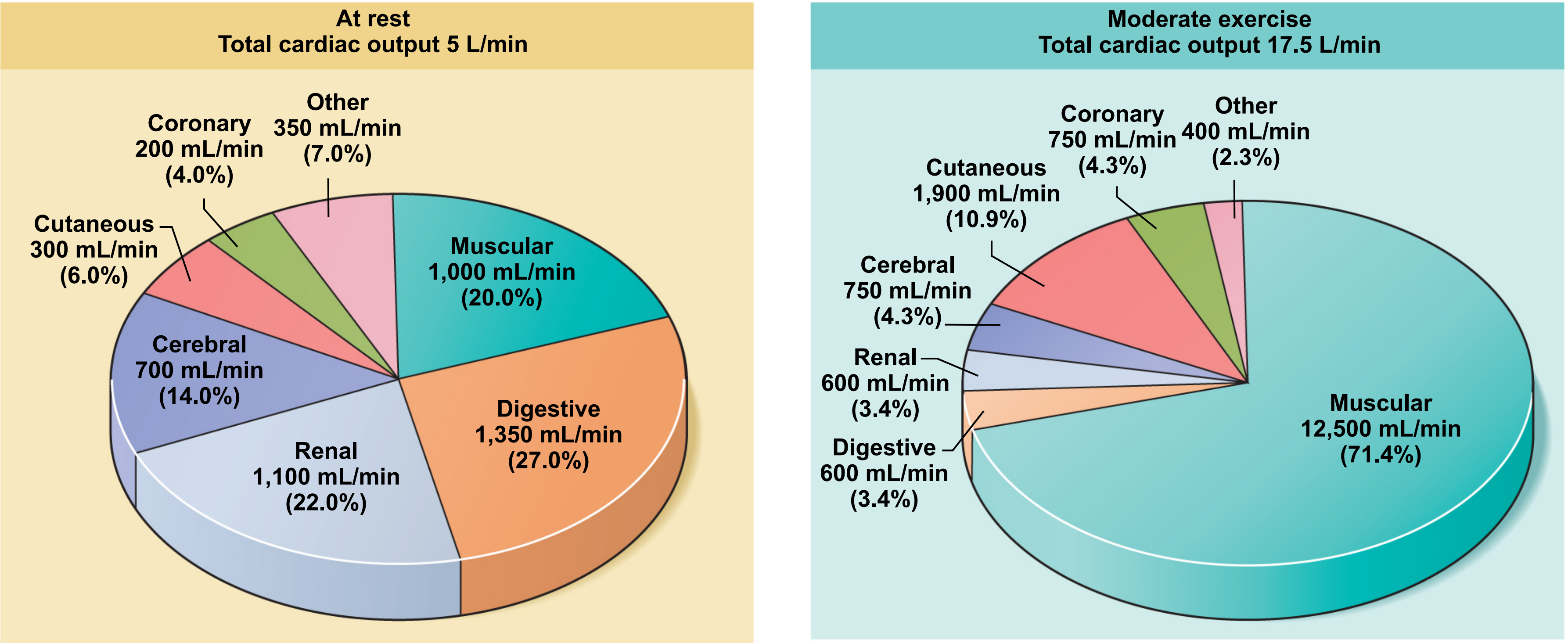


Figure 20.15

during exercise

- increased perfusion of lungs, myocardium, and skeletal muscles
- decreased perfusion of kidneys and digestive tract

Capillary Exchange

- the most important blood in the body is in the capillaries
- only through capillary walls are exchanges made between the blood and surrounding tissues
- **capillary exchange** – two way movement of fluid across capillary walls
  – water, oxygen, glucose, amino acids, lipids, minerals, antibodies, hormones, wastes, carbon dioxide, ammonia
- chemicals pass through the capillary wall by **three routes**
  – **through endothelial cell cytoplasm**
  – **intercellular clefts between endothelial cells**
  – **filtration pores (fenestrations) of the fenestrated capillaries**
- mechanisms involved
  – **diffusion**, **transcytosis**, **filtration** ,and **reabsorption**

Capillary Exchange - Diffusion

- **diffusion** is the most important form of capillary exchange
  - glucose and oxygen being more concentrated in blood diffuse out of the blood
  - carbon dioxide and other waste being more concentrated in tissue fluid diffuse into the blood
- capillary diffusion can only occur if:
  - the solute can permeate the plasma membranes of the endothelial cell, or
  - find passages large enough to pass through
    - filtration pores and intracellular clefts
- **lipid soluble substances**
  - steroid hormones, O_2 and CO_2 diffuse easily through plasma membranes
- **water soluble substances**
  - glucose and electrolytes must pass through filtration pores and intercellular clefts
- large particles - proteins, held back

Capillary Exchange - Transcytosis

- endothelial cells pick up material on one side of the plasma membrane by pinocytosis or receptor-mediated endocytosis, transport vesicles across cell, and discharge material on other side by exocytosis
- important for fatty acids, albumin and some hormones (insulin)

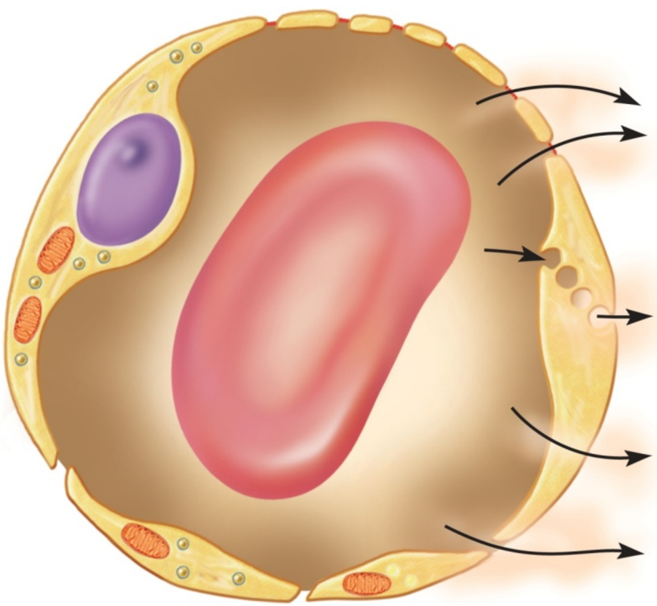


Figure 20.16

- fluid filters out of the arterial end of the capillary and osmotically reenters at the venous end
  - delivers materials to the cell and removes metabolic wastes
- opposing forces
  - **blood hydrostatic pressure** drives fluid out of capillary
    - high on arterial end of capillary, low on venous end
  - **colloid osmotic pressure** (COP) draws fluid into capillary
    - results from plasma proteins (albumin)- more in blood
    - **oncotic pressure** = net COP (blood COP - tissue COP)
- **hydrostatic pressure**
  - physical force exerted against a surface by a liquid
    - blood pressure is an example
- capillaries reabsorb about **85%** of the fluid they filter
- other **15%** is absorbed by the **lymphatic system** and returned to the blood

Capillary Filtration and Reabsorption

- **capillary filtration** at arterial end
- **capillary reabsorption** at venous end
- variations
  - location
    - glomeruli- devoted to filtration
    - alveolar capillary - devoted to absorption
  - activity or trauma
    - increases filtration

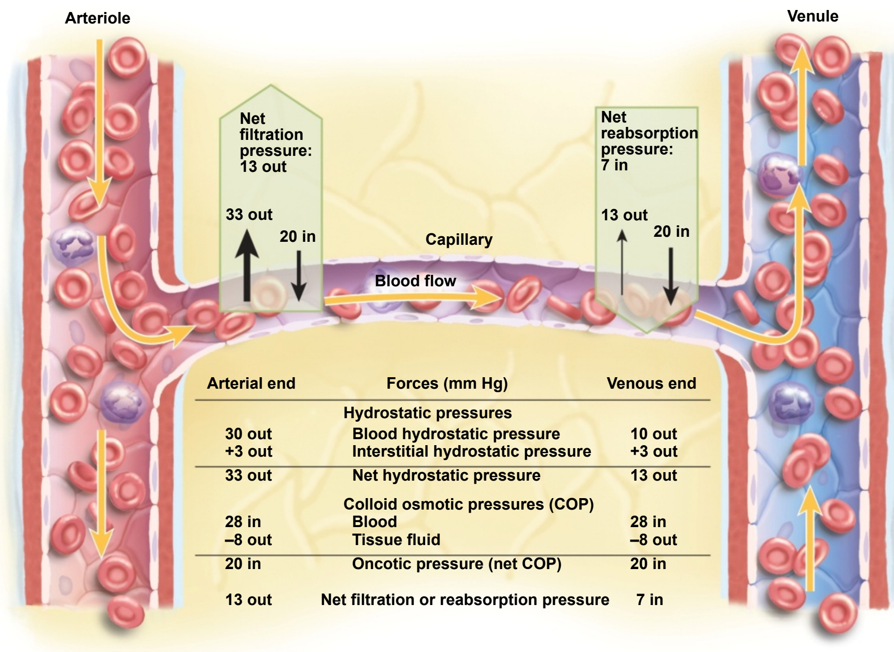
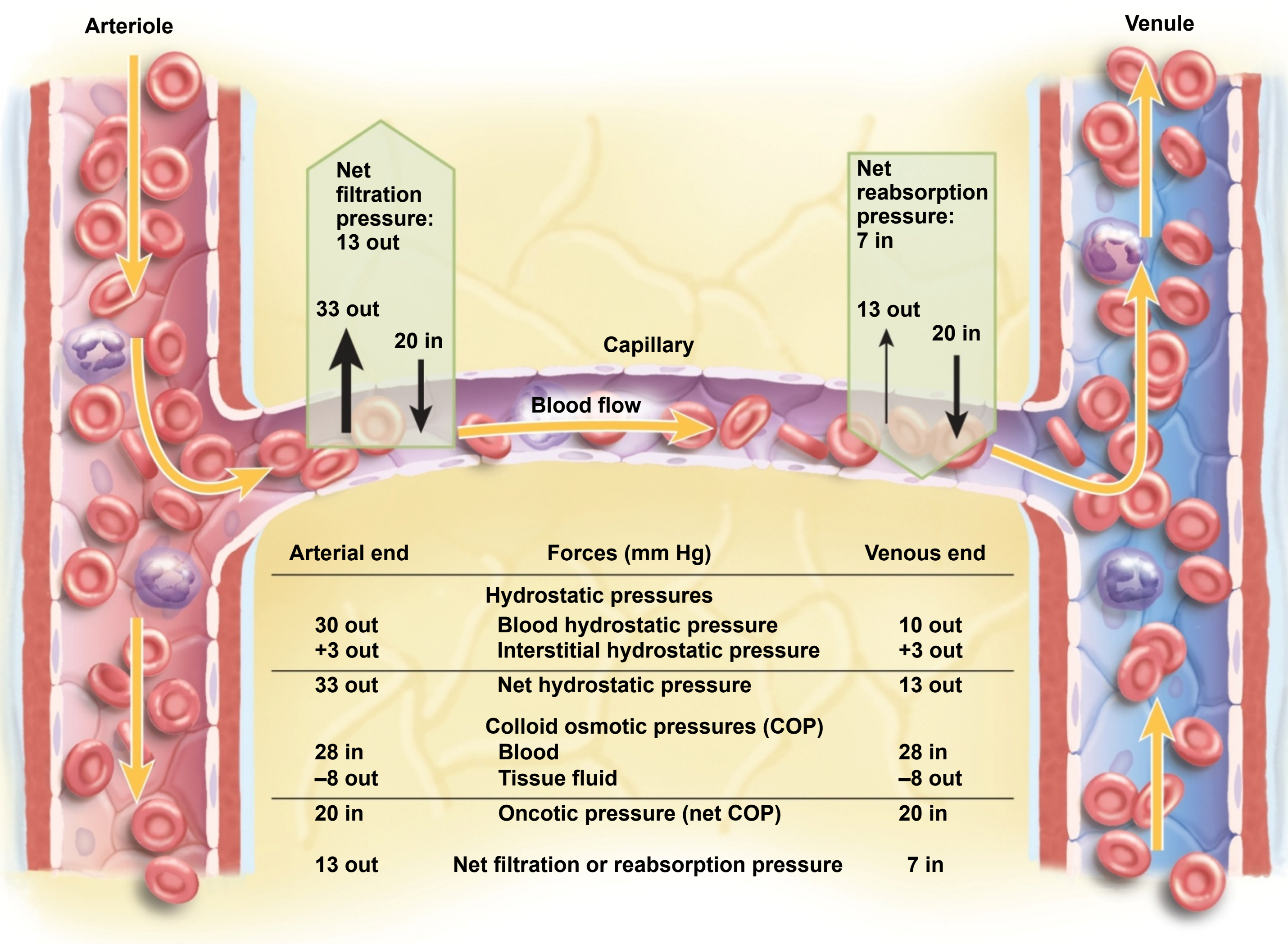


Figure 20.17

Capillary Filtration and Reabsorption



Arterial end	Forces (mm Hg)	Venous end
	Hydrostatic pressures	
30 out	Blood hydrostatic pressure	10 out
+3 out	Interstitial hydrostatic pressure	+3 out
33 out	Net hydrostatic pressure	13 out
	Colloid osmotic pressures (COP)	
28 in	Blood	28 in
–8 out	Tissue fluid	–8 out
20 in	Oncotic pressure (net COP)	20 in
13 out	Net filtration or reabsorption pressure	7 in

Figure 20.17

Variations in Capillary Activity

- capillaries usually reabsorb most of the fluid they filter – exception:
  - **kidney capillaries** in glomeruli do not reabsorb
  - **alveolar capillaries** in lung absorb completely to keep fluid out of air spaces

- capillary activity varies from moment to moment
  - collapsed in resting tissue, reabsorption predominates since BP is low
  - metabolically active tissue has increase in capillary flow and BP
    - increase in muscular bulk by 25% due to accumulation of fluid

Edema

- **edema** – the accumulation of excess fluid in a tissue
  - occurs when fluid filters into a tissue faster than it is absorbed
- three primary causes
  - **increased capillary filtration**
    - kidney failure, histamine release, old age, poor venous return
  - **reduced capillary absorption**
    - hypoproteinemia, liver disease, dietary protein deficiency
  - **obstructed lymphatic drainage**
    - surgical removal of lymph nodes

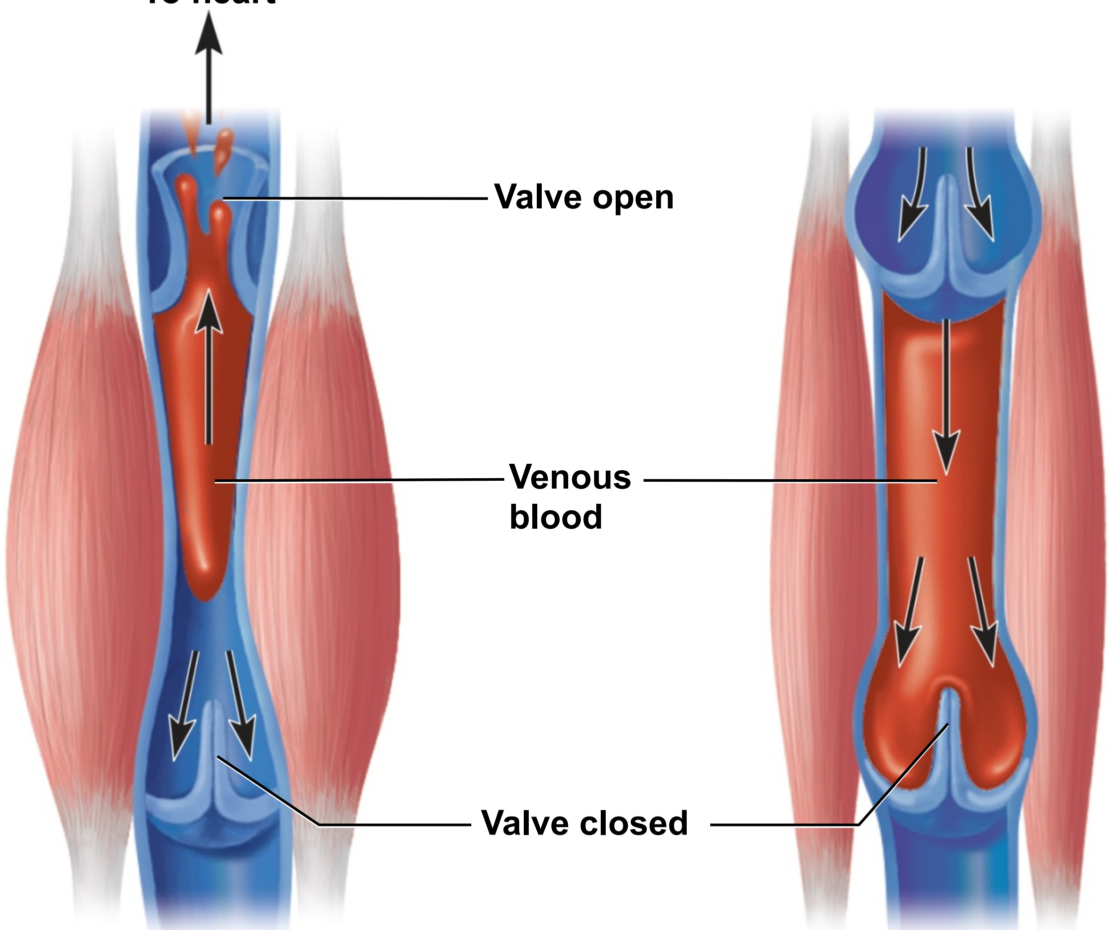
Consequences of Edema

- tissue necrosis
  - oxygen delivery and waste removal impaired
- pulmonary edema
  - suffocation threat
- cerebral edema
  - headaches, nausea, seizures, and coma
- severe edema or circulatory shock
  - excess fluid in tissue spaces causes low blood volume and low blood pressure

Mechanisms of Venous Return

- **venous return** – the flow of blood back to the heart
  - **pressure gradient**
    - blood pressure is the most important force in venous return
    - 7-13 mm Hg venous pressure towards heart
    - venules (12-18 mm Hg) to **central venous pressure –** point where the venae cavae enter the heart (~5 mm Hg)
  - **gravity** drains blood from head and neck
  - **skeletal muscle pump** in the limbs
    - contracting muscle squeezed out of the compressed part of the vein
  - **thoracic (respiratory) pump**
    - inhalation - thoracic cavity expands and thoracic pressure decreases, abdominal pressure increases forcing blood upward
      - central venous pressure fluctuates
    - 2mm Hg- inhalation, 6mm Hg-exhalation
    - blood flows faster with inhalation
  - **cardiac suction** of expanding atrial space

Skeletal Muscle Pump



(a) Contracted skeletal muscles

(b) Relaxed skeletal muscles

Figure 20.19 a-b

Venous Return and Physical Activity

- **exercise increases venous return** in many ways:
  - heart beats faster, harder increasing CO and BP
  - vessels of skeletal muscles, lungs, and heart dilate and increase flow
  - increased respiratory rate, increased action of thoracic pump
  - increased skeletal muscle pump
- **venous pooling** occurs with inactivity
  - venous pressure not enough force blood upward
  - with prolonged standing, CO may be low enough to cause dizziness
    - prevented by tensing leg muscles, activate skeletal muscle pump
  - jet pilots wear pressure suits

Circulatory Shock

- **circulatory shock** – any state in which cardiac output is insufficient to meet the body's metabolic needs
  - **cardiogenic shock** - inadequate pumping of heart (MI)
  - **low venous return (LVR)** – cardiac output is low because too little blood is returning to the heart
    - three principal forms
      1. **hypovolemic shock** - most common
         -loss of blood volume: trauma, burns, dehydration
      2. **obstructed venous return shock**
         -tumor or aneurysm compresses a vein
      3. **venous pooling (vascular) shock**
         -next slide

Vascular Shock and Others

- **venous pooling (vascular) shock**
  - long periods of standing, sitting or widespread vasodilation
  - **neurogenic shock** - loss of vasomotor tone, vasodilation
    - causes from emotional shock to brainstem injury
- **septic shock**
  - bacterial toxins trigger vasodilation and increased capillary permeability
- **anaphylactic shock**
  - severe immune reaction to antigen, histamine release, generalized vasodilation, increased capillary permeability