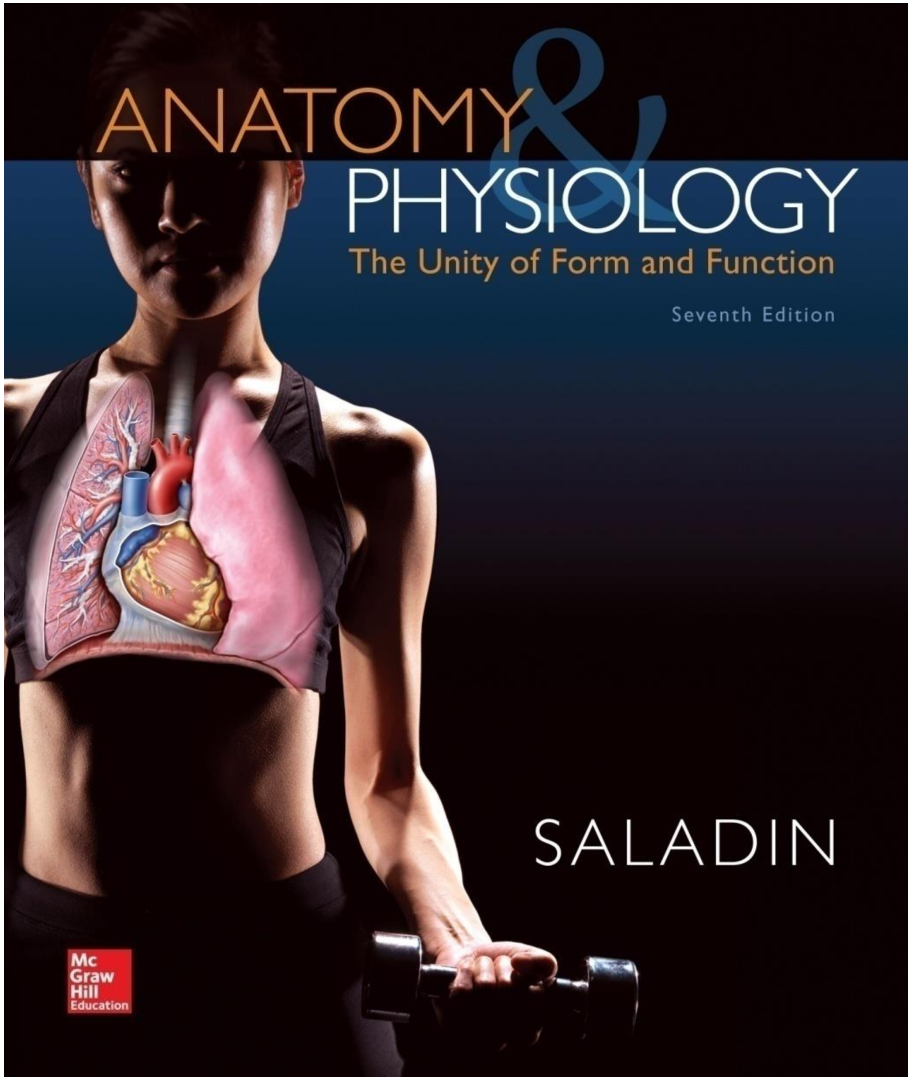
Chapter 20 Lecture Outline

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.



Introduction

- **The route taken by blood was a point of much confusion for many centuries**
  - Chinese emperor Huang Ti (2697–2597 BC) correctly believed that blood flowed in a circuit around the body and back to the heart
  - Roman physician Galen (129–c.199) thought blood flowed back and forth (like air in and out of lungs); he thought the liver created blood out of nutrients and organs consumed it
  - English physician William Harvey (1578–1657) performed experiments to show that the heart pumped blood and that it traveled in a circuit
    - Many of Harvey’s contemporaries rejected his ideas
    - After microscope was invented, capillaries were discovered by van Leeuwenhoek and Malpighi
    - Harvey’s work was the start of experimental physiology and it demonstrated how empirical science could overthrow dogma

General Anatomy of the Blood Vessels

- **Expected Learning Outcomes**
  - Describe the structure of a blood vessel.
  - Describe the different types of arteries, capillaries, and veins.
  - Trace the general route usually taken by the blood from the heart and back again.
  - Describe some variations on this route.

General Anatomy of the Blood Vessels

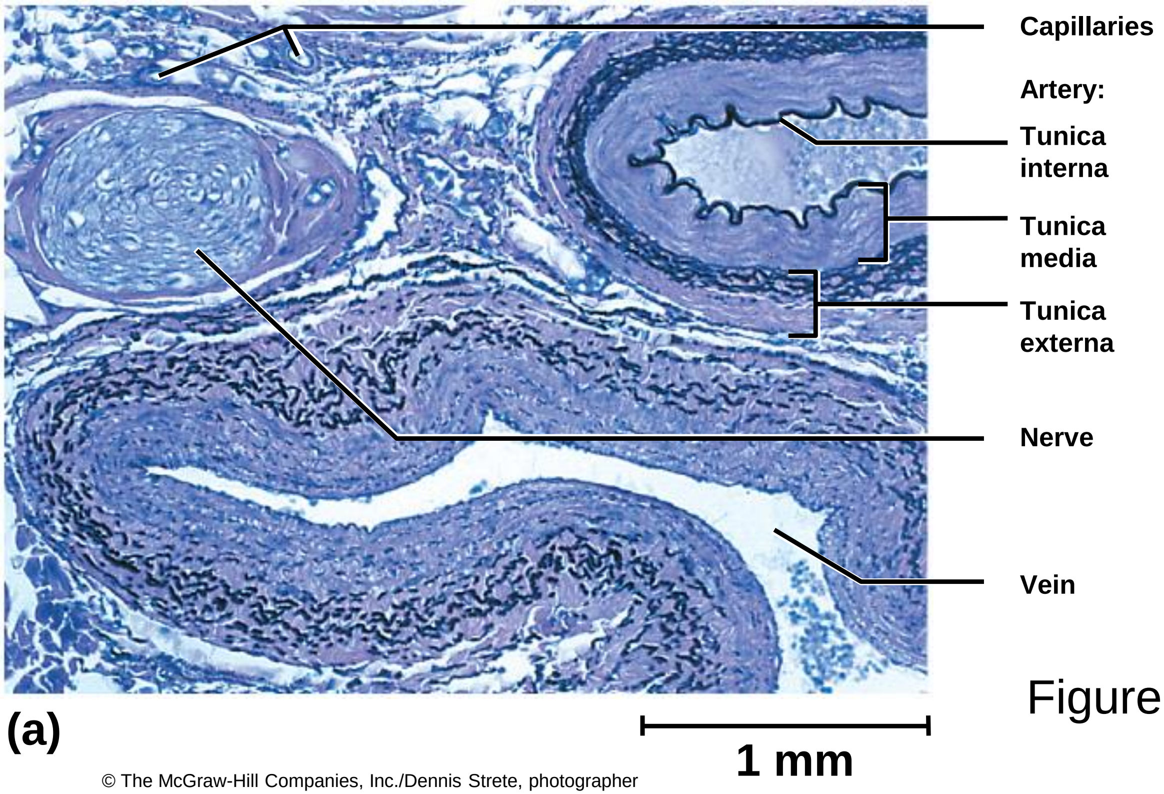


Figure 20.1a

- **Arteries** carry blood away from heart
- **Veins** carry blood back to heart
- **Capillaries** connect smallest arteries to smallest veins

The Vessel Wall

- **Walls of arteries and veins have three layers (tunics): tunica interna, tunica media, tunica externa**

- **Tunica interna (tunica intima)**
  - Lines the blood vessel and is exposed to blood
  - **Endothelium:** simple squamous epithelium overlying basement membrane and sparse layer of loose connective tissue
    - Acts as a **selectively permeable barrier**
    - **Secretes chemicals** that stimulate dilation or constriction of the vessel

The Vessel Wall

- **Endothelium (continued)**
  - 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

The Vessel Wall

- **Tunica media**
  - Middle layer
  - Consists of **smooth muscle**, collagen, and elastic tissue
  - Strengthens vessels and prevents blood pressure from rupturing them
  - **Regulates diameter** of the blood vessel

The 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 outer part of the larger vessels

The Vessel Wall

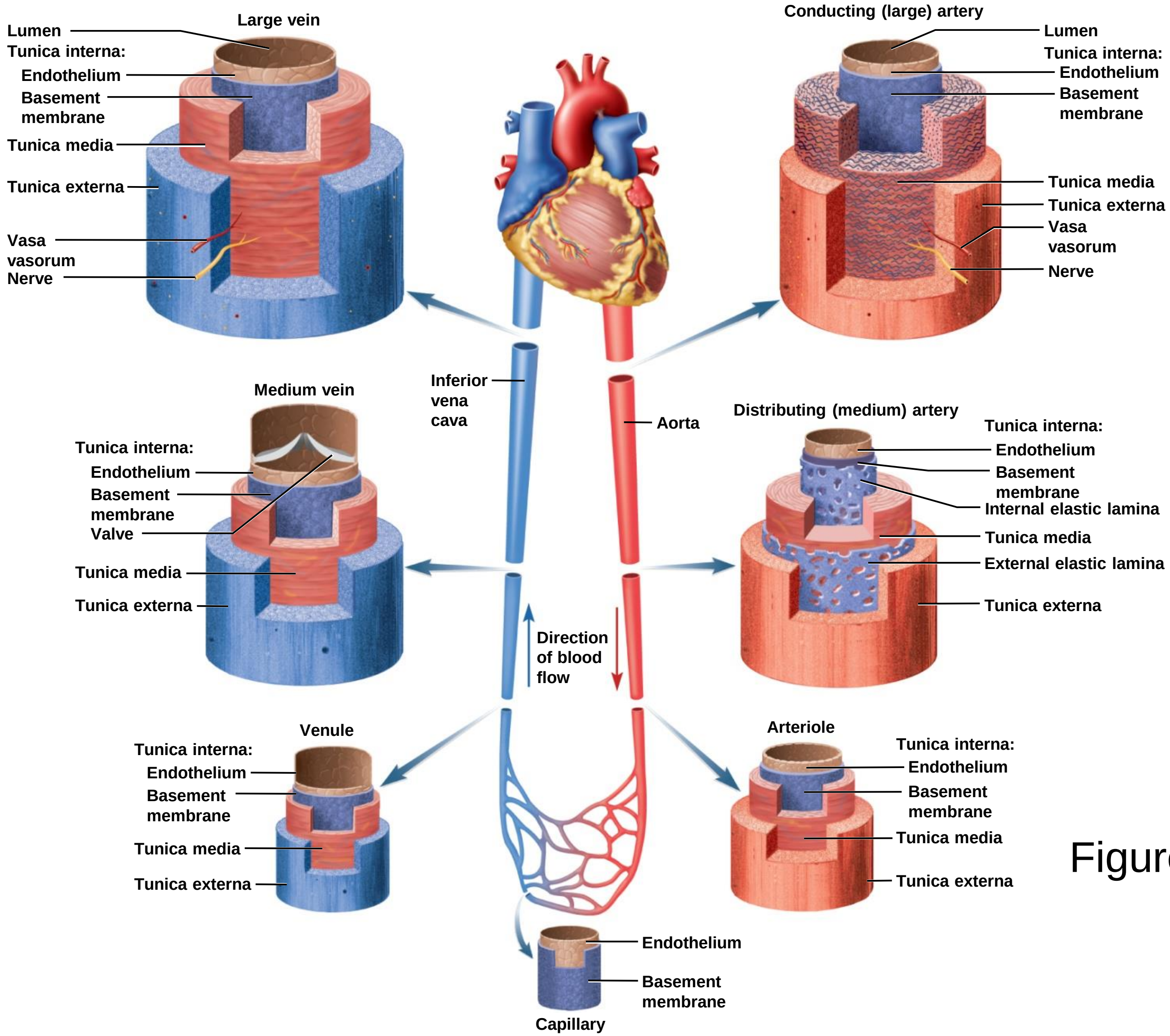


Figure 20.2

Arteries

- **Arteries** are sometimes called **resistance vessels** because of their strong, resilient tissue structure
- **Arteries are classified by size**
  - **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
      - Expansion takes pressure of smaller downstream vessels
      - Recoil maintains pressure during relaxation and keeps blood flowing

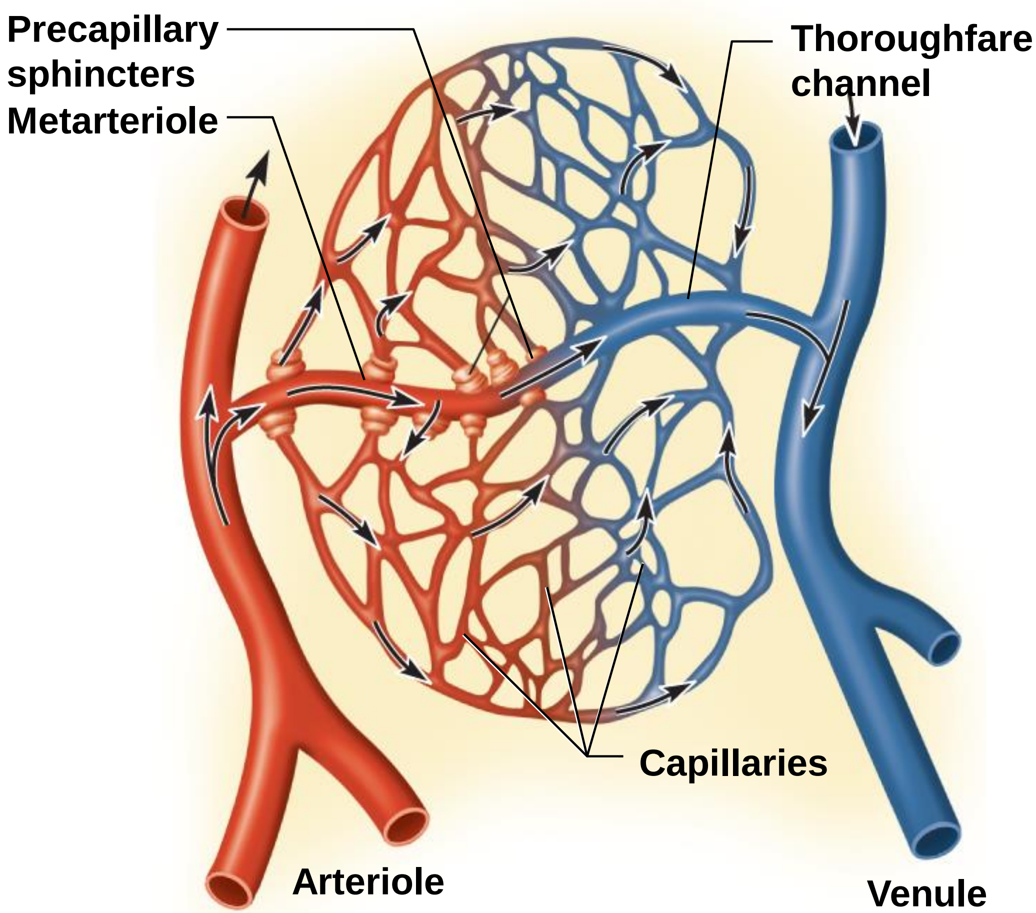
Arteries

- **Arteries are classified by size (continued)**
  - **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

Arteries

- **Arteries are classified by size (continued)**
  - **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**
    - In some places, short vessels that link arterioles to capillaries
    - Muscle cells form a **precapillary sphincter** around entrance to capillary
      - Constriction of these sphincters reduces blood flow through their capillaries
      - Diverts blood to other tissues

Arteries



(a) Sphincters open

Figure 20.7a

Aneurysm

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

Arterial Sense Organs

- **Sensory structures in walls of major vessels that monitor blood pressure and chemistry**
  - Transmit information to brainstem to regulate heart rate, blood vessel diameter, and respiration
  - **Carotid sinuses:** baroreceptors
    - In walls of internal carotid artery
    - Monitor blood pressure
      - Transmit signals through glossopharyngeal nerve
      - Allow for baroreflex

Arterial Sense Organs

- **Sensory structures (continued)**
  - **Carotid bodies:** chemoreceptors
    - Oval bodies near branch of common carotids
    - Monitor blood chemistry
    - Transmit signals through glossopharyngeal nerve to brainstem respiratory centers
    - Adjust respiratory rate to stabilize pH, CO_2, and O_2
  - **Aortic bodies:** chemoreceptors
    - One to three bodies in walls of aortic arch
    - Same structure and function as carotid bodies, but innervation is by vagus nerve

Capillaries

- **Capillaries**—exchange vessels: site where gasses, nutrients, wastes, and hormones pass between the blood and tissue fluid
  - 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 (permeability): continuous capillaries, fenestrated capillaries, and sinusoids

Types of Capillaries

- **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

Types of Capillaries

- **Three types of capillaries (continued)**
  - **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
      - Allow 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

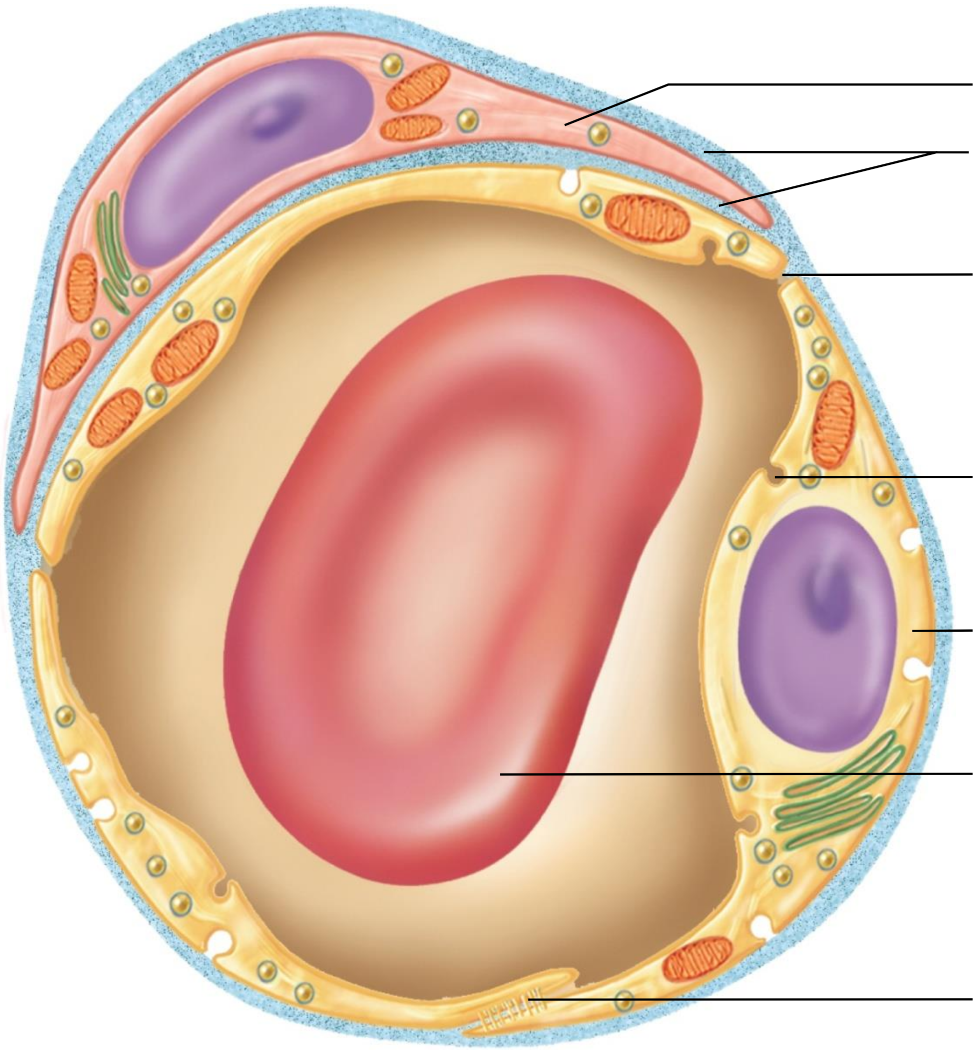
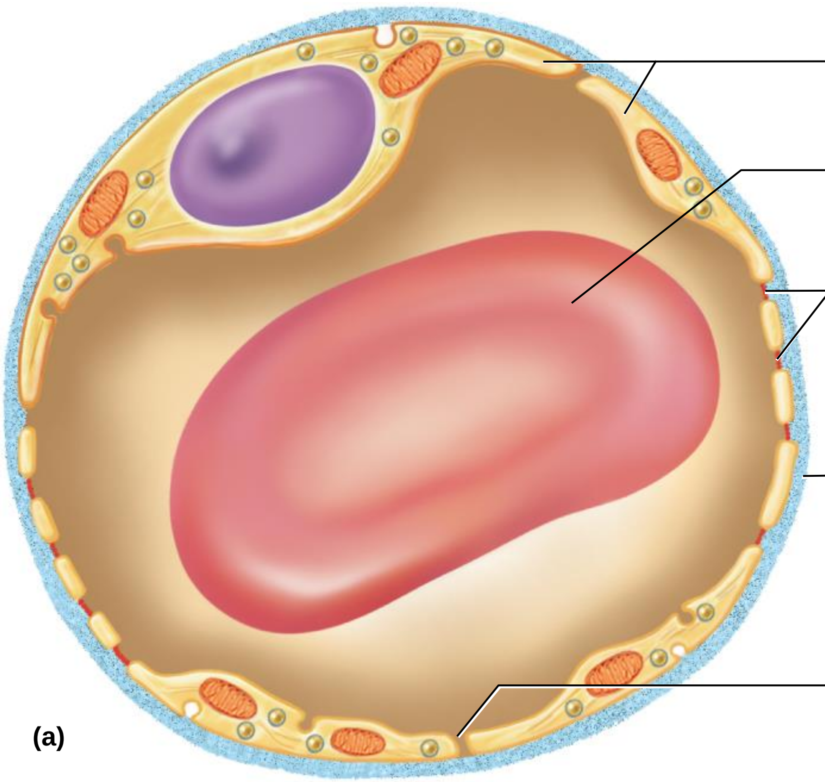
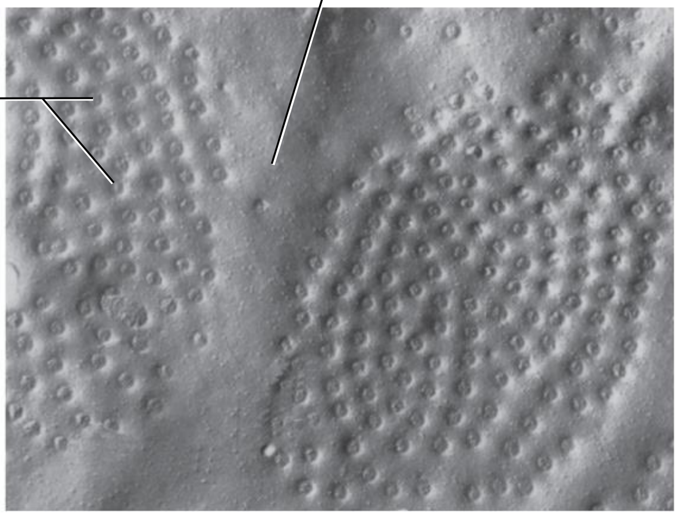


Figure 20.4

Fenestrated Capillary





(b): © Courtesy of S. McNutt

Figure 20.5a

Figure 20.5b

Sinusoid in Liver

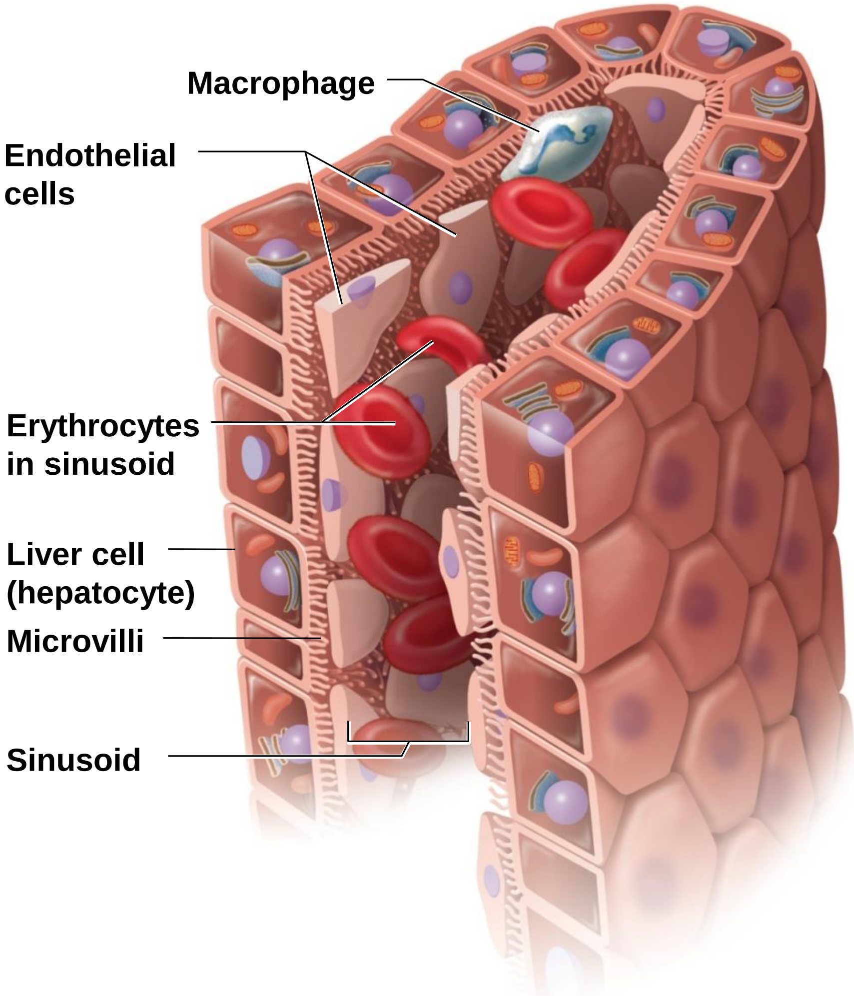
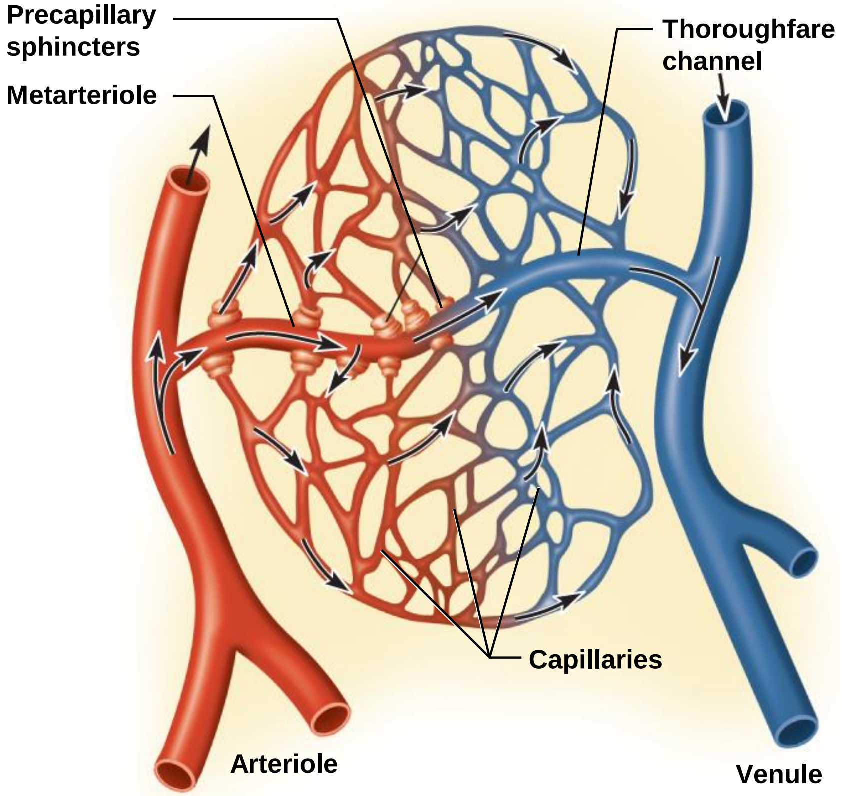


Figure 20.6

Capillary Beds

- **Capillary beds** are networks of 10-100 capillaries
  - Usually supplied by a single arteriole or metarteriole
  - At distal end, capillaries transition to venules or drain into a throroughfare channel (continuation of metarteriole)
  - At any given time, three-fourths of body's capillaries are shut down
    - Most control of flow involves constriction of arterioles that are upstream from the capillaries
    - Within the capillary bed, precapillary shincters control flow
      - When sphincters are relaxed, capillaries are well perfused with blood
      - When sphincters contract, they constrict the entry to the capillary and blood bypasses the capillary

Capillary Beds

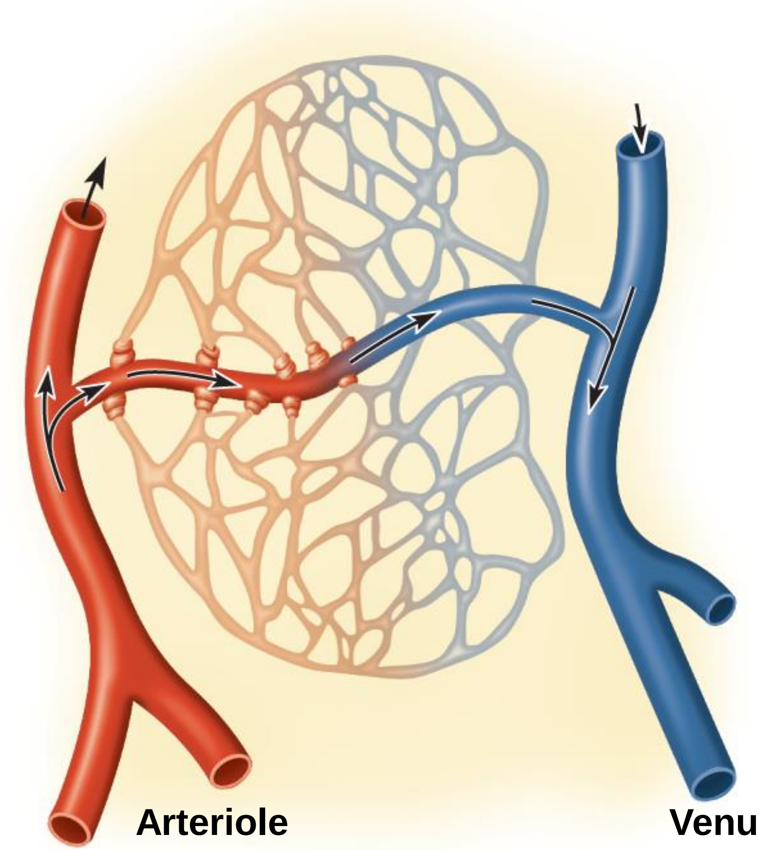


(a) Sphincters open

Figure 20.7a

When sphincters are open, the capillaries are well perfused

Capillary Beds



(b) Sphincters closed

Figure 20.7b

When the sphincters are closed, little to no blood flow occurs (example: capillaries in skeletal muscles at rest)

Veins

- **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**
  - Averages 10 mm Hg with little fluctuation

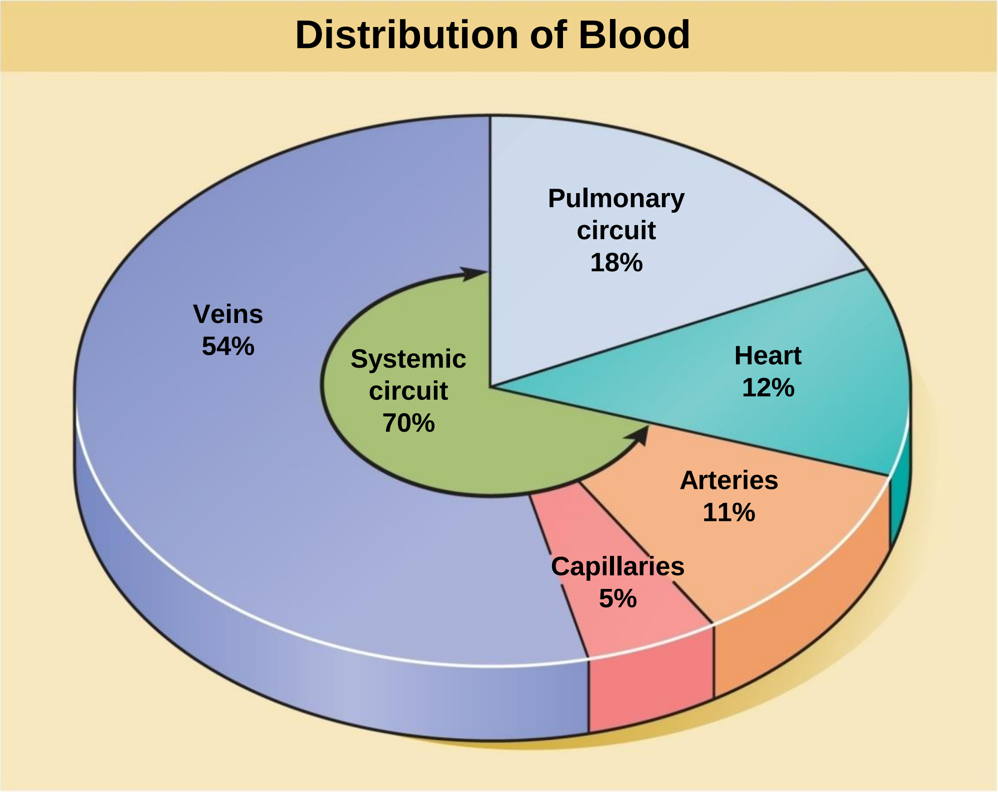


Figure 20.8

Veins

- **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

Veins

- **Muscular venules**—up to 1 mm in diameter
  - One 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

Veins

- **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 vasomotor responses

- **Large veins**—diameter 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 of 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 for blood**
  - 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

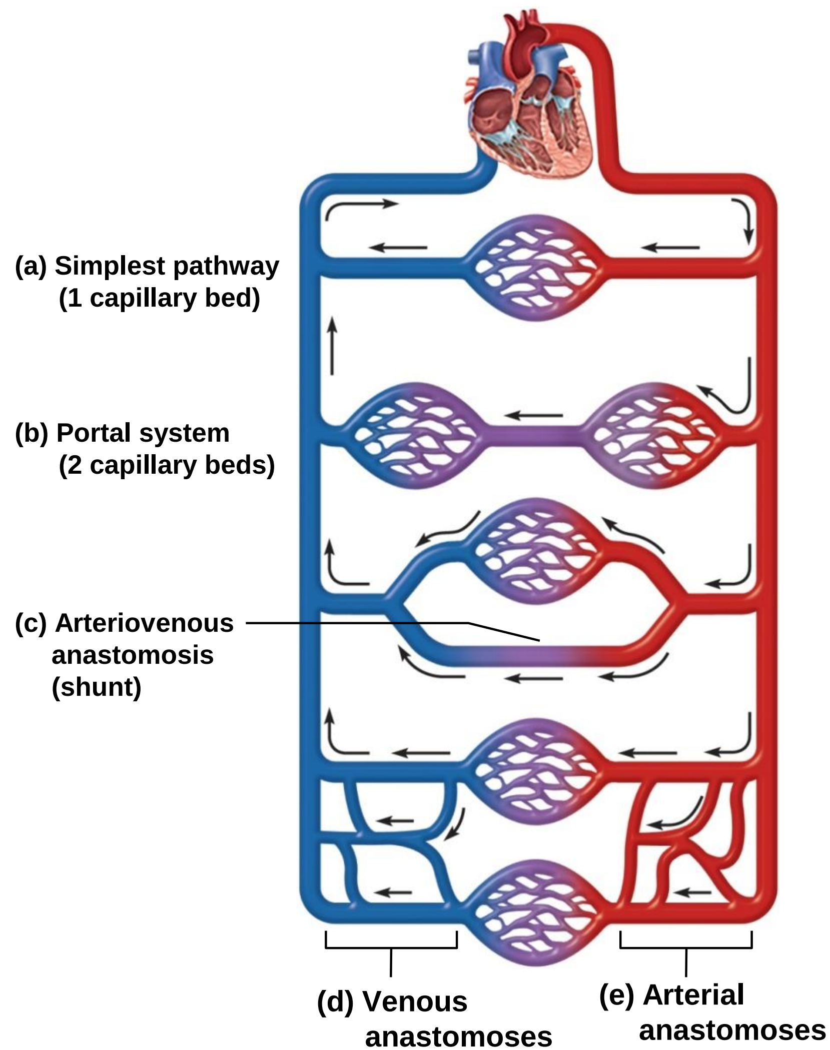


Figure 20.9

Circulatory Routes

- **Portal system**
  - Blood flows through **two consecutive capillary** networks before returning to heart
    - Between hypothalamus and anterior pituitary
    - In kidneys
    - Between intestines to liver

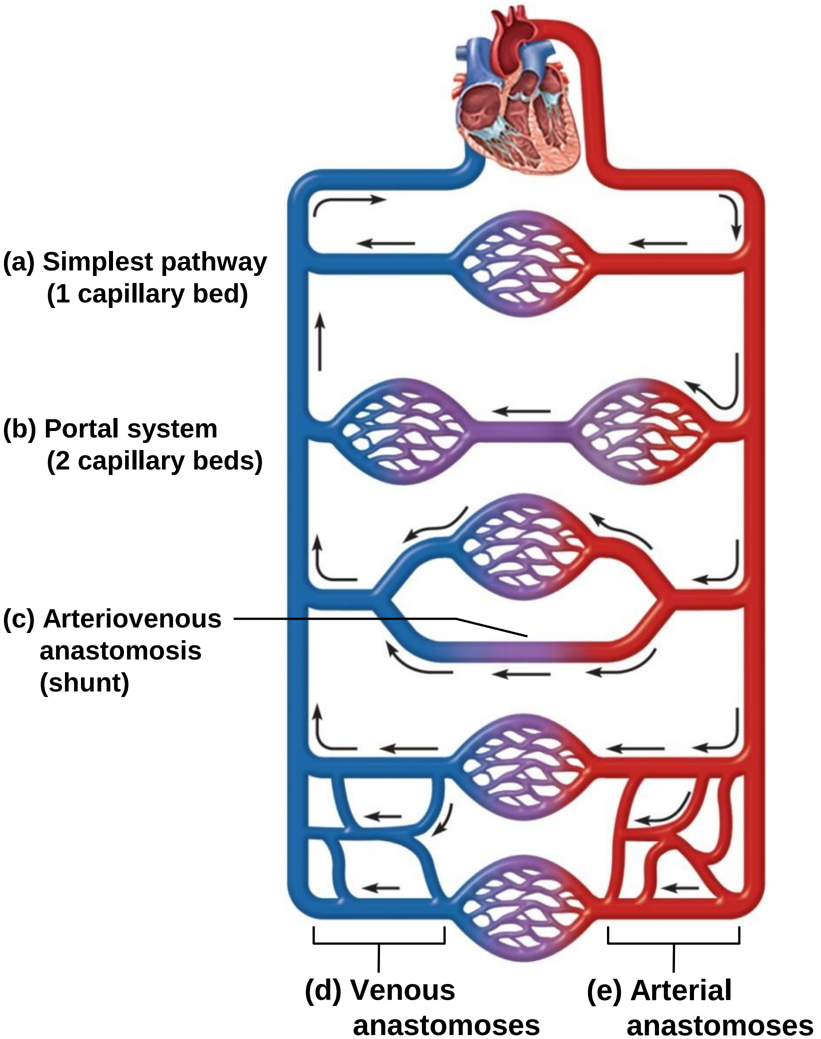


Figure 20.9

Circulatory Routes

- **Anastomosis**—convergence point between two vessels other than capillaries
- **Arteriovenous anastomosis (shunt)**
  - Artery flows directly into vein, bypassing capillaries

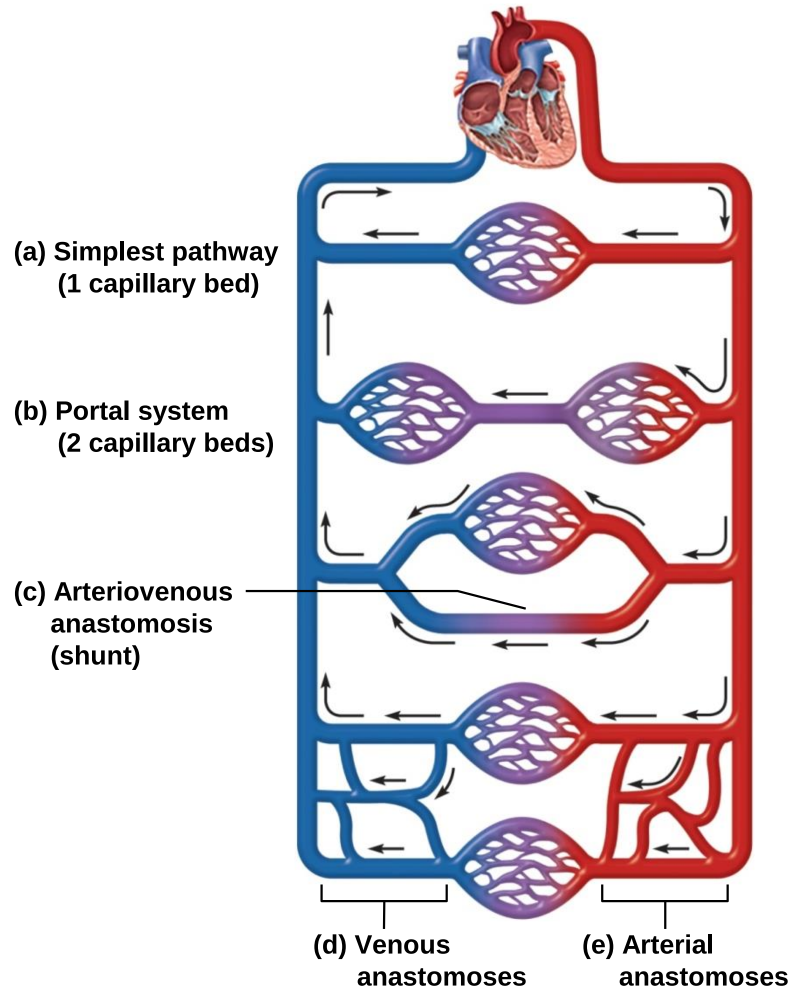


Figure 20.9

Circulatory Routes

- **Venous anastomosis**
  – Most common
  – One vein empties directly into another
  – Reason vein blockage is less serious than arterial blockage

- **Arterial anastomosis**
  – Two arteries merge
  – Provides **collateral (alternative) routes** of blood supply to a tissue
  – Coronary circulation and common around joints

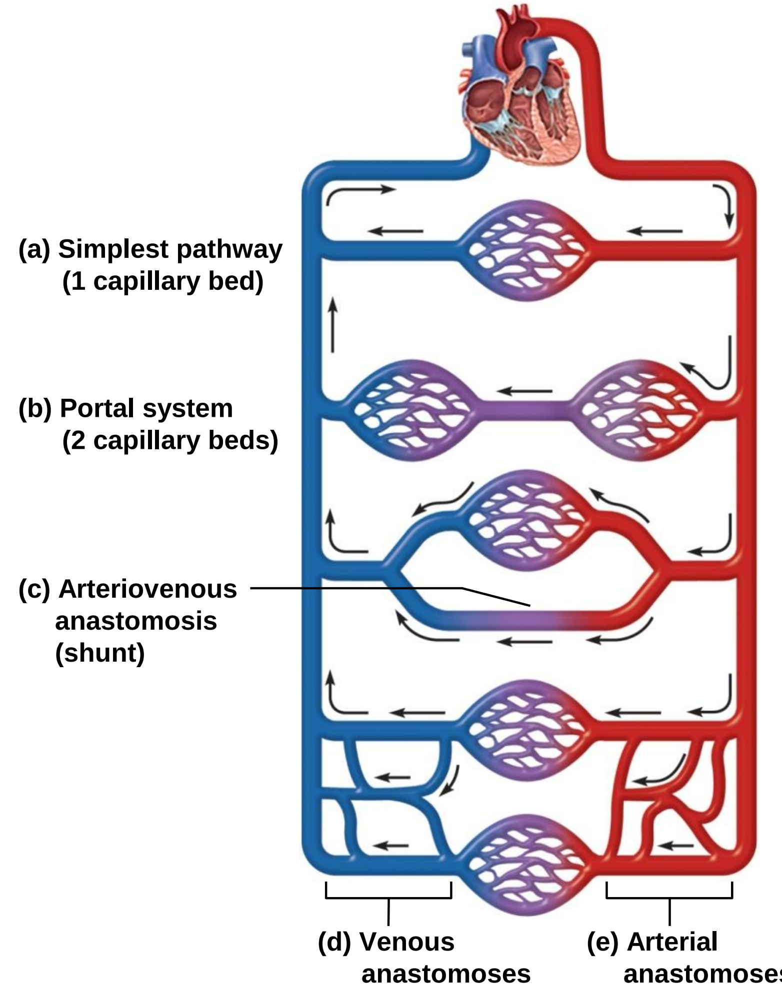


Figure 20.9

Blood Pressure, Resistance, and Flow

- **Expected Learning Outcomes**
  - Explain the relationship between blood pressure, resistance, and flow.
  - Describe how blood pressure is expressed and how pulse pressure and mean arterial pressure are calculated.
  - Describe three factors that determine resistance to blood flow.
  - Explain how vessel diameter influences blood pressure and flow.
  - Describe some local, neural, and hormonal influences on vessel diameter.

Blood Pressure, Resistance, and 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)**

Blood Pressure, Resistance, and Flow

- **Important for delivery of nutrients and oxygen, and removal of metabolic wastes**
- **Hemodynamics**
  - Physical principles of blood flow based on **pressure** and **resistance**
    - $F \propto \Delta P/R$ (F = flow, ΔP = difference in pressure, R = resistance)
    - 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**
  - A close approximation of pressure at exit of left ventricle
- **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**

Blood Pressure

- **Pulse pressure**—difference between systolic and diastolic pressure
  - Important measure of driving force on circulation and 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 + (one-third of pulse pressure)
  - Average blood pressure that most influences risk level for edema, fainting (syncope), atherosclerosis, kidney failure, and aneurysm

Blood Pressure

- **Since pressure varies across the cardiac cycle, blood flow in arteries is pulsatile**
  – Speed surges from 40 cm/s to 120 cm/s
  – Blood spurts intermittently from an open artery
- **In capillaries and veins, blood flows at steady speed**
  – Bleeding from veins tends to be slow and steady
- **BP tends to rise with age**
  – Arteriosclerosis—stiffening of arteries due to deterioration of elastic tissues of artery walls
  – Atherosclerosis—build up of lipid deposits that become plaques

Blood Pressure

- **Hypertension**—high blood pressure
  - – Chronic resting BP > 140/90
  - – Consequences
    - Can weaken arteries, cause aneurysms, promote atherosclerosis
- **Hypotension**—chronic low resting BP
  - – Caused by blood loss, dehydration, anemia

Blood Pressure

- BP determined by **cardiac output, blood volume,** and **resistance to flow**
  - Blood volume regulated mainly by kidneys

BP Changes with Distance

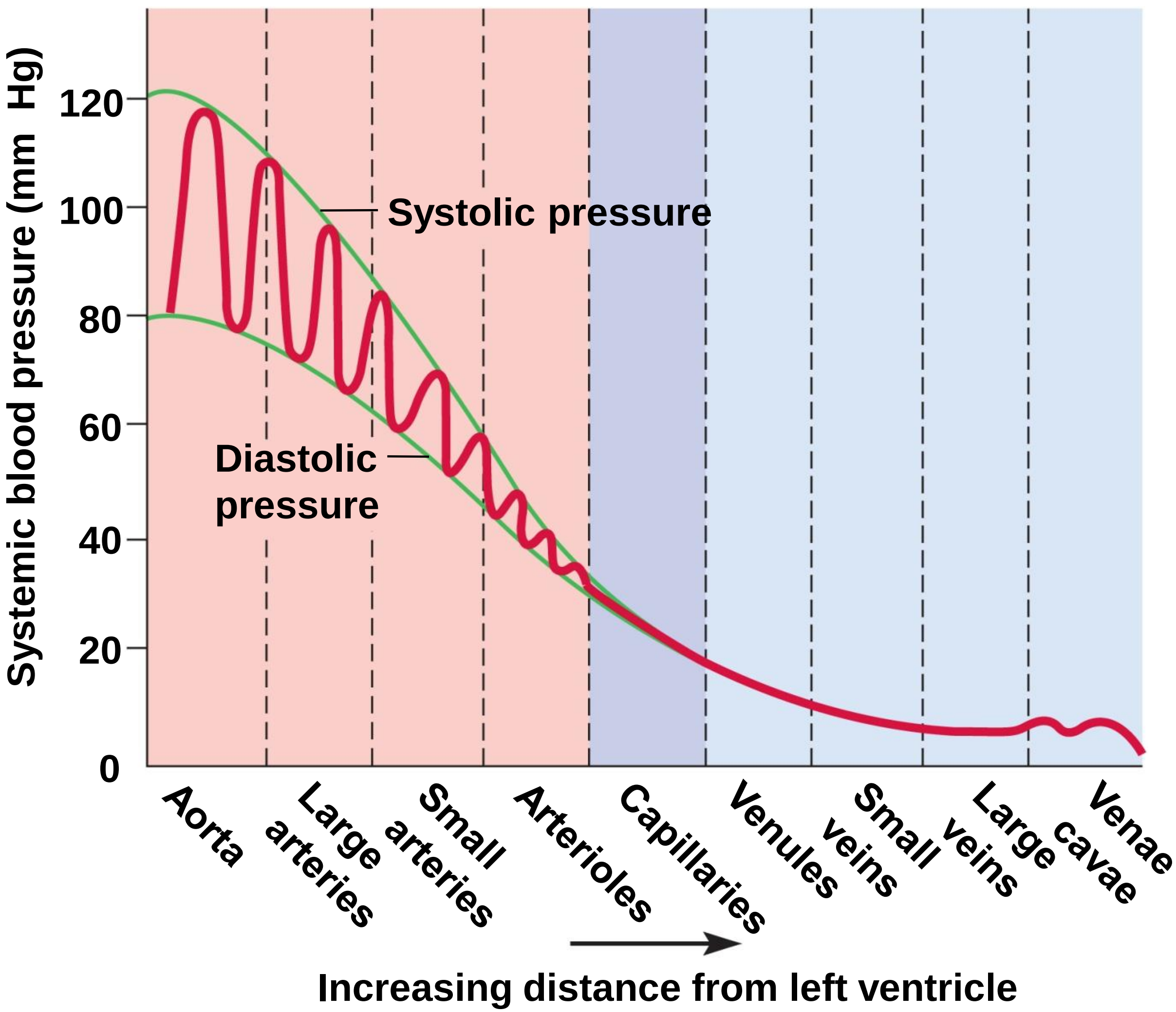


Figure 20.10

Peripheral Resistance

- **Peripheral resistance**—the opposition to flow that blood encounters in vessels away from the heart
- **Resistance hinges on three variables: blood viscosity, vessel length, and vessel radius**
  - **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

Peripheral Resistance

- **Vessel radius:** most powerful influence over flow
  - Only significant way of controlling resistance
  - **Vasoreflexes**—changes in vessel radius
    - **Vasoconstriction:** when smooth muscle of tunica media contracts
    - **Vasodilation:** relaxation of the smooth muscle, allowing blood pressure to expand vessel
  - 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*), $F \propto r^4$
    - Small changes in blood vessel radius can cause large changes in flow (mL/min)

Peripheral Resistance

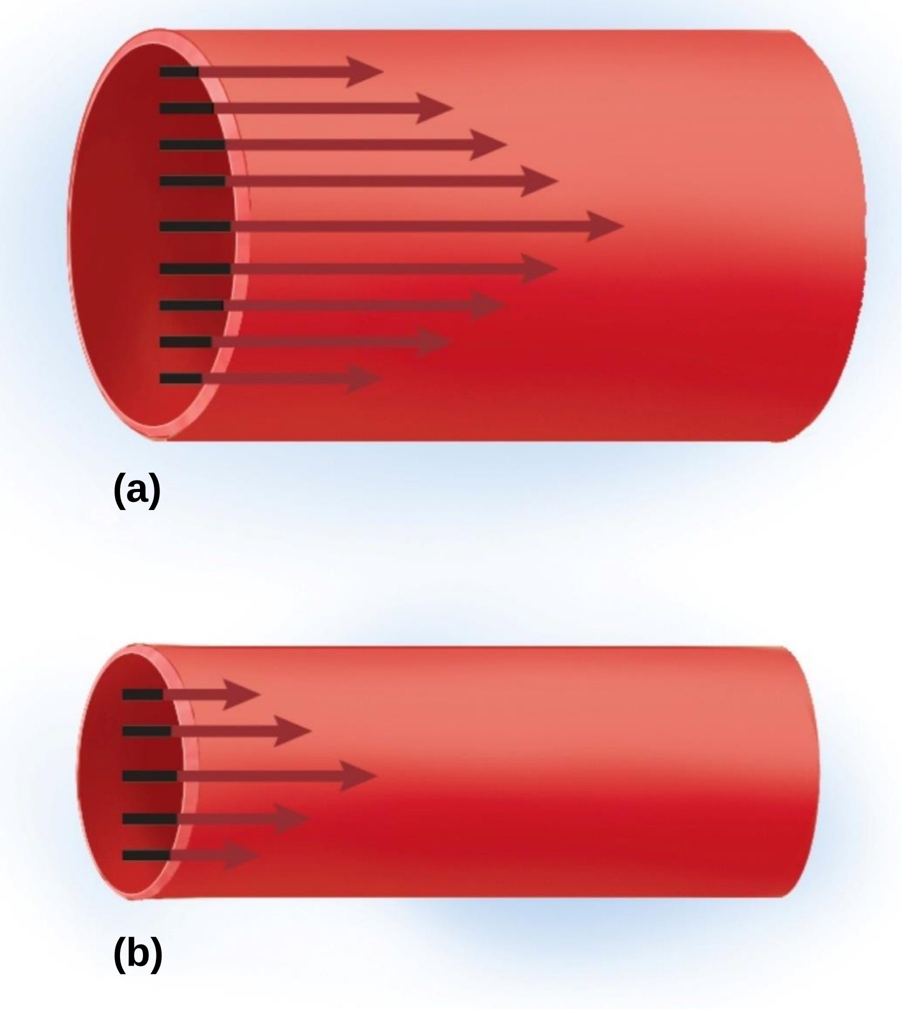


Figure 20.11

Peripheral Resistance

- 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 become greater and greater

Peripheral Resistance

- From **capillaries** to **vena cava,** velocity increases again
  - Since veins are larger they create less resistance than capillaries
  - Large amount of blood forced into smaller channels
  - Blood in veins never regains velocity it had in large arteries
    - Veins are further from the pumping heart
    - Veins are more compliant (they stretch more) than arteries

Peripheral Resistance

- **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 changing radius
- **Arterioles produce half of the total peripheral resistance**

Regulation of Blood Pressure and Flow

- **Vasoreflexes** are quick and powerful ways of altering blood pressure and flow
- **Three ways of controlling vasomotor activity**
  - Local control
  - Neural control
  - Hormonal control

Local Control

- **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 removes metabolites
  - When wastes are removed, vessels constrict

Local Control

- **Vasoactive chemicals**—substances secreted by platelets, endothelial cells, and perivascular tissue to stimulate vasomotor responses
  - Histamine, bradykinin, and prostaglandins stimulate vasodilation
  - Endothelial cells secrete prostacyclin and nitric oxide (vasodilators)

Local Control

- **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 several growth factors and inhibitors

Neural Control

- **The central and autonomic nervous systems also exert control over blood vessel size**

- **Vasomotor center** of medulla exerts **sympathetic** control over blood vessels throughout the body
  - Stimulates most vessels to **constrict,** but dilates vessels in cardiac muscle to meet demands of exercise
  - Vasomotor center is the integrating center for three autonomic reflexes
    - **Baroreflexes**
    - **Chemoreflexes**
    - **Medullary ischemic reflex**

Neural Control

- **Baroreflex**—automatic, negative feedback response to change in blood pressure
  - Increases in BP detected by **carotid sinuses**
  - **Glossopharyngeal nerve** sends signals to brainstem
  - Results in 1) inhibition of sympathetic cardiac and vasomotor neurons, and 2) excitation of vagal fibers that slow heart rate and thus reduce BP
  - Decreases in BP have the opposite effect

- Baroreflexes govern **short-term** regulation of BP
  - Adjustments for rapid changes in posture
  - Not helpful in correcting chronic hypertension
  - After 2 days or less they adjust their set point

Negative Feedback Control of BP

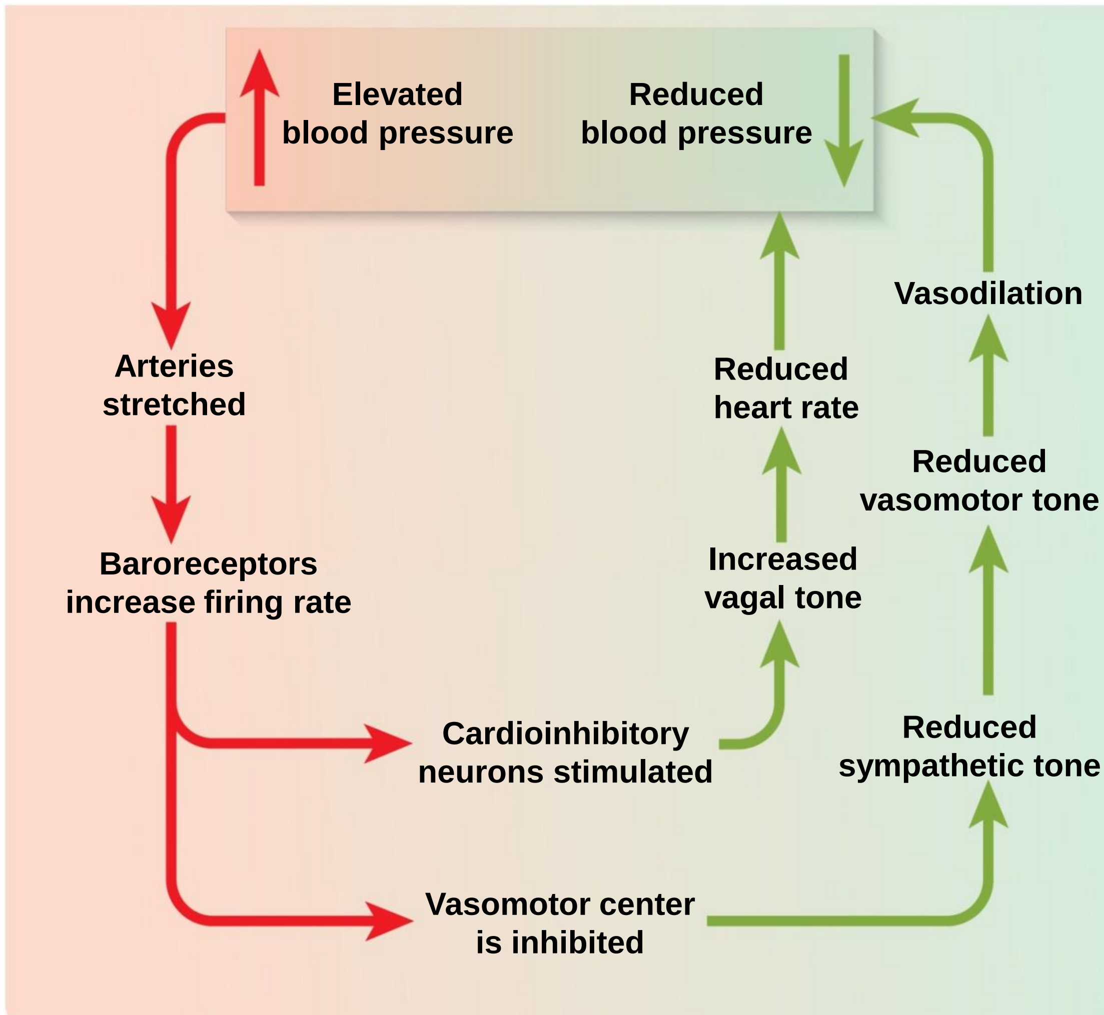


Figure 20.13

Neural Control

- **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

Neural Control

- **Primary role**: adjust respiration to changes in blood chemistry
- **Secondary role**: vasoreflexes
  - 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

Neural Control

- **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
  - 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

Hormonal Control

- **ADH** promotes water retention and raises BP
  - Pathologically high concentrations; also a vasoconstrictor (aka vasopressin)
- **Epinephrine and norepinephrine** effects
  - Most blood vessels
    - Bind to α-adrenergic receptors—**vasoconstriction**
  - In cardiac muscle blood vessels
    - Bind to β-adrenergic receptors—**vasodilation**

Two Purposes of Vasoreflexes

- **Two purposes of dilation and constriction: 1) general control of BP and 2) routing blood from one body region to another**

- 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

Two Purposes of Vasoreflexes

- 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
  - If a specific artery constricts, the pressure downstream drops, pressure upstream rises

Two Purposes of Vasoreflexes

- **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

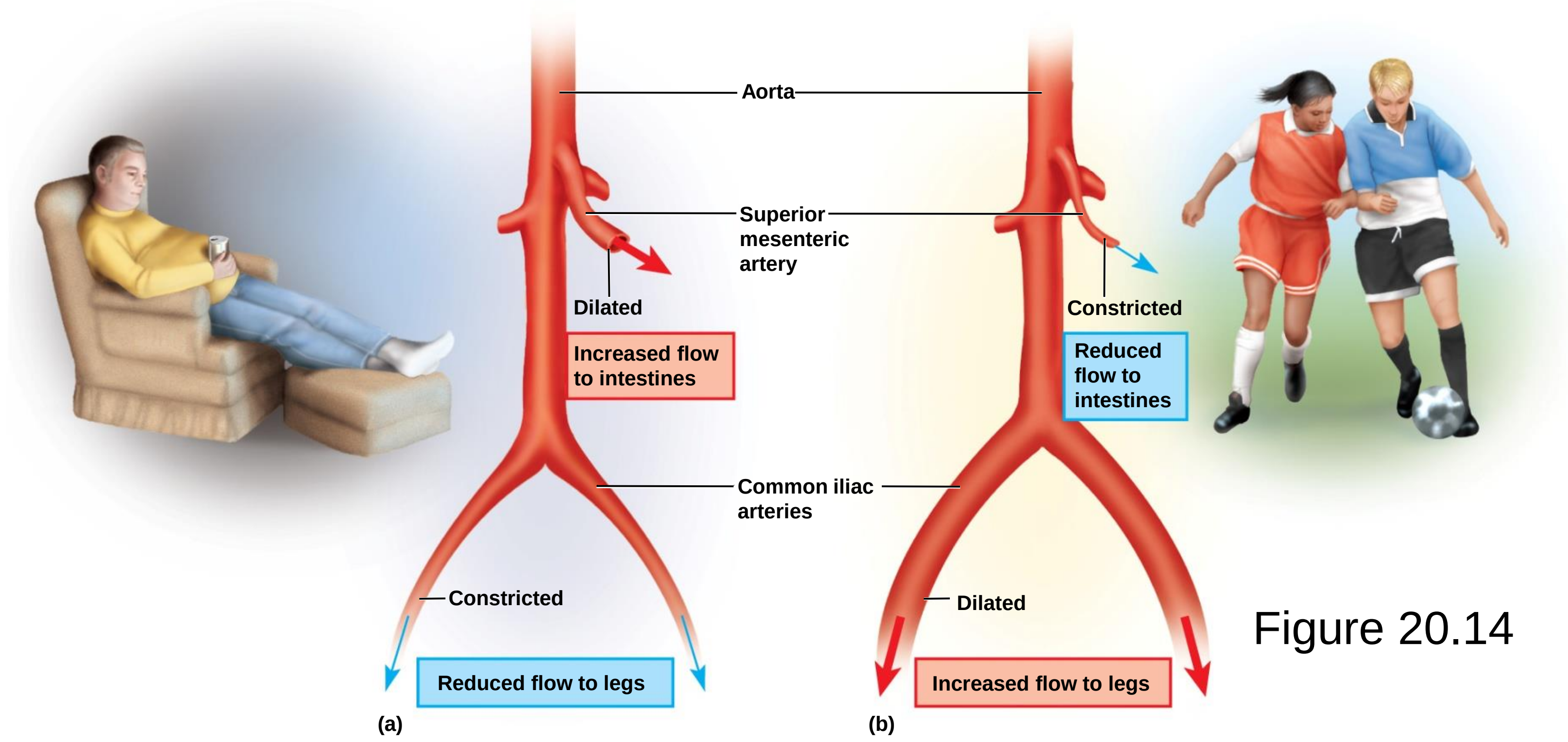


Figure 20.14

- **Arteries shift blood flow with changing priorities**

Blood Flow Comparison

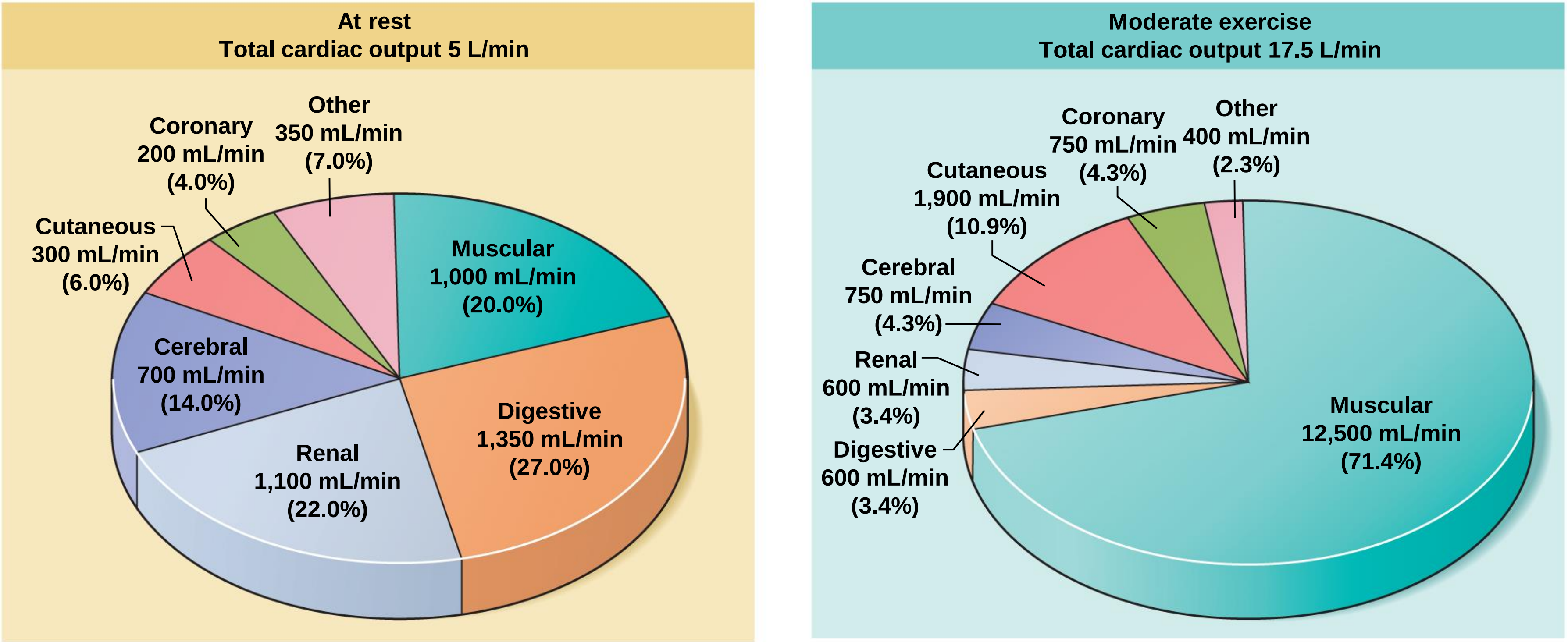


Figure 20.15

- **During exercise**
  - Increased perfusion of lungs, myocardium, and skeletal muscles
  - Decreased perfusion of kidneys and digestive tract

Capillary Exchange

- **Expected Learning Outcomes**
  - Describe how materials get from the blood to the surrounding tissues.
  - Describe and calculate the forces that enable capillaries to give off and reabsorb fluid.
  - Describe the causes and effects of edema.

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

Capillary Exchange

- 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**

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

Diffusion

- **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 such as proteins held back**

Transcytosis

- **Trancytosis—**endothelial cells pick up material on one side of their 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)**

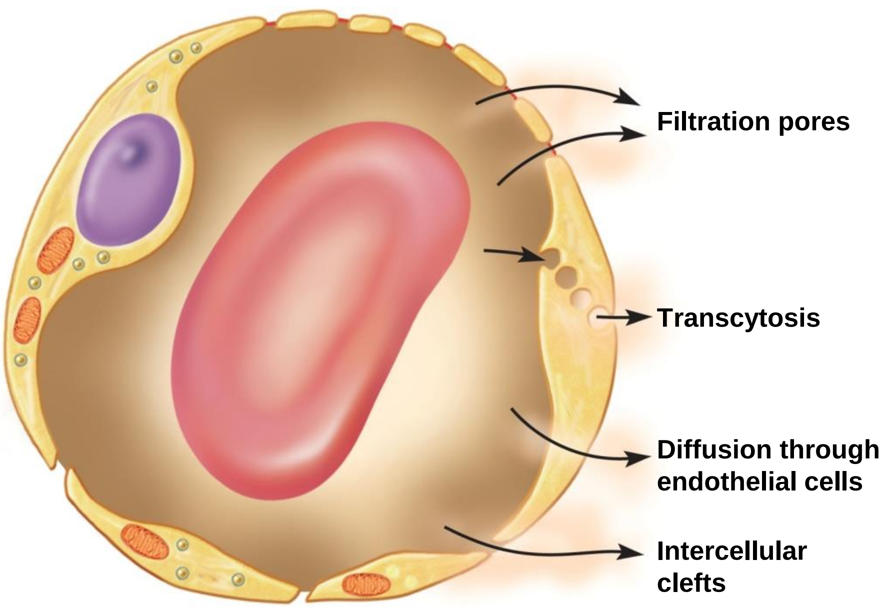


Figure 20.16

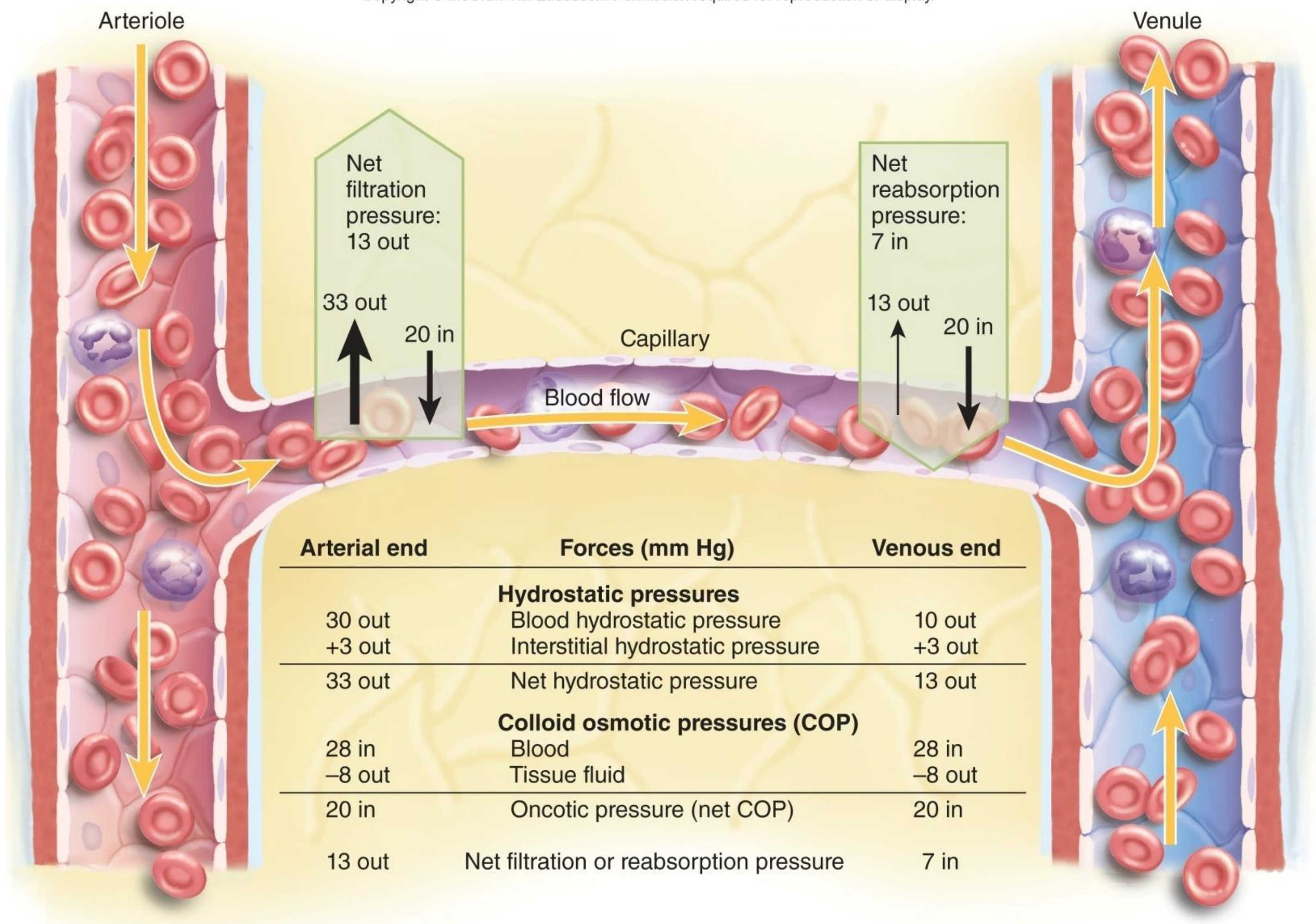
Filtration and Reabsorption

- **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)

Filtration and Reabsorption

- **Hydrostatic pressure**
  - Physical force exerted against a surface by a liquid
    - Blood pressure in vessels is hydrostatic pressure
- Capillaries reabsorb about **85%** of the fluid they filter
- Other **15%** is absorbed by the **lymphatic system** and returned to the blood

Filtration and Reabsorption

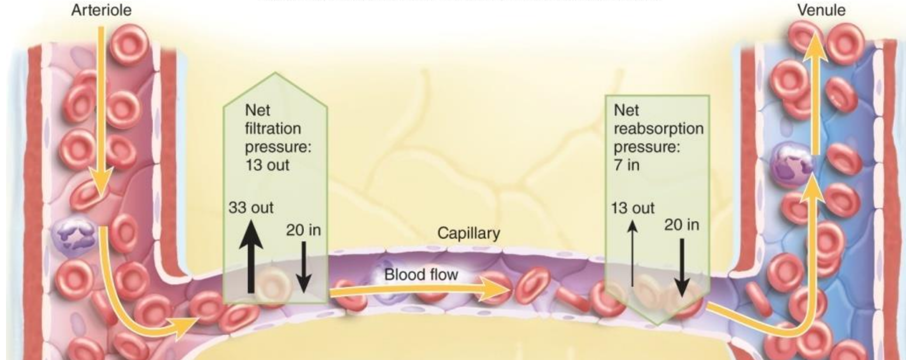


Arterial end	Forces (mm Hg)	Venous end
	Hydrostatic pressures	
30 out	Blood hydrostatic pressure	10 out
+3 out	Interstitial hydrostatic pressure	+3 out
33 out	Net hydrostatic pressure	13 out
	Colloid osmotic pressures (COP)	
28 in	Blood	28 in
–8 out	Tissue fluid	–8 out
20 in	Oncotic pressure (net COP)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

Figure 20.17

The Forces of 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



Arterial end	Forces (mm Hg)	Venous end
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	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 Filtration and Reabsorption

- **Capillaries usually reabsorb most of the fluid they filter with certain exceptions**
  - **Kidney capillaries** in glomeruli do not reabsorb
  - **Alveolar capillaries** in lung absorb completely to keep fluid out of air spaces

Variations in Capillary Filtration and Reabsorption

- **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**—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

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

Venous Return and Circulatory Shock

- **Expected Learning Outcomes**
  - Explain how blood in the veins is returned to the heart.
  - Discuss the importance of physical activity in venous return.
  - Discuss several causes of circulatory shock.
  - Name and describe the stages of shock.

Mechanisms of Venous Return

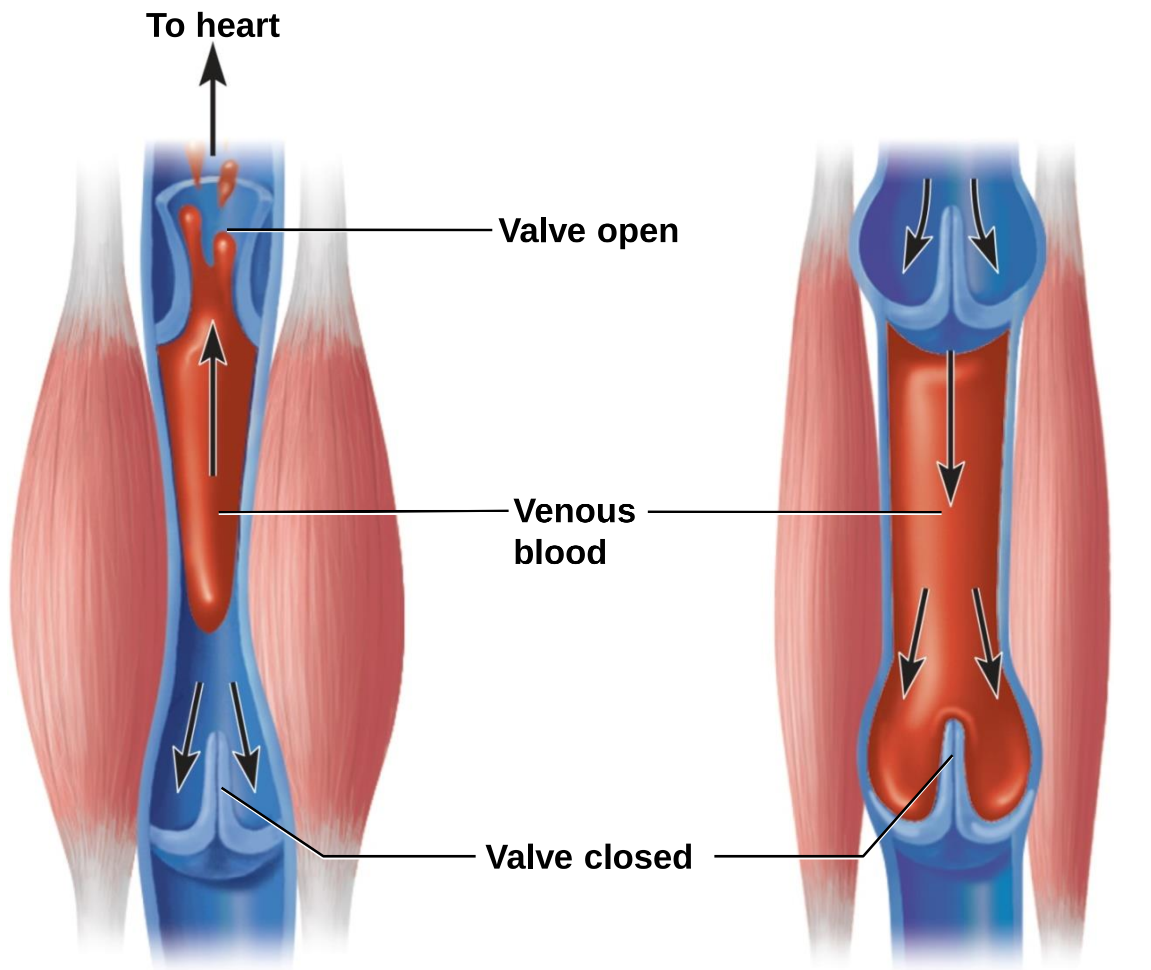
- **Venous return**—the flow of blood back to the heart; relies on: pressure gradient, gravity, skeletal muscle pump, thoracic pump, and cardiac suction
  - **Pressure gradient**
    - Blood pressure is the most important force in venous return
    - 7 to 13 mm Hg venous pressure toward heart
    - Venules (12 to 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 squeezes blood out of the compressed part of the vein

Mechanisms of Venous Return

Venous Return (Continued)

- **Thoracic (respiratory) pump**
  - Inhalation—thoracic cavity expands and thoracic pressure decreases, abdominal pressure increases, forcing blood upward
    - Central venous pressure fluctuates
  - 2 mm Hg—inhalation, 6 mm Hg—exhalation
  - Blood flows faster with inhalation
- **Cardiac suction** of expanding atrial space

The Skeletal Muscle Pump



(a) Contracted skeletal muscles

(b) Relaxed skeletal muscles

Figure 20.19

Venous Return and Physical Activity

- **Exercise increases venous return** in many ways
  - Heart beats faster and 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 Return and Physical Activity

- **Venous pooling** occurs with inactivity
  - Venous pressure not enough to 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

Circulatory Shock

(Continued)

- Three principal forms of LVR shock:
  - **Hypovolemic shock**—most common
    - Loss of blood volume: trauma, burns, dehydration
  - **Obstructed venous return shock**
    - Tumor or aneurysm compresses a vein
  - **Venous pooling (vascular) shock**
    - Long periods of standing, sitting, or widespread vasodilation

Circulatory Shock

- **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

Responses to Circulatory Shock

- **Compensated shock**
  - Several homeostatic mechanisms bring about spontaneous recovery
    - Example: If a person faints and falls to a horizontal position, gravity restores blood flow to the brain
- **Decompensated shock**
  - When compensation fails
  - Life-threatening positive feedback loops occur
  - Condition gets worse causing damage to cardiac and brain tissue

Special Circulatory Routes

- **Expected Learning Outcomes**
  - Explain how the brain maintains stable perfusion.
  - Discuss the causes and effects of strokes and transient ischemic attacks.
  - Explain the mechanisms that increase muscular perfusion during exercise.
  - Contrast the blood pressure of the pulmonary circuit with that of the systemic circuit, and explain why the difference is important in pulmonary function.

Brain

- **Total blood flow to the brain fluctuates less than that of any other organ (700 mL/min.)**
  – Seconds of deprivation causes loss of consciousness
  – Four to 5 minutes causes irreversible brain damage
  – Though total flow is constant, blood is shifted to active brain areas from moment to moment

Brain

- **Brain regulates its own blood flow to match changes in BP and chemistry**
  - Cerebral arteries dilate as systemic BP drops, constrict as BP rises
  - Main chemical stimulus: pH
    - $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + (HCO_3)^-$
    - **Hypercapnia**—CO_2 levels increase in brain, pH decreases, triggers vasodilation
    - **Hypocapnia**—raises pH, stimulates vasoconstriction
      - Occurs with hyperventilation, may lead to ischemia, dizziness, and sometimes syncope

Brain

- **Transient ischemic attacks (TIAs)**—brief episodes of cerebral ischemia
  - Caused by spasms of diseased cerebral arteries
  - Dizziness, loss of vision, weakness, paralysis, headache, or aphasia
  - Lasts from a moment to a few hours
  - Often early warning of impending stroke

Brain

- **Stroke,** or **cerebral vascular accident (CVA)**
  - Sudden death of brain tissue caused by ischemia
    - Atherosclerosis, thrombosis, ruptured aneurysm
  - Effects range from unnoticeable to fatal
    - Blindness, paralysis, loss of sensation, loss of speech common
  - Recovery depends on surrounding neurons, collateral circulation

Skeletal Muscles

- Variable blood flow depending on **state of exertion**
- **At rest**
  - Arterioles constrict, most capillary beds shut down
  - Total flow about 1 L/min.
- **During exercise**
  - Arterioles dilate in response to muscle metabolites such as lactic acid, CO_2, and H^+
  - Blood flow can increase 20-fold
    - Blood is diverted from digestive and urinary organs
- **Muscular contraction impedes flow**
  - Isometric contraction causes fatigue faster than intermittent isotonic contractions

Lungs

- **Low** pulmonary blood pressure (25/10 mm Hg)
  - Flow slower, more time for gas exchange
  - Oncotic pressure overrides blood (hydrostatic) pressure
    - Pulmonary capillaries absorb fluid (almost no filtration)
    - Prevents fluid accumulation in alveolar walls and lumens
- **Unique response to hypoxia**
  - Pulmonary arteries constrict in diseased area
  - Redirects flow to better ventilated region

Anatomy of the Pulmonary Circuit

- **Expected Learning Outcome**
  - Trace the route of blood through the pulmonary circuit.

Anatomy of the Pulmonary Circuit

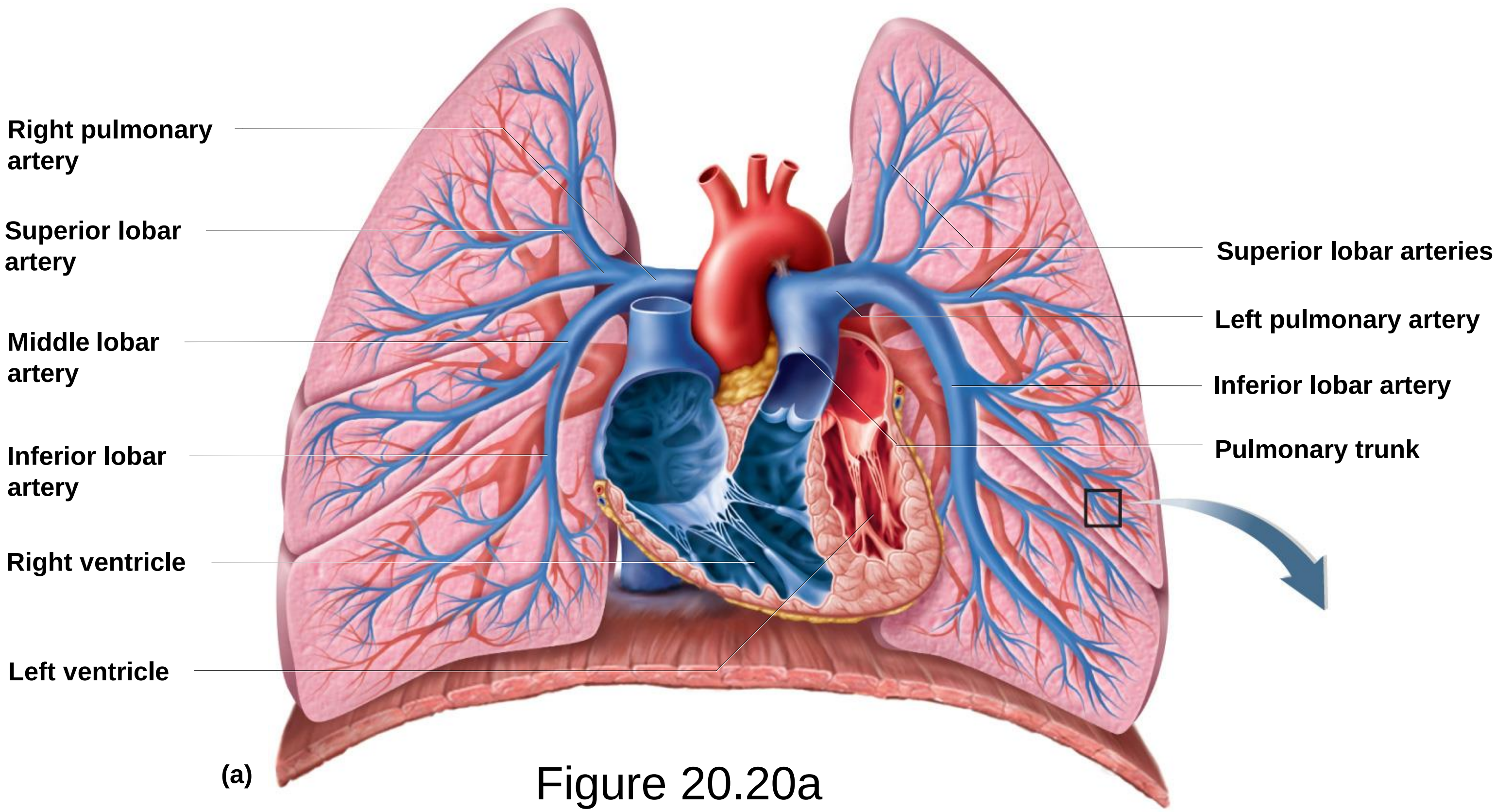
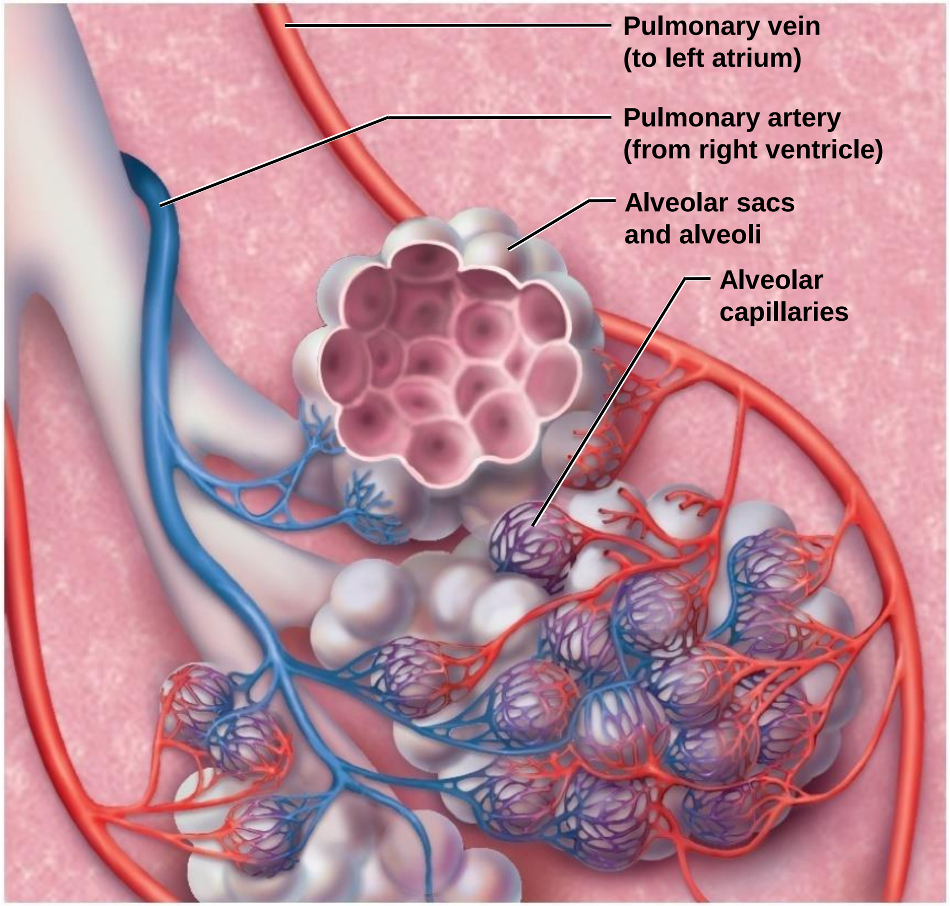


Figure 20.20a

- **Pulmonary trunk to pulmonary arteries to lungs**
  – Lobar branches for each lobe (three right, two left)
- **Pulmonary veins return to left atrium**
  – Increased O_2 and reduced CO_2 levels

Anatomy of the Pulmonary Circuit

- **Basket-like capillary beds surround alveoli**
- **Exchange of gases with air and blood at alveoli**



(b)

Figure 20.20b

Systemic Vessels of the Axial Region

- **Expected Learning Outcomes**
  - Identify the principal systemic arteries and veins of the axial region.
  - Trace the flow of blood from the heart to any major organ of the axial region and back to the heart.

The Major Systemic Arteries

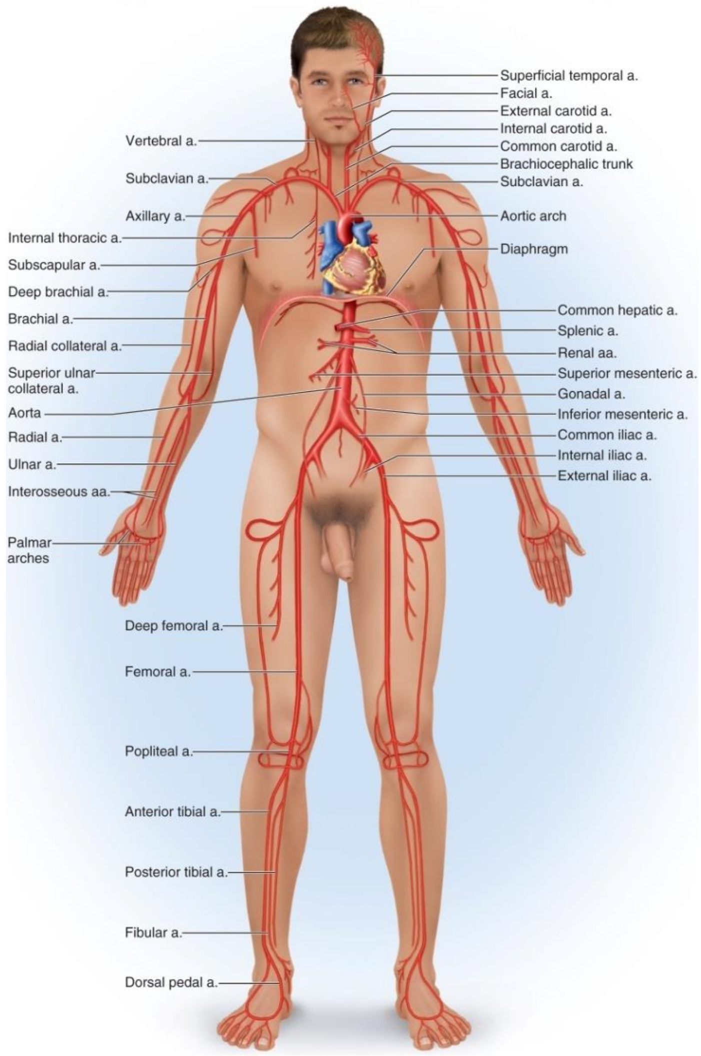


Figure 20.21

- **Arteries supply oxygen and nutrients to all organs**

The Aorta and Its Major Branches

- **Ascending aorta**
  - Right and left **coronary arteries** supply heart
- **Aortic arch**
  - **Brachiocephalic**
    - Right common carotid supplying right side of head
    - Right subclavian supplying right shoulder and upper limb
  - **Left common carotid** supplying left side of head
  - **Left subclavian** supplying shoulder and upper limb
- **Descending aorta:** differently named in chest and abdomen
  - **Thoracic aorta** above diaphragm
  - **Abdominal aorta** below diaphragm

The Aorta and Its Major Branches

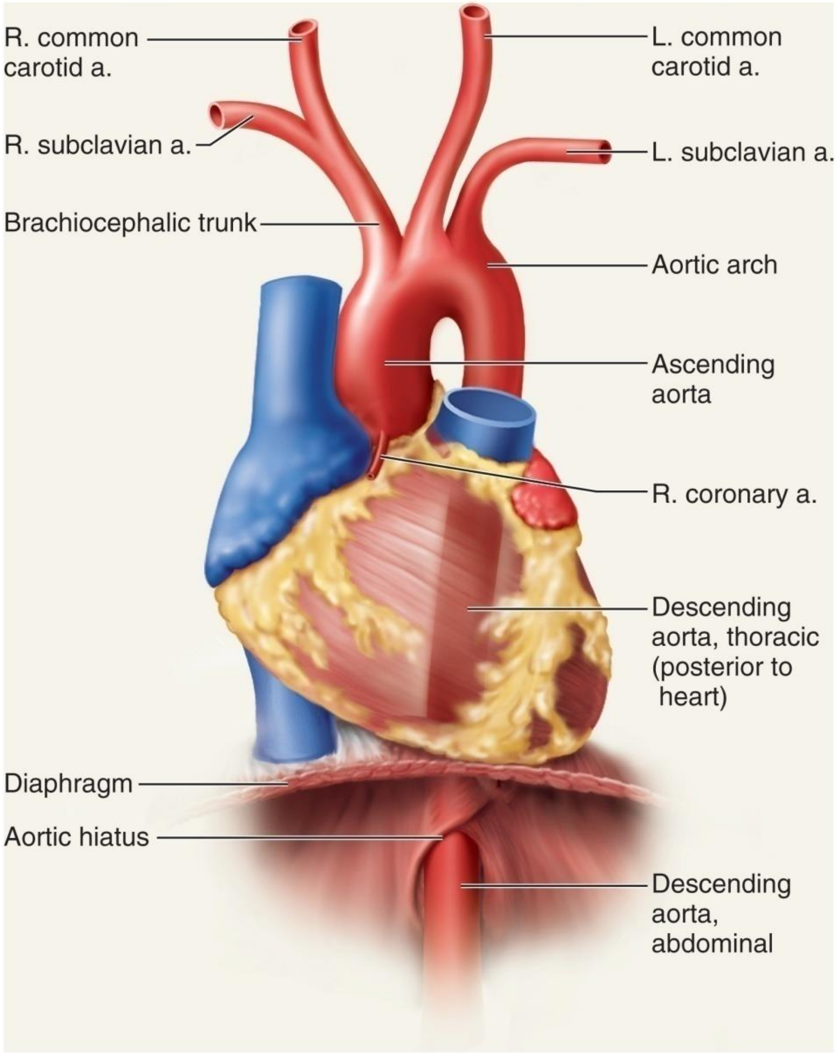
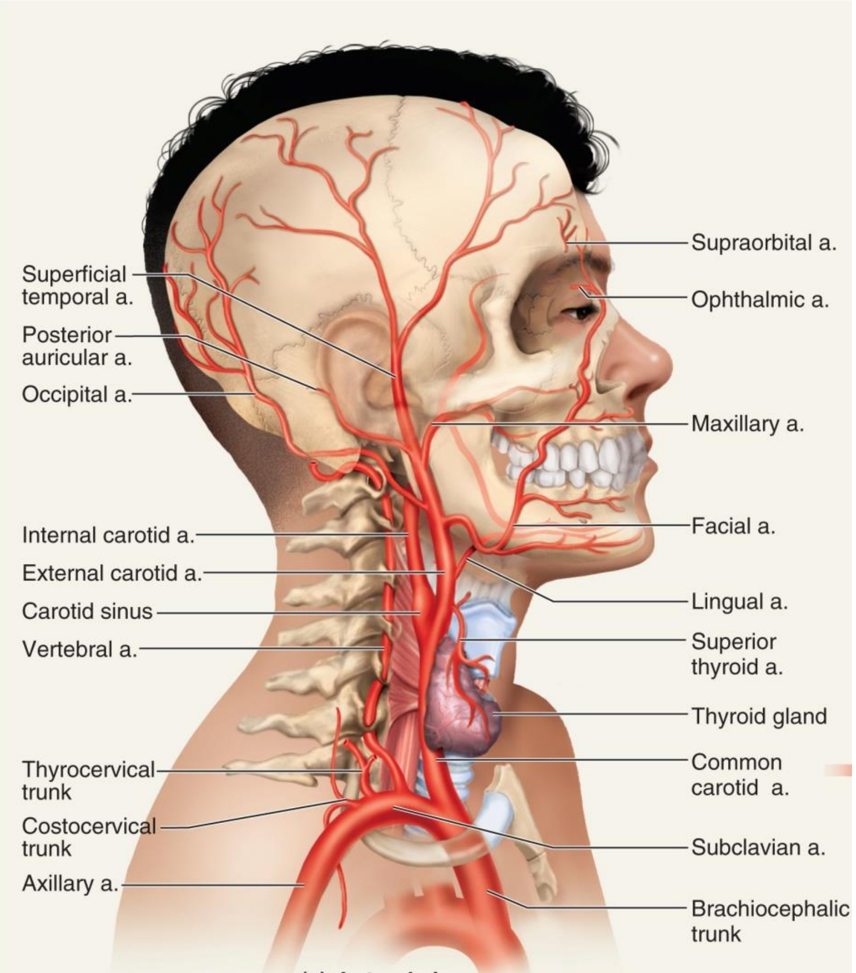


Figure 20.23

Arteries of the Head and Neck



(a) Lateral view

Figure 20.24a

- **Common carotid divides into internal and external carotids**
  - External carotid supplies most external head structures

Arteries of the Head and Neck

- Paired **vertebral arteries** combine to form **basilar artery** on pons
- **Circle of Willis** arterial anastomosis on base of brain receiving blood from basilar and internal carotid arteries; serves cerebrum
  - Surrounds pituitary gland and optic chiasm
  - Includes anterior and posterior cerebral and communicating arteries

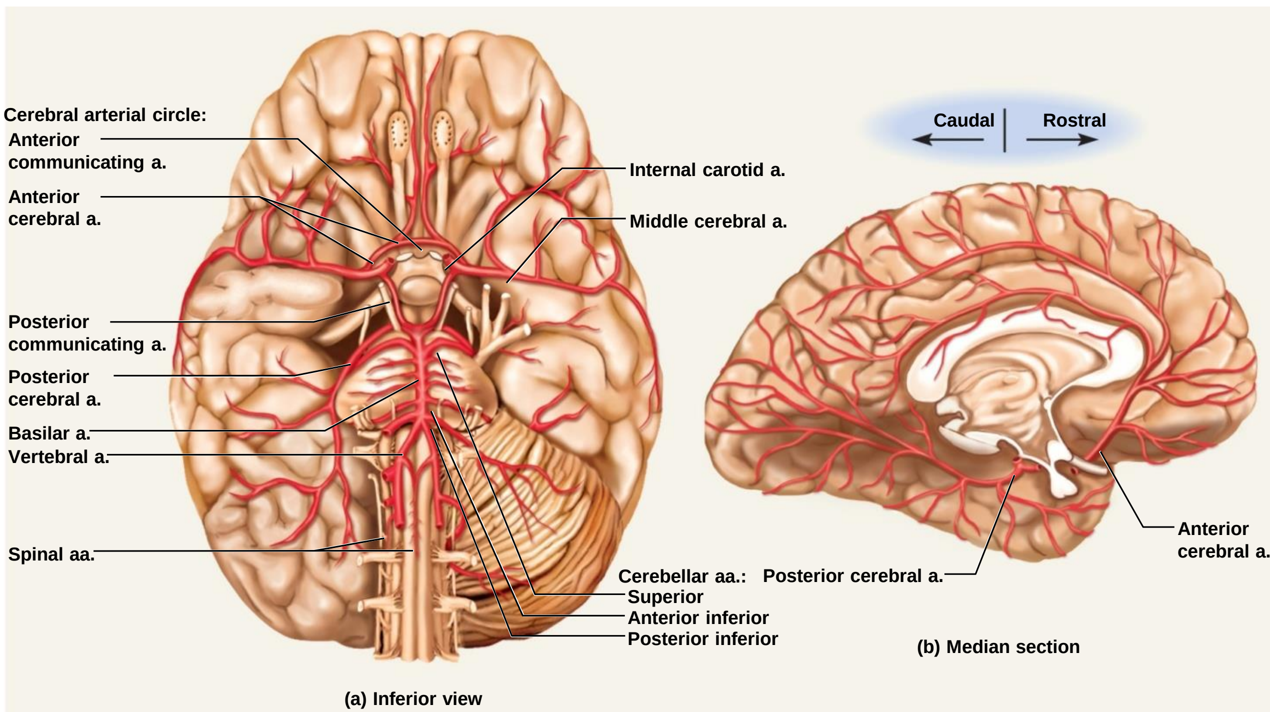


Figure 20.25

The Major Systemic Veins

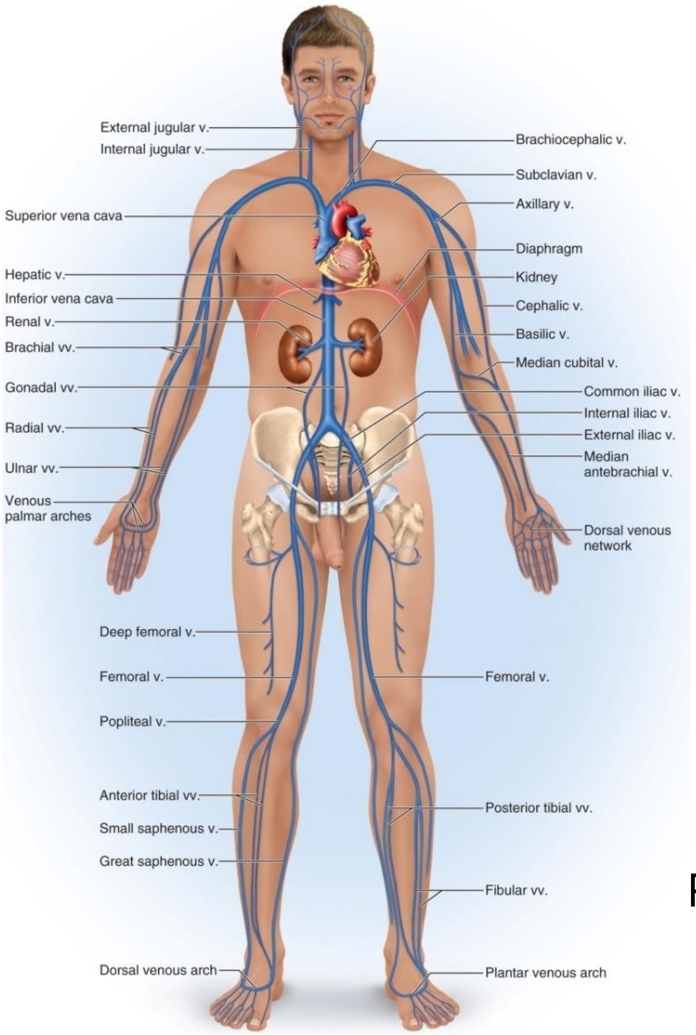
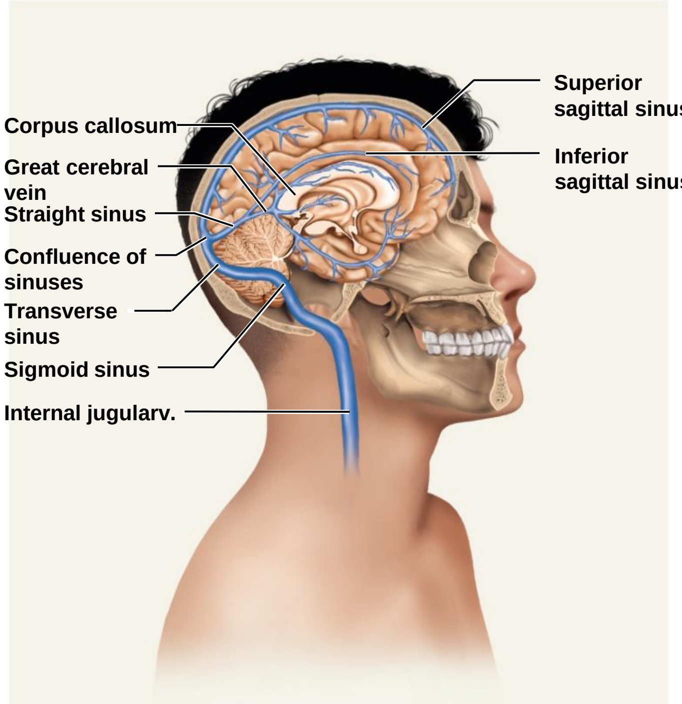


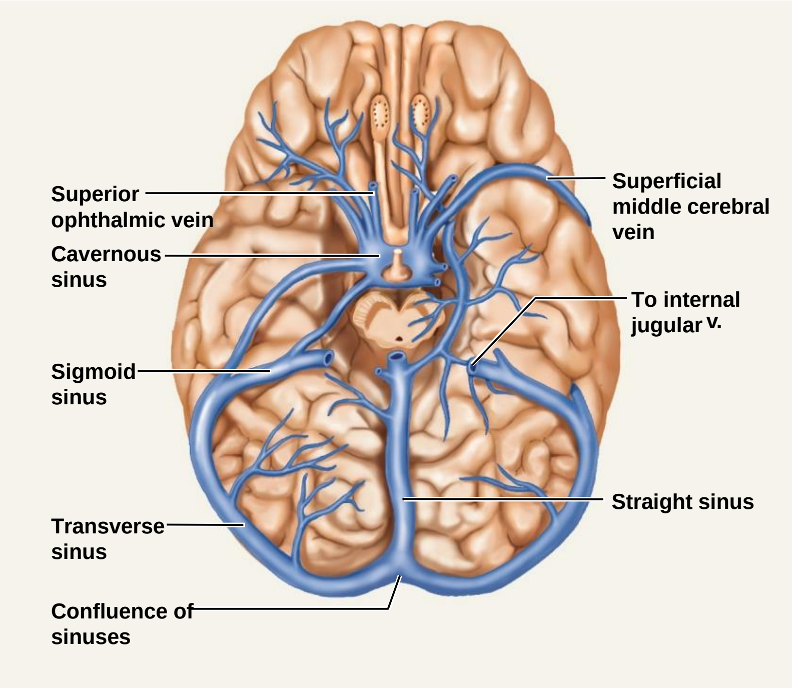
Figure 20.22

- **Deep veins run parallel to arteries while superficial veins have many anastomoses**

Veins of the Head and Neck



(a) Dural venous sinuses, medial view

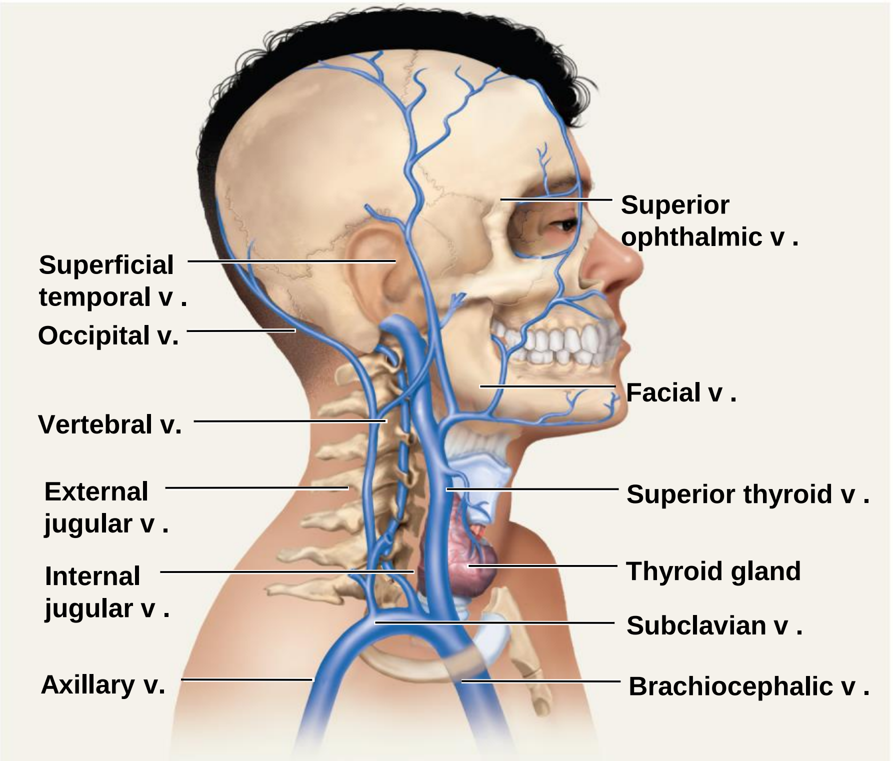


(b) Dural venous sinuses, inferior view

Figure 20.26a,b

- Large, thin-walled **dural sinuses** form between layers of dura mater
- **Drain blood from brain to internal jugular vein**

Veins of the Head and Neck

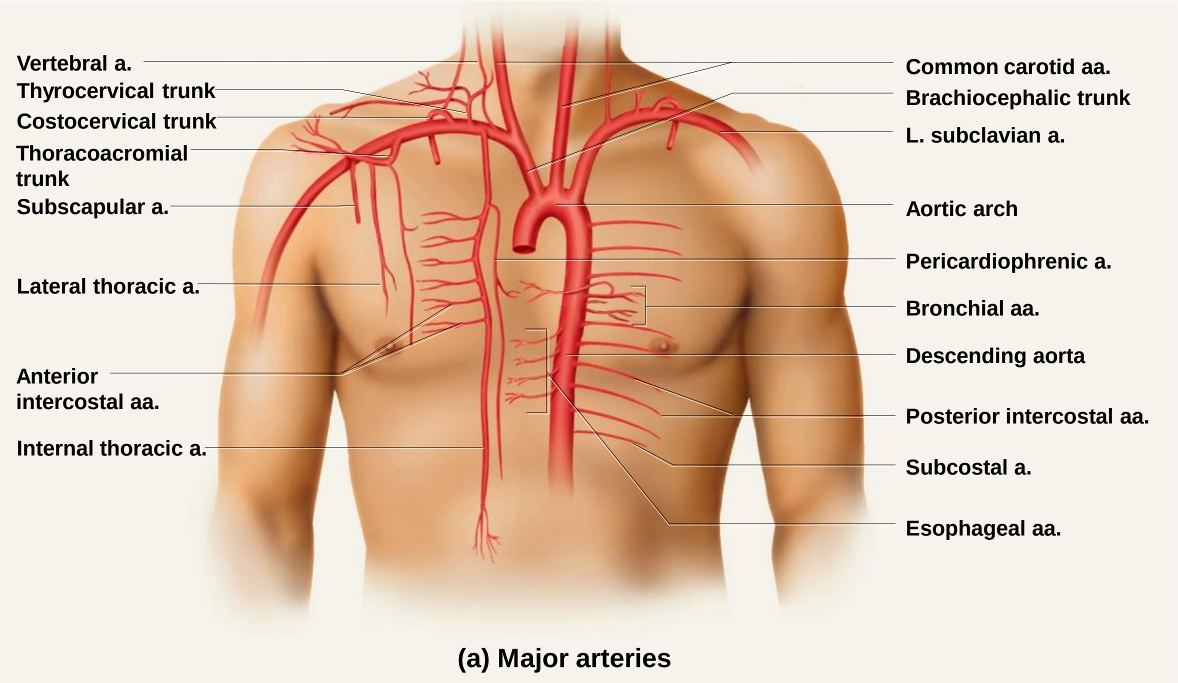


(c) Superficial veins of the head and neck

Figure 20.26c

- **Internal jugular vein** receives most of the blood from the brain
- Branches of **external jugular vein** drain the external structures of the head
- Upper limb is drained by **subclavian vein**

Arteries of the Thorax



(a) Major arteries

Figure 20.27a

- **Thoracic aorta supplies viscera and body wall**
  - Bronchial, esophageal, and mediastinal branches
  - Posterior intercostal and phrenic arteries
- **Internal thoracic, anterior intercostal, and pericardiophrenic arise from subclavian artery**

Arteries of the Abdominal and Pelvic Region

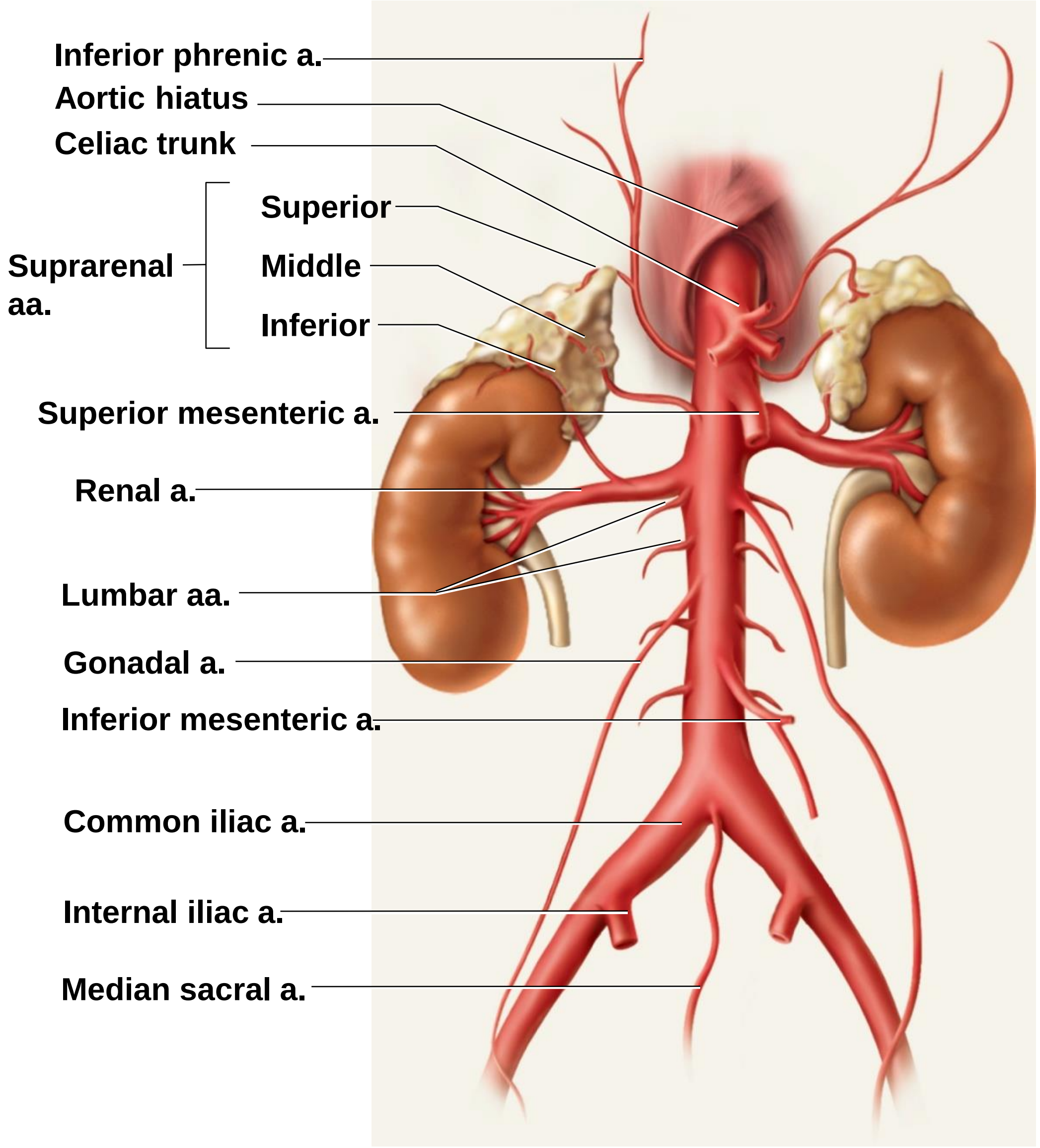
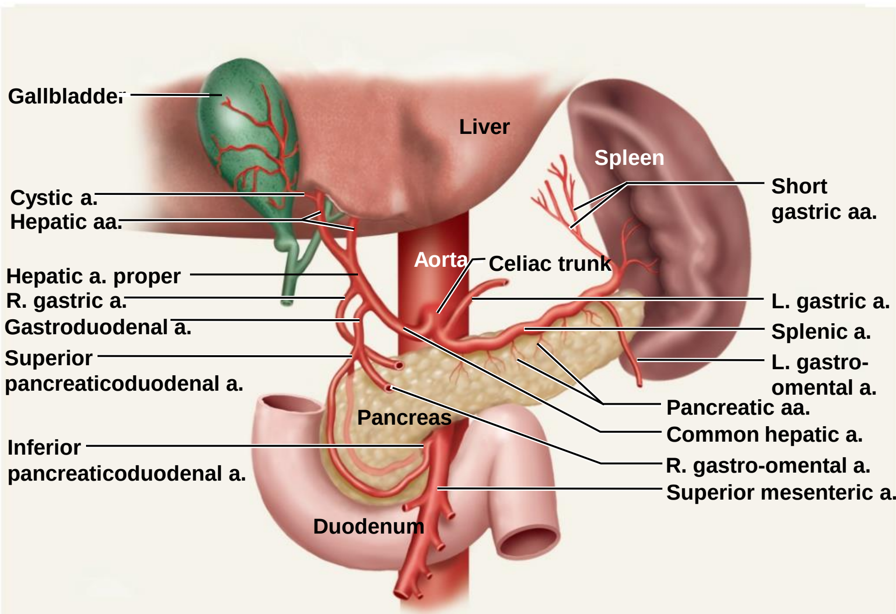
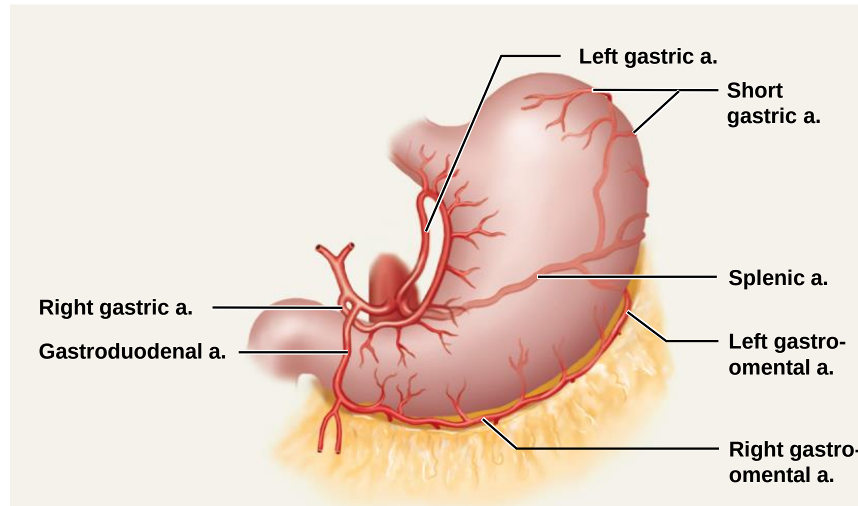


Figure 20.29

Arteries of the Abdominal and Pelvic Region



(a) Branches of the celiac trunk

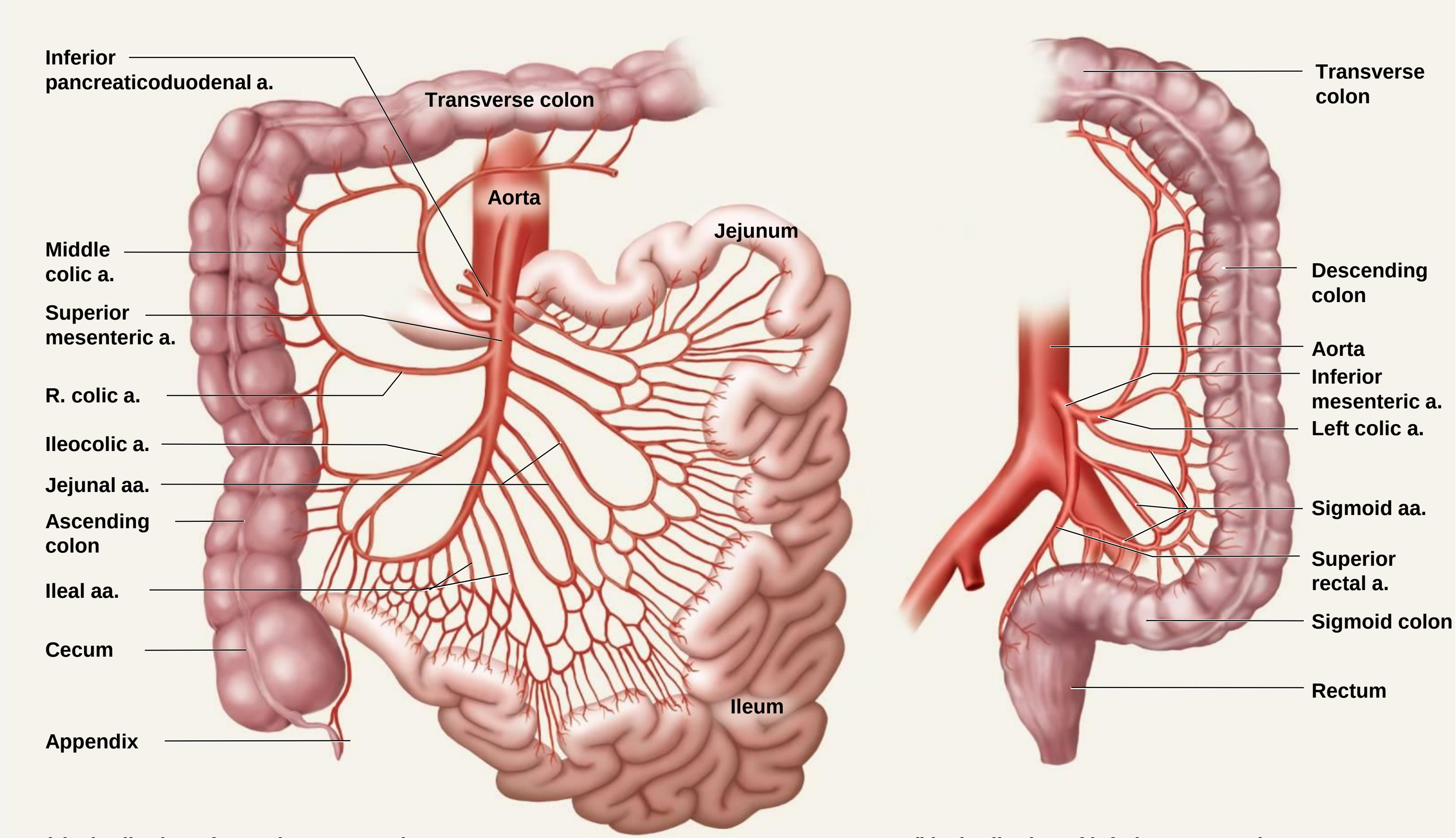


(b) Celiac circulation to the stomach

Figure 20.30a,b

- Branches of **celiac trunk** supply upper abdominal viscera—stomach, spleen, liver, and pancreas

Arteries of the Abdominal and Pelvic Region



(a) Distribution of superior mesenteric artery

(b) Distribution of inferior mesenteric artery

Figure 20.31a,b

Veins of the Abdominal and Pelvic Region

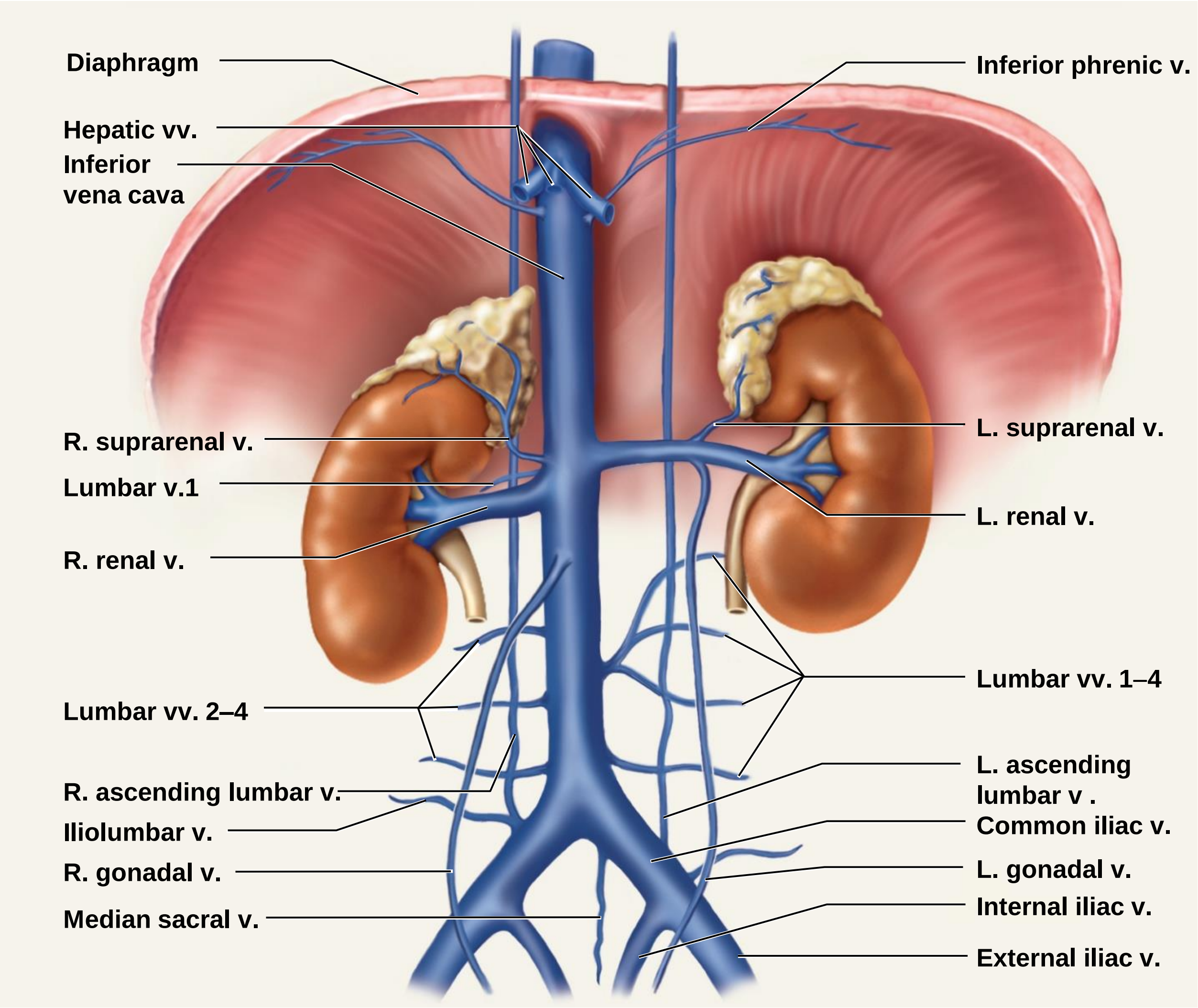


Figure 20.32

Veins of the Abdominal and Pelvic Region

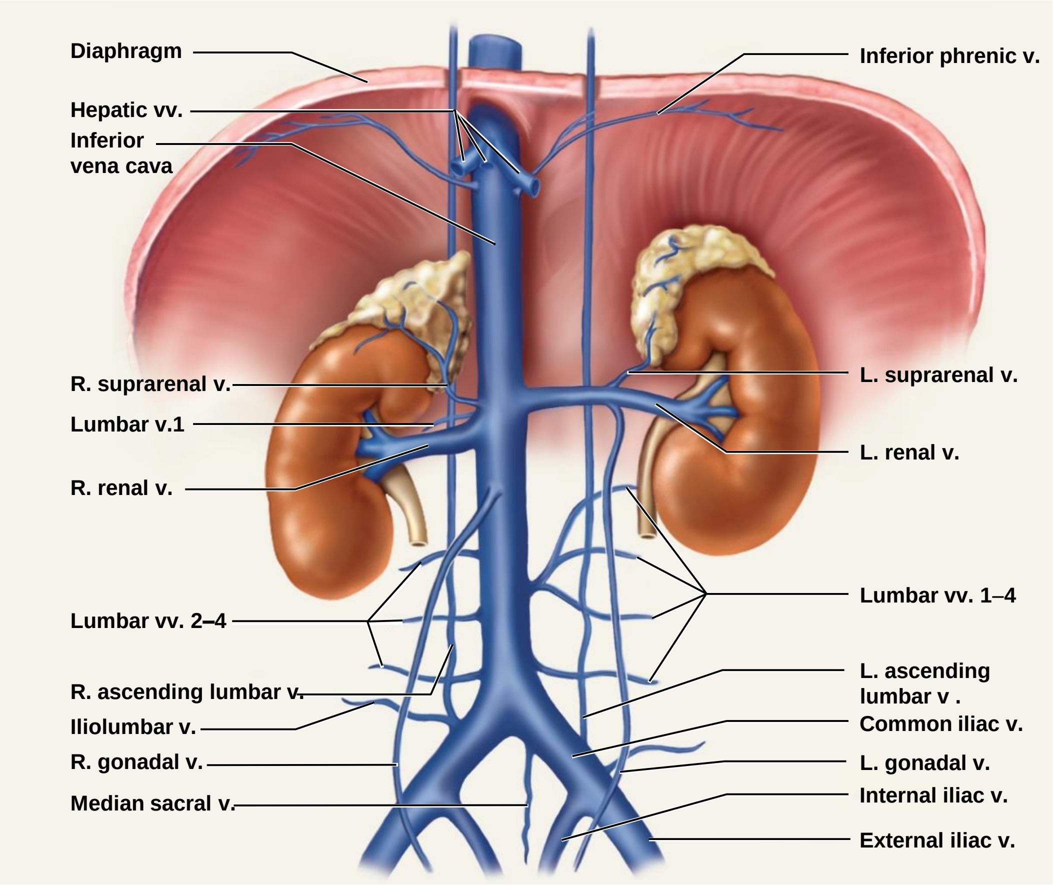


Figure 20.32

- **Hepatic portal system drains nutrient-rich blood from viscera (stomach, spleen, and intestines) to liver so that blood sugar levels are maintained**

Portal Hypertension and Ascites

- **Obstruction of hepatic circulation can cause blood pressure to back up in the hepatic portal system**
- **Schistosomiasis**—as liver venules are clogged with eggs of parasitic worms, inflammation results
- **Spleen enlarges**
- **High pressure in vessels of abdominal viscera cause fluid leakage**
- **Ascites**—distension of abdomen

Figure 20.33

Systemic Vessels of the Appendicular Region

- **Expected Learning Outcomes**
  - Identify the principal systemic arteries and veins of the limbs.
  - Trace the flow of blood from the heart to any region of the upper or lower limb and back to the heart.

Arteries of the Upper Limb

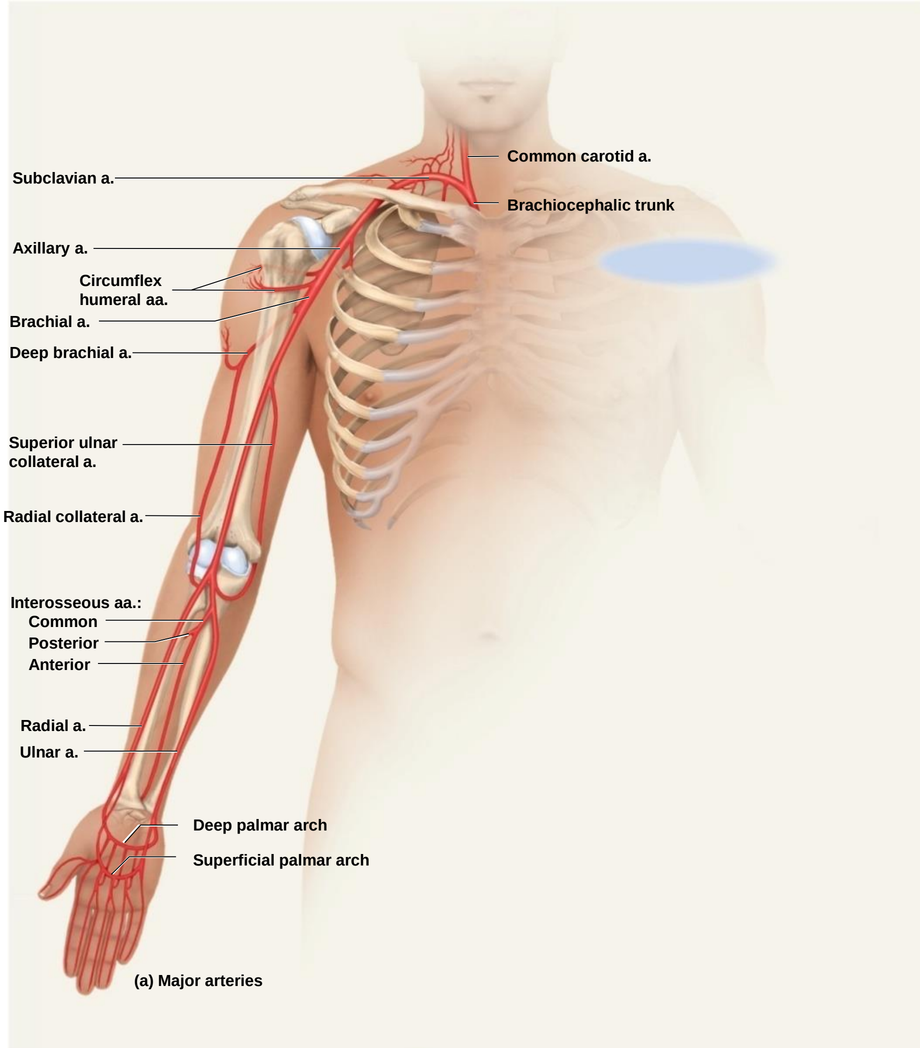
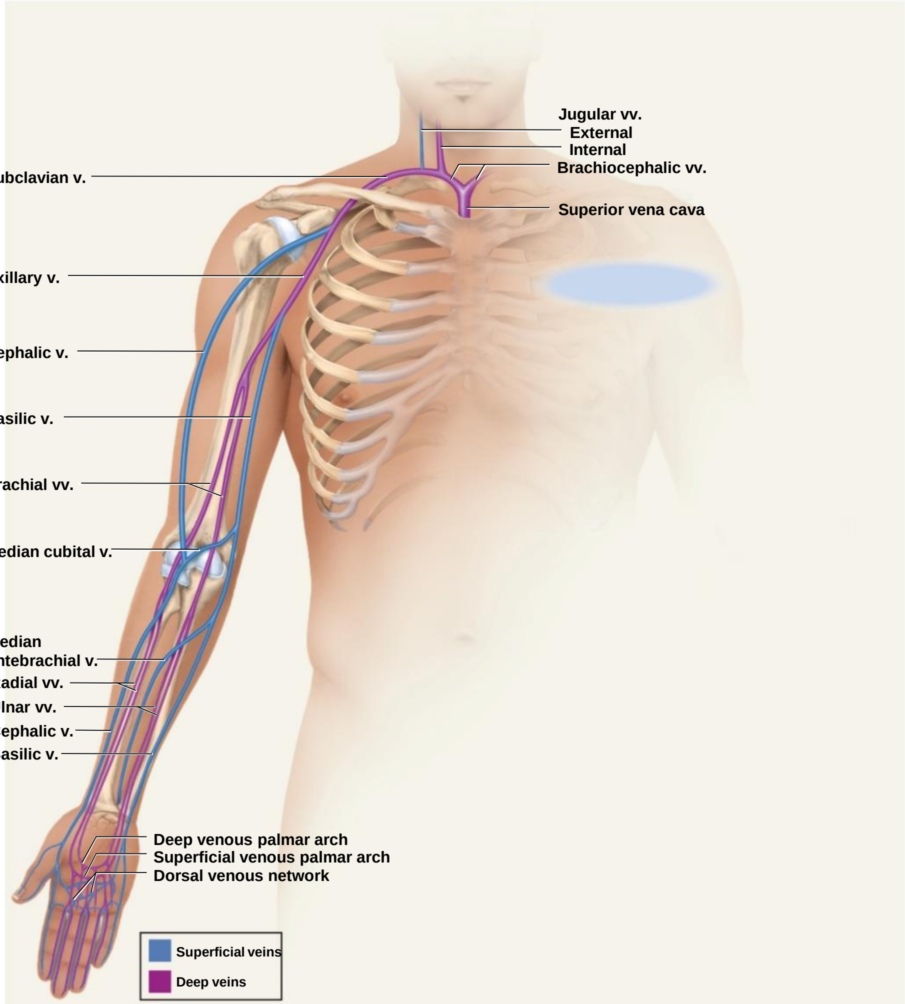


Figure 20.35a

- **Subclavian passes between clavicle and first rib**
- **Vessel changes names as it passes to different regions**
  - **Subclavian** to **axillary** to **brachial** to **radial** and **ulnar**
  - **Brachial** used for BP and **radial** artery for pulse

Veins of the Upper Limb



(a) Major veins

Figure 20.36a

Arteries of the Lower Limb

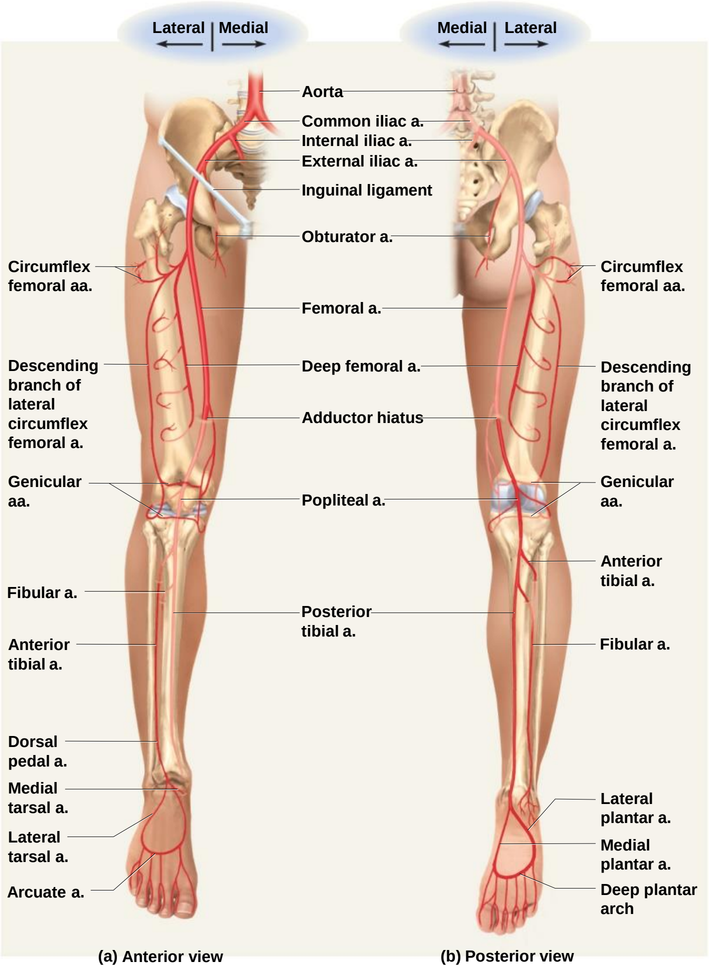


Figure 20.37a,b

- **Branches to the lower limb arise from external iliac branch of the common iliac artery**

Veins of the Lower Limb

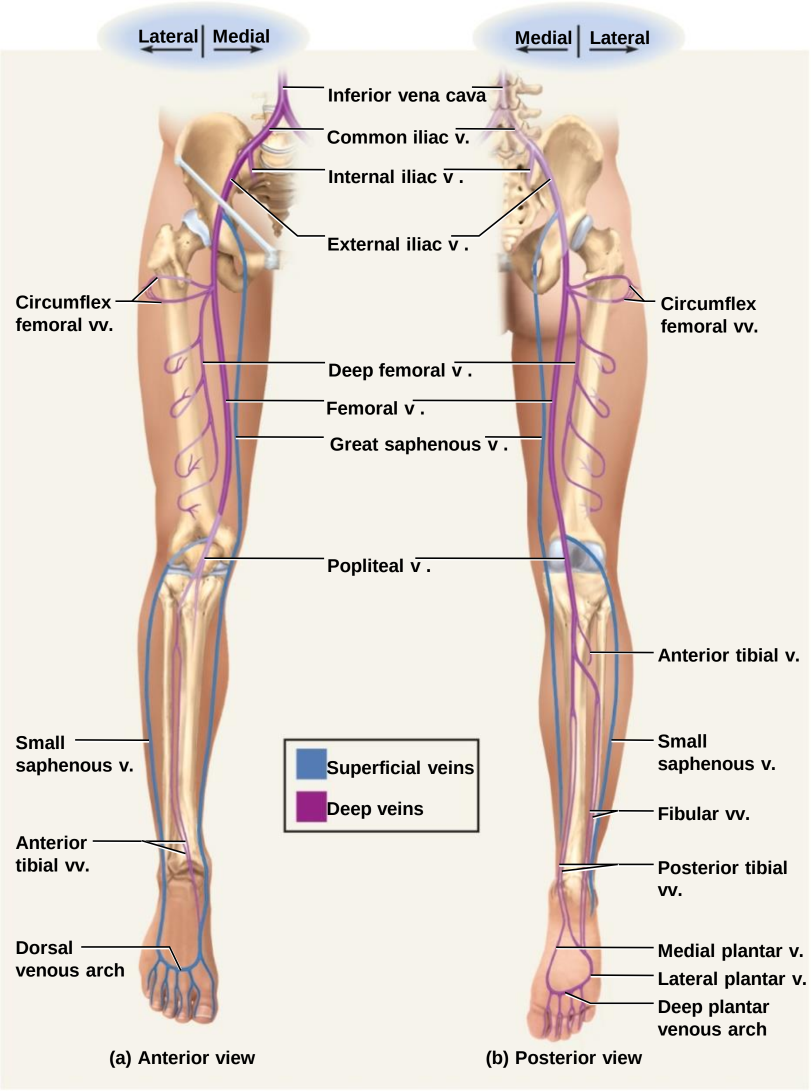


Figure 20.39a,b

Arterial Pressure Points

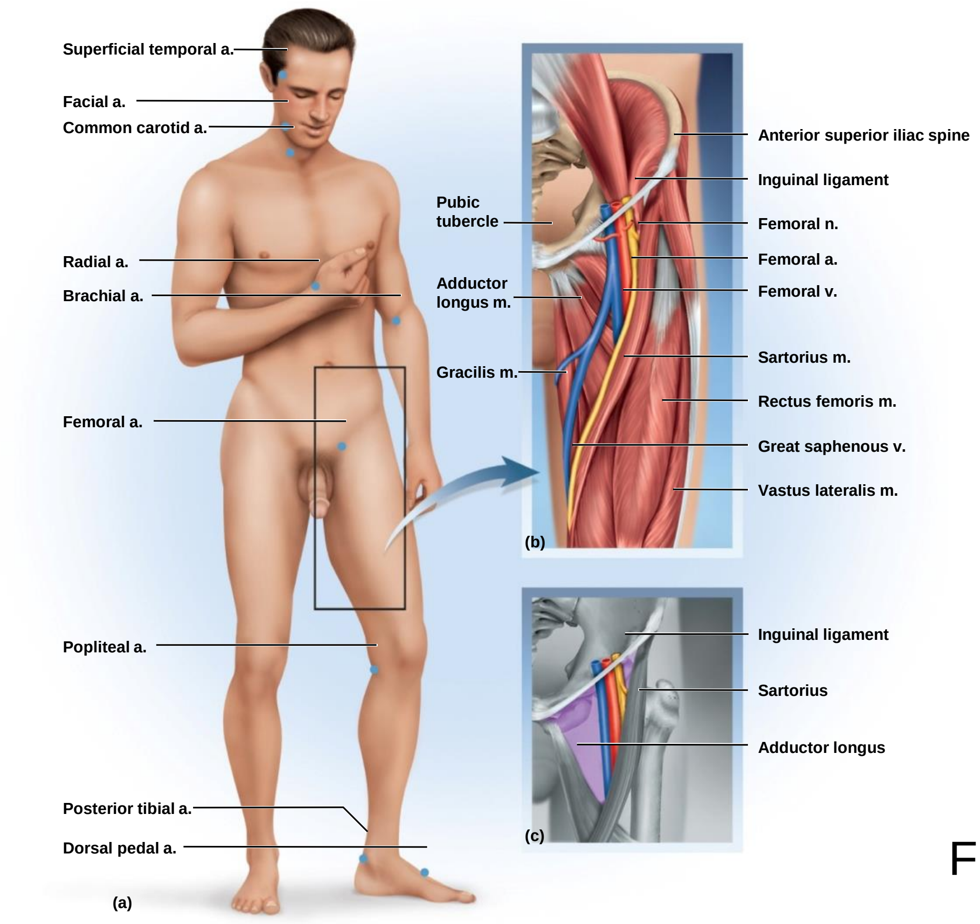


Figure 20.41a–c

- **Some major arteries close to surface allow for palpation of pulse and serve as pressure points to reduce arterial bleeding**

Hypertension—The “Silent Killer”

- **Hypertension**—most common cardiovascular disease affecting about 30% of Americans over 50
- **“The silent killer”**
  - Major cause of heart failure, stroke, and kidney failure
    - Damages heart by increasing afterload
      - Myocardium enlarges until overstretched and inefficient
    - Renal arterioles thicken in response to stress
      - Drop in renal BP leads to salt retention (aldosterone) and worsens the overall hypertension

Hypertension—The "Silent Killer"

- **Primary hypertension**
  - Obesity, sedentary behavior, diet, nicotine
  - 90% of cases
- **Secondary hypertension**—secondary to other disease
  - Kidney disease, atherosclerosis, hyperthyroidism, Cushing syndrome
  - 10% of cases