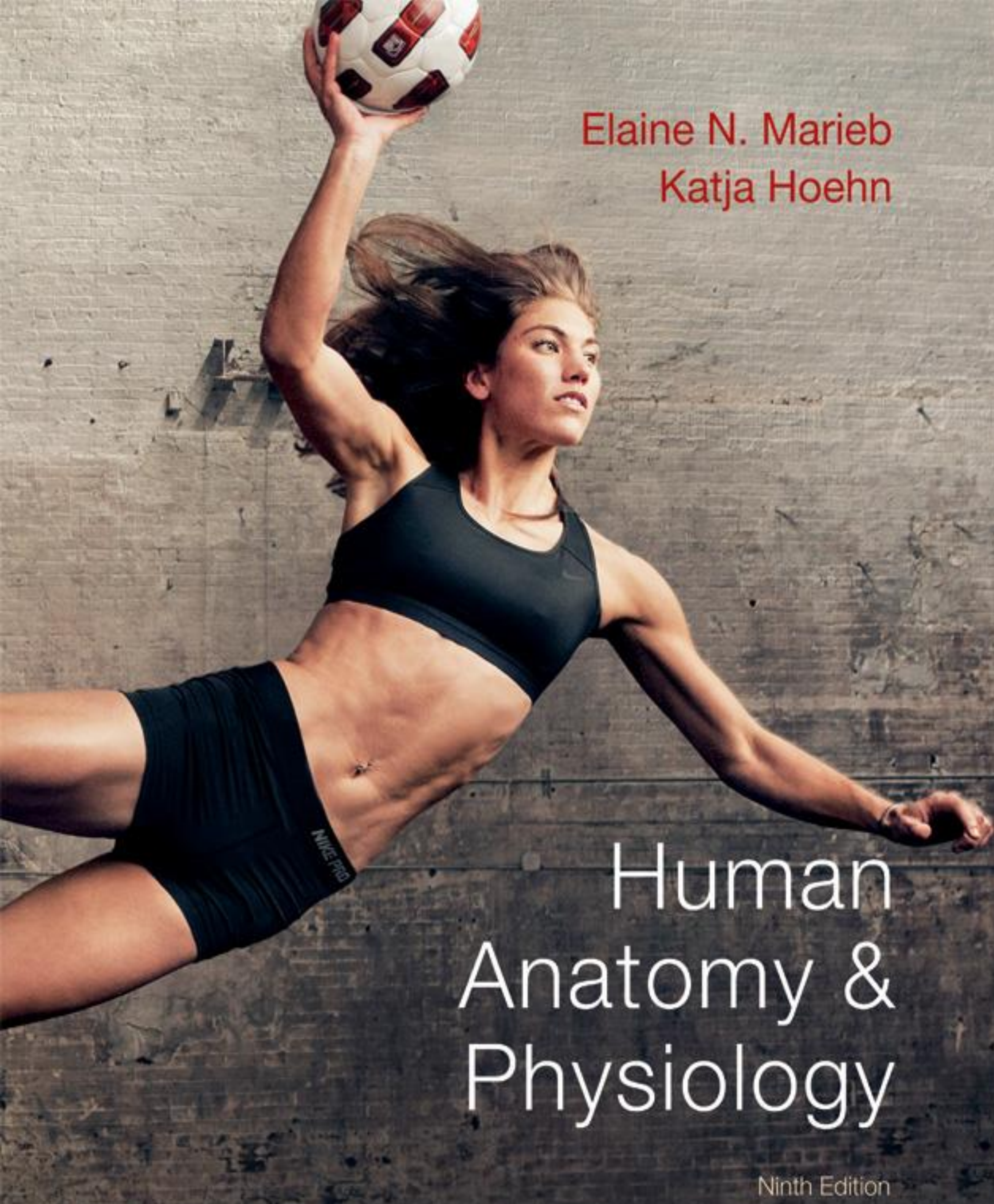

PowerPoint® Lecture Slides
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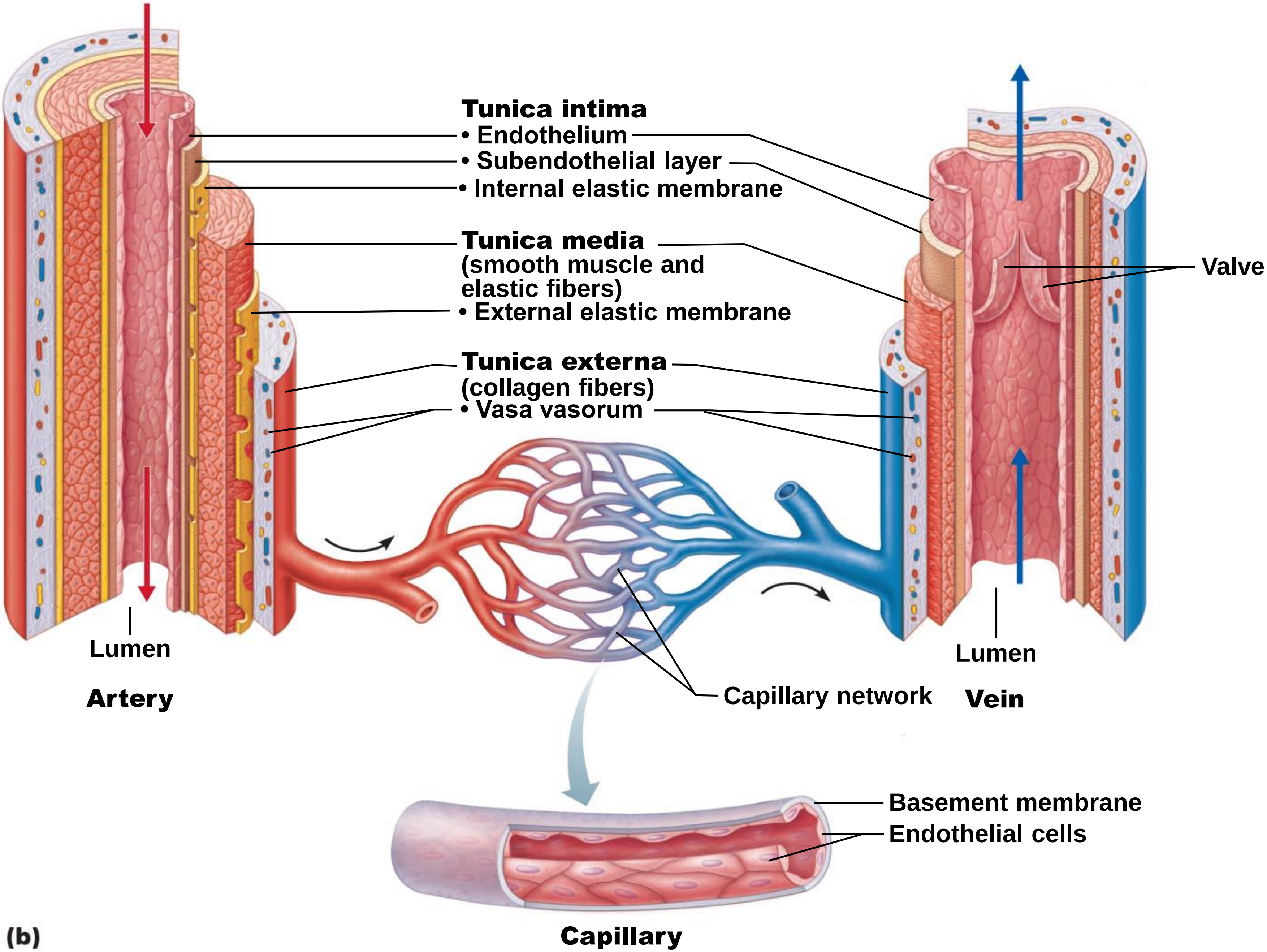
CHAPTER 19

The Cardiovascular System: Blood Vessels: Part A

Structure of Blood Vessel Walls

- Lumen
  - Central blood-containing space
- Three wall layers in arteries and veins
  - **Tunica intima, tunica media, and tunica externa**
- Capillaries
  - **Endothelium** with sparse basal lamina

Figure 19.1b Generalized structure of arteries, veins, and capillaries.



Tunics

- Tunica intima
  - Endothelium lines lumen of all vessels
    - Continuous with endocardium
    - Slick surface reduces friction
  - **Subendothelial layer** in vessels larger than 1 mm; connective tissue basement membrane

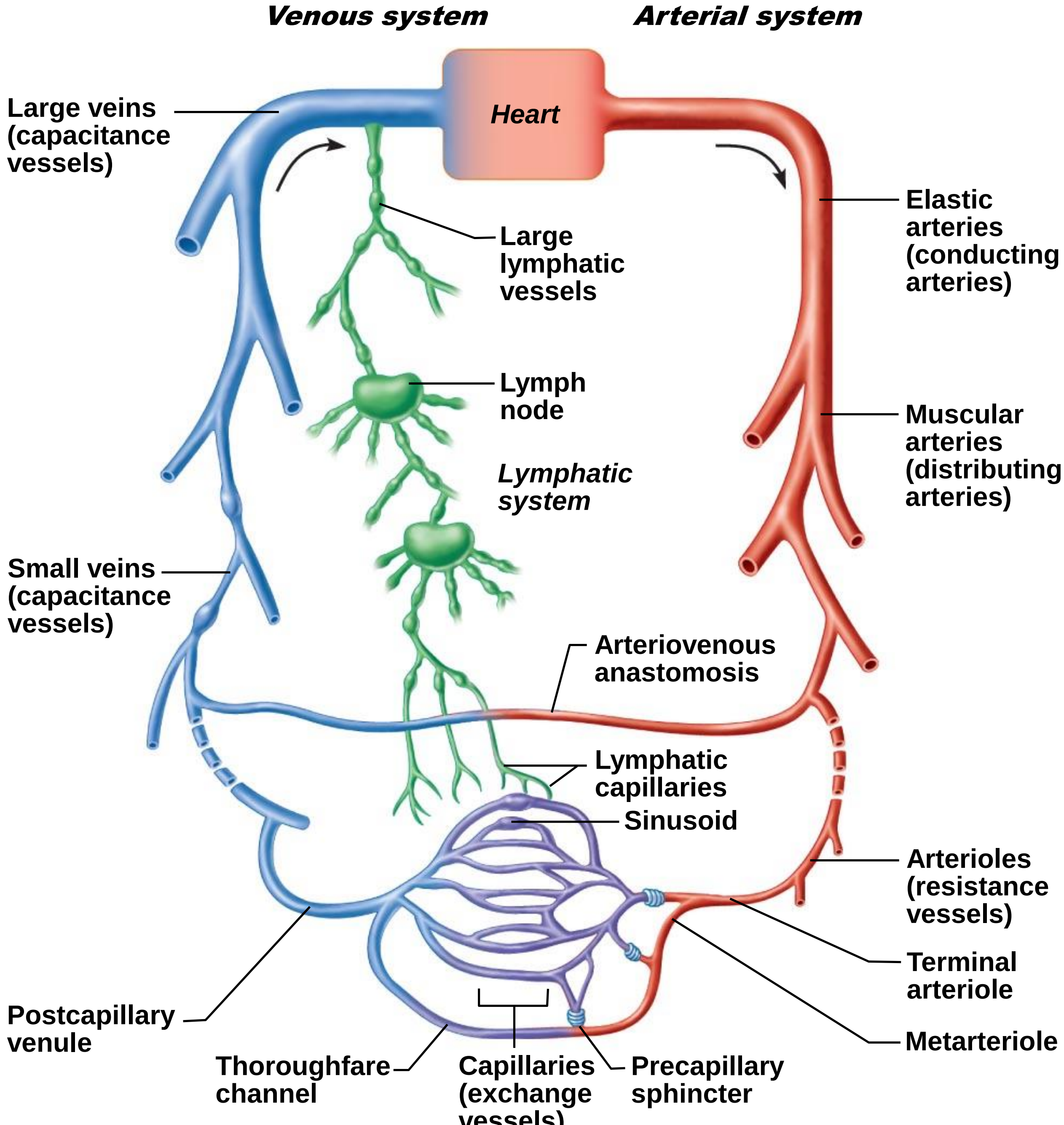
Tunics

- Tunica media
  - Smooth muscle and sheets of elastin
  - Sympathetic vasomotor nerve fibers control **vasoconstriction** and **vasodilation** of vessels
    - Influence blood flow and blood pressure

Tunics

- Tunica externa (tunica adventitia)
  - Collagen fibers protect and reinforce; anchor to surrounding structures
  - Contains nerve fibers, lymphatic vessels
  - **Vasa vasorum** of larger vessels nourishes external layer

Figure 19.2 The relationship of blood vessels to each other and to lymphatic vessels.



Arterial System: Elastic Arteries

- Large thick-walled arteries with elastin in all three tunics
- Aorta and its major branches
- Large lumen offers low resistance
- Inactive in vasoconstriction
- Act as pressure reservoirs—expand and recoil as blood ejected from heart
  - Smooth pressure downstream

Arterial System: Muscular Arteries

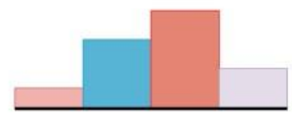
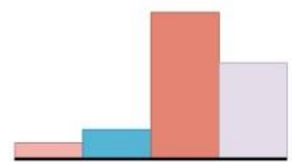
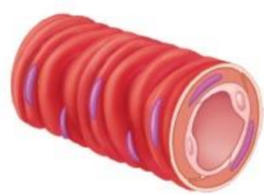
- Distal to elastic arteries
  - Deliver blood to body organs
- Thick tunica media with more smooth muscle
- Active in vasoconstriction

Arterial System: Arterioles

- Smallest arteries
- Lead to capillary beds
- Control flow into capillary beds via vasodilation and vasoconstriction

Table 19.1 Summary of Blood Vessel Anatomy (1 of 2)

Table 19.1 Summary of Blood Vessel Anatomy

VESSEL TYPE/ ILLUSTRATION*	AVERAGE LUMEN DIAMETER (D) AND WALL THICKNESS (T)	RELATIVE TISSUE MAKEUP (Endothelium, Elastic Tissues, Smooth Muscles, Fibrous (Collagenous) Tissues)
 Elastic artery	D: 1.5 cm T: 1.0 mm	
 Muscular artery	D: 6.0 mm T: 1.0 mm	
 Arteriole	D: 37.0 µm T: 6.0 µm	

Capillaries

- Microscopic blood vessels
- Walls of thin tunica intima
  - In smallest one cell forms entire circumference
- **Pericytes** help stabilize their walls and control permeability
- Diameter allows only single RBC to pass at a time

Capillaries

- In all tissues except for cartilage, epithelia, cornea and lens of eye
- Provide direct access to almost every cell
- Functions
  - Exchange of gases, nutrients, wastes, hormones, etc., between blood and interstitial fluid

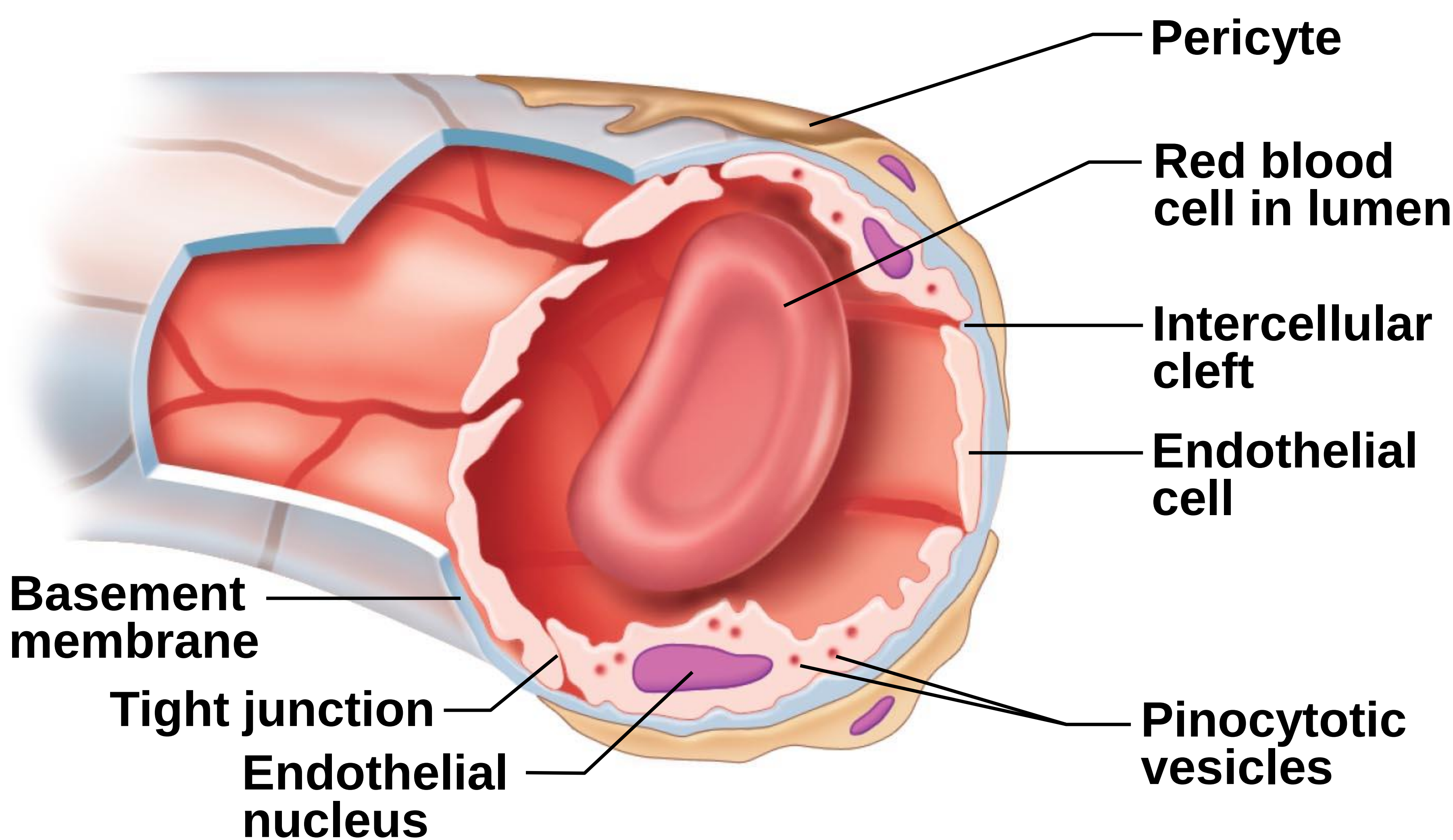
Capillaries

- Three structural types
  1. Continuous capillaries
  2. Fenestrated capillaries
  3. Sinusoid capillaries (sinusoids)

Continuous Capillaries

- Abundant in skin and muscles
  - Tight junctions connect endothelial cells
  - Intercellular clefts allow passage of fluids and small solutes
- Continuous capillaries of brain unique
  - Tight junctions complete, forming blood brain barrier

Figure 19.3a Capillary structure.

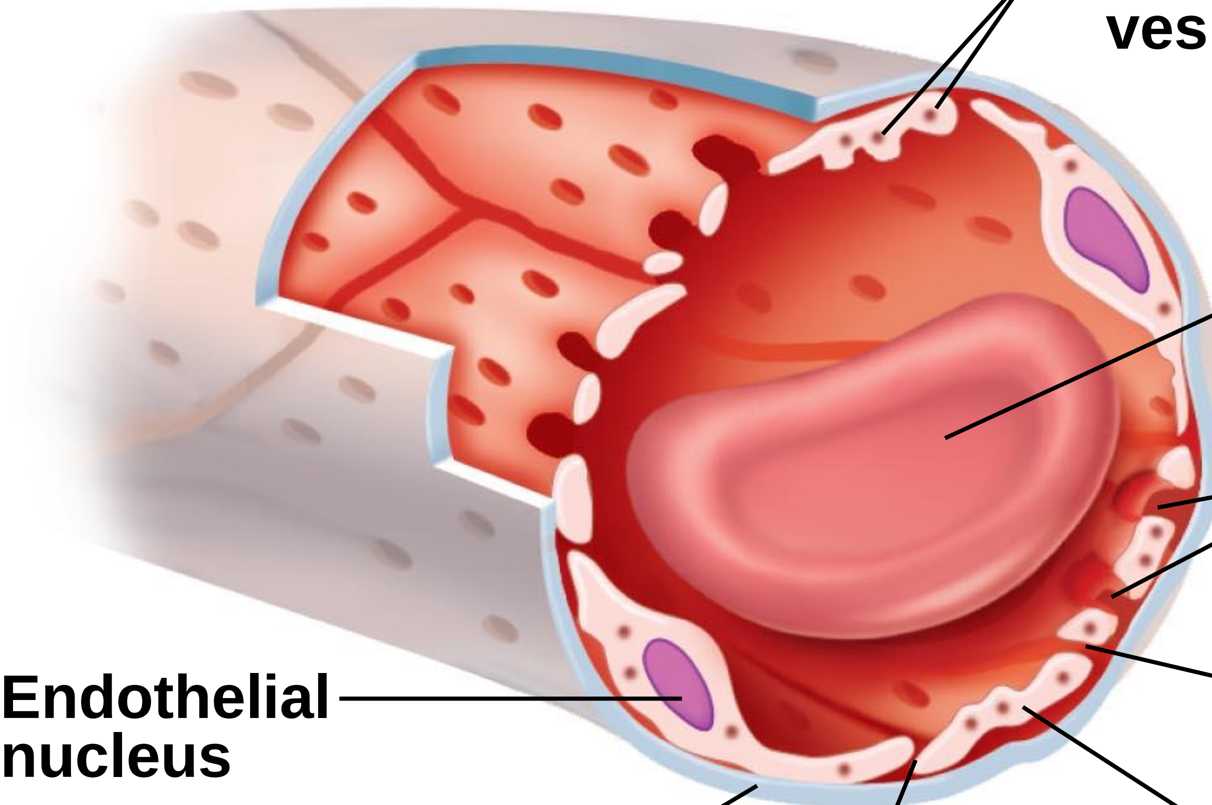


(a) Continuous capillary. Least permeable, and most common (e.g., skin, muscle).

Fenestrated Capillaries

- Some endothelial cells contain pores (fenestrations)
- More permeable than continuous capillaries
- Function in absorption or filtrate formation (small intestines, endocrine glands, and kidneys)

Figure 19.3b Capillary structure.

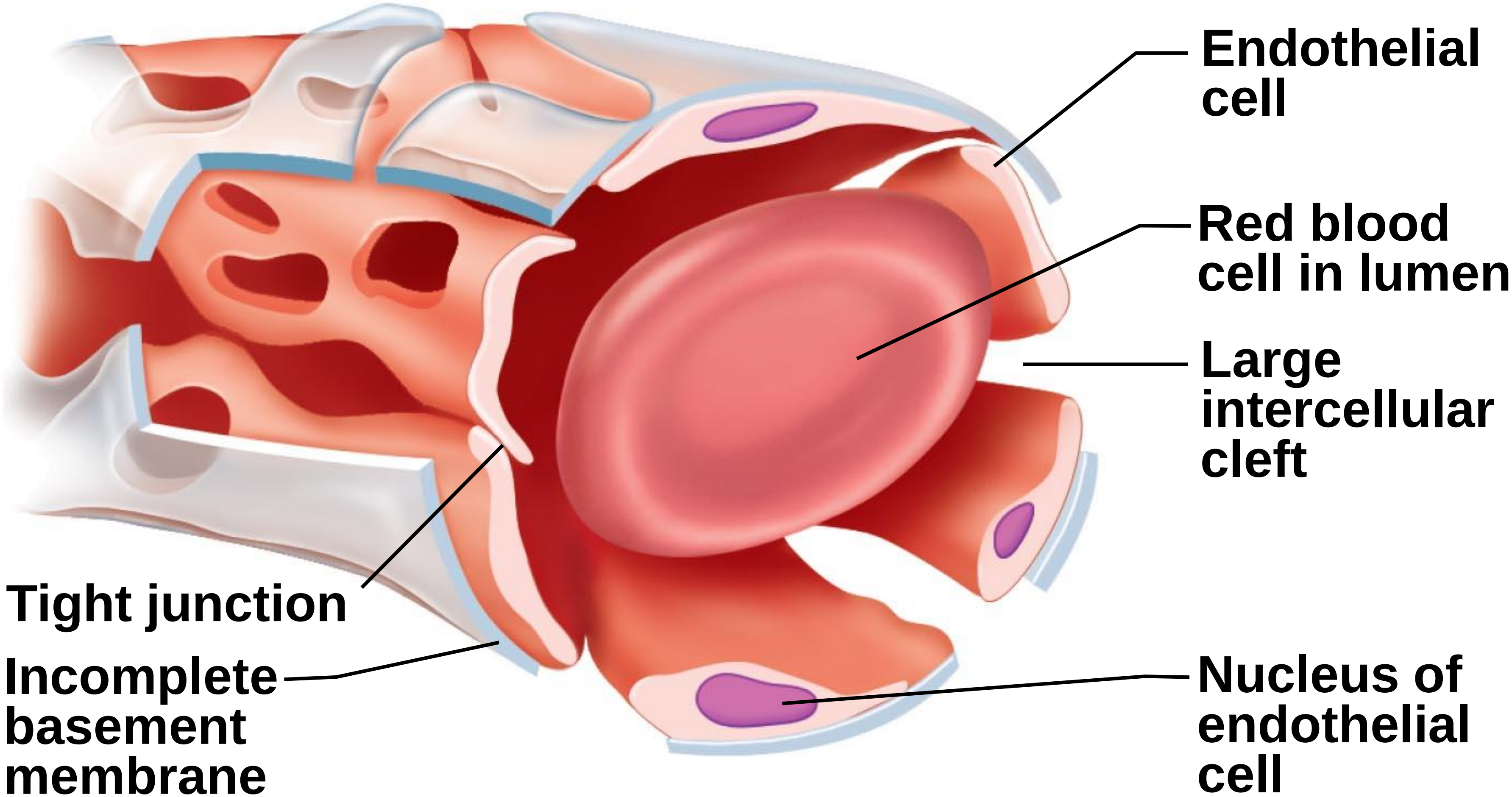


(b) Fenestrated capillary. Large fenestrations (pores) increase permeability. Occurs in areas of active absorption or filtration (e.g., kidney, small intestine).

Sinusoid Capillaries

- Fewer tight junctions; usually fenestrated; larger intercellular clefts; large lumens
- Blood flow sluggish – allows modification
  - Large molecules and blood cells pass between blood and surrounding tissues
- Found only in the liver, bone marrow, spleen, adrenal medulla
- Macrophages in lining to destroy bacteria

Figure 19.3c Capillary structure.



(c) Sinusoid capillary. Most permeable. Occurs in special locations (e.g., liver, bone marrow, spleen).

Capillary Beds

- **Microcirculation**
  - Interwoven networks of capillaries between arterioles and venules
  - **Terminal arteriole → metarteriole**
  - Metarteriole continuous with **thoroughfare channel** (intermediate between capillary and venule)
  - Thoroughfare channel → **postcapillary venule** that drains bed

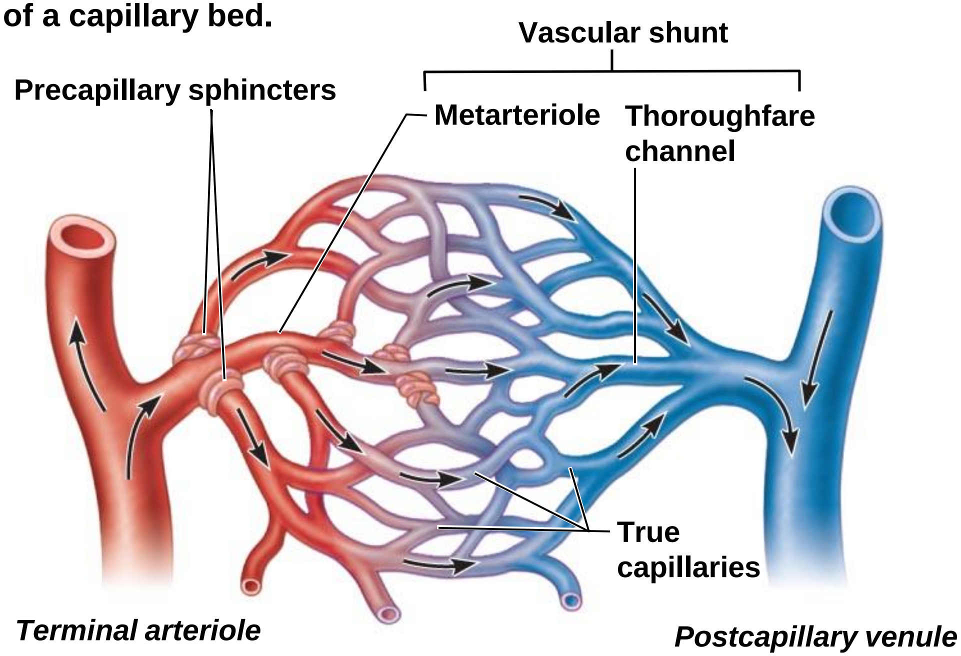
Capillary Beds: Two Types of Vessels

- **Vascular shunt** (metarteriole—thoroughfare channel)
  - Directly connects terminal arteriole and postcapillary venule
- **True capillaries**
  - 10 to 100 exchange vessels per capillary bed
  - Branch off metarteriole or terminal arteriole

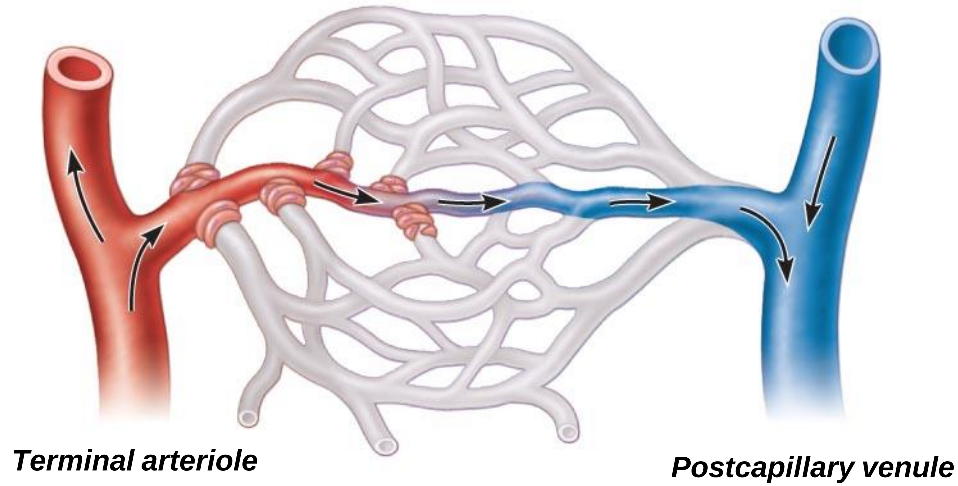
Blood Flow Through Capillary Beds

- True capillaries normally branch from metarteriole and return to thoroughfare channel
- **Precapillary sphincters** regulate blood flow into true capillaries
  - Blood may go into true capillaries or to shunt
- Regulated by local chemical conditions and vasomotor nerves

Figure 19.4 Anatomy of a capillary bed.



(a) Sphincters open—blood flows through true capillaries.

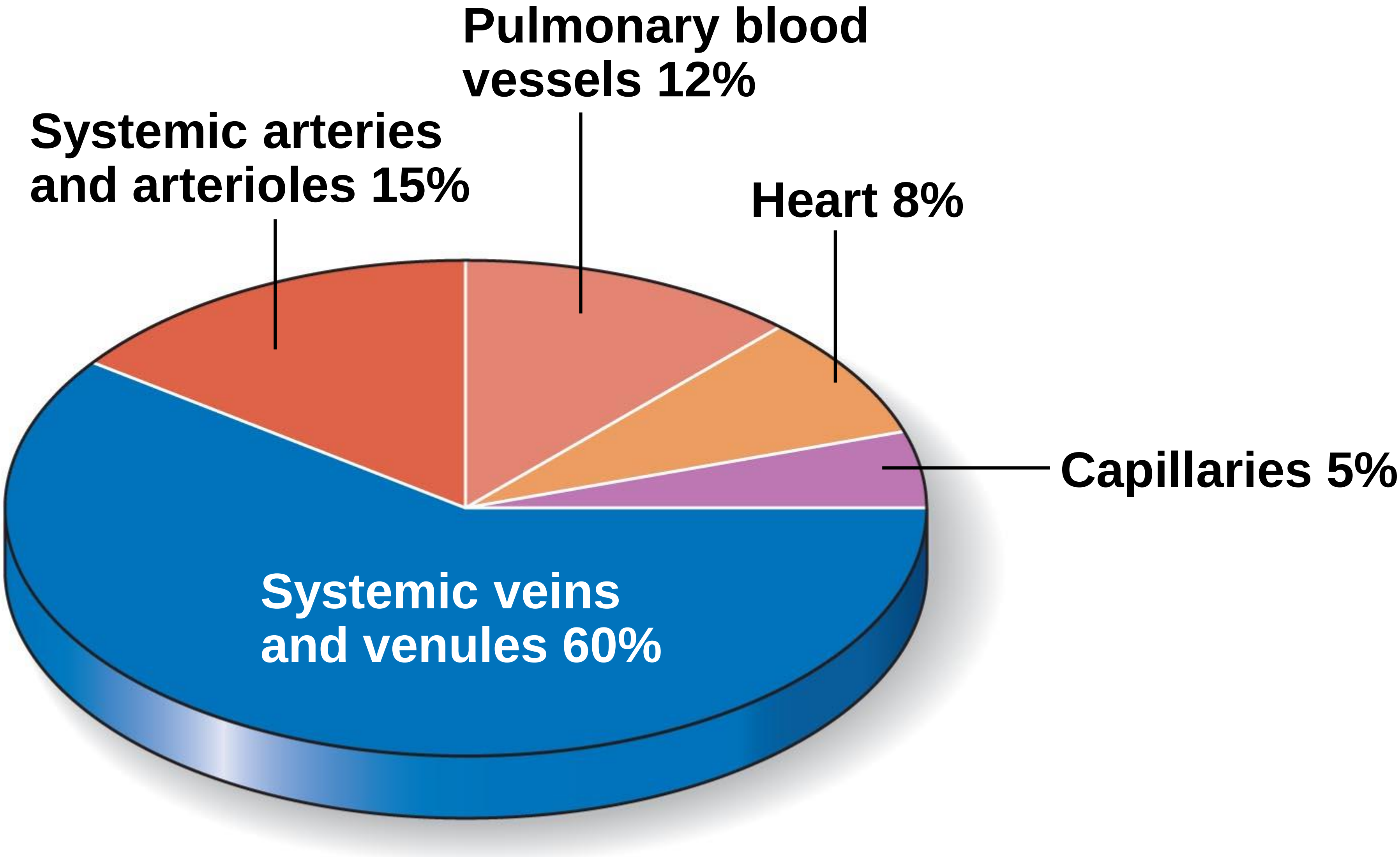


(b) Sphincters closed—blood flows through metarteriole – thoroughfare channel and bypasses true capillaries.

Venous System: Venules

- Formed when capillary beds unite
  - Smallest postcapillary venules
  - Very porous; allow fluids and WBCs into tissues
  - Consist of endothelium and a few pericytes
- Larger venules have one or two layers of smooth muscle cells

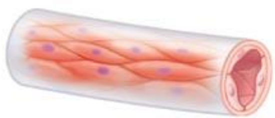
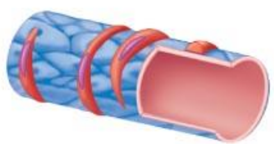
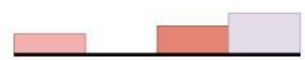
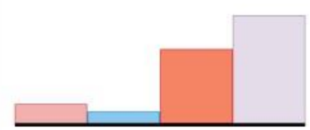
Figure 19.5 Relative proportion of blood volume throughout the cardiovascular system.



Veins

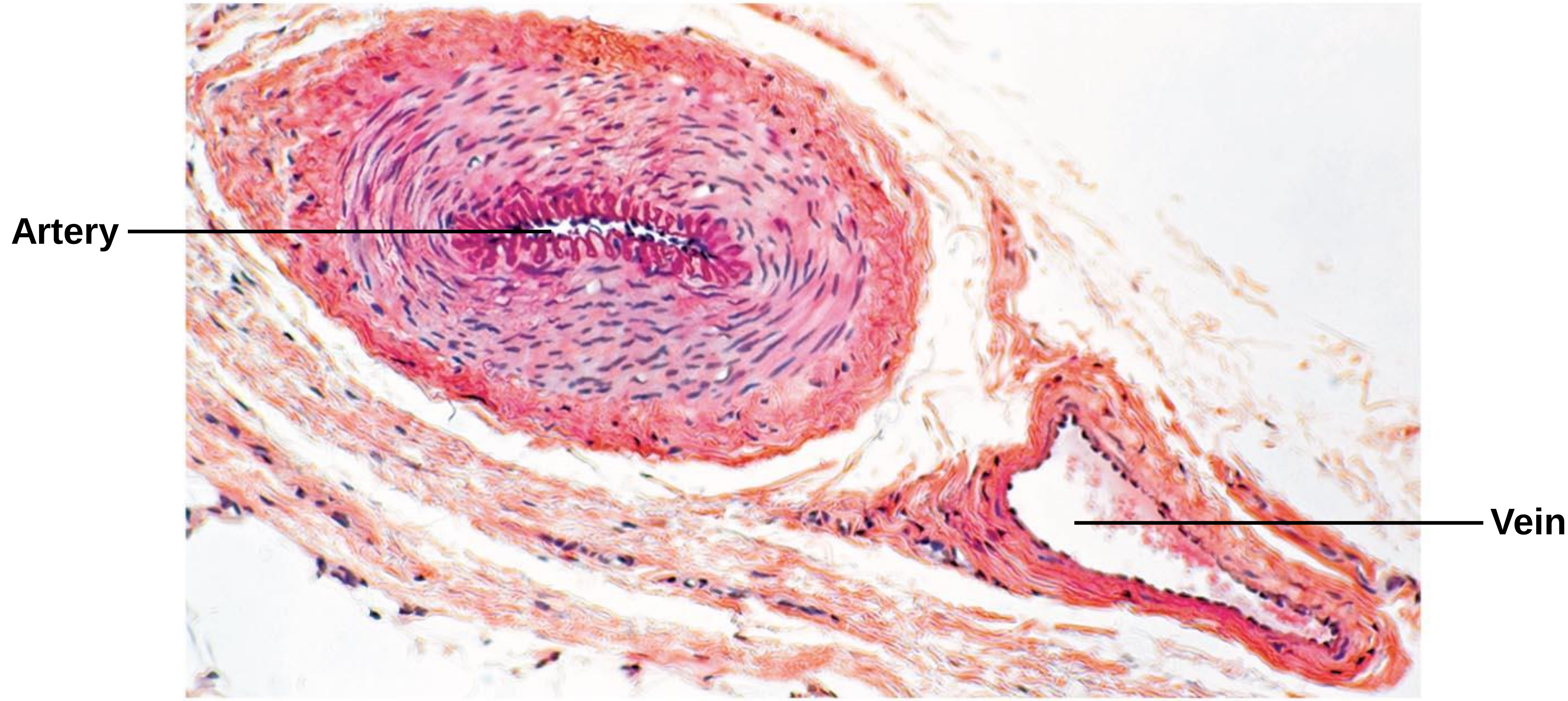
- Adaptations ensure return of blood to heart despite low pressure
  - Large-diameter lumens offer little resistance
  - **Venous valves** prevent backflow of blood
    - Most abundant in veins of limbs
  - **Venous sinuses**: flattened veins with extremely thin walls (e.g., coronary sinus of the heart and dural sinuses of the brain)

Table 19.1 Summary of Blood Vessel Anatomy *(continued)*

VESSEL TYPE/ ILLUSTRATION*	AVERAGE LUMEN DIAMETER (D) AND WALL THICKNESS (T)	*RELATIVE TISSUE MAKEUP*			
		Endothelium	*Elastic Tissues*	*Smooth Muscles*	*Fibrous (Collagenous) Tissues*
 Capillary	D: 9.0 µm T: 0.5 µm				
 Venule	D: 20.0 µm T: 1.0 µm				
 Vein	D: 5.0 mm T: 0.5 mm				

*Size relationships are not proportional. Smaller vessels are drawn relatively larger so detail can be seen. See column 2 for actual dimensions.

Figure 19.1a Generalized structure of arteries, veins, and capillaries.



(a)

Vascular Anastomoses

- Interconnections of blood vessels
- **Arterial anastomoses** provide alternate pathways (**collateral channels**) to given body region
  - Common at joints, in abdominal organs, brain, and heart; none in retina, kidneys, spleen
- Vascular shunts of capillaries are examples of arteriovenous anastomoses
- **Venous anastomoses** are common

Physiology of Circulation: Definition of Terms

- **Blood flow**
  - Volume of blood flowing through vessel, organ, or entire circulation in given period
    - Measured as ml/min
    - Equivalent to cardiac output (CO) for entire vascular system
    - Relatively constant when at rest
    - Varies widely through individual organs, based on needs

Physiology of Circulation: Definition of Terms

- **Blood pressure** (BP)
  - Force per unit area exerted on wall of blood vessel by blood
    - Expressed in mm Hg
    - Measured as systemic arterial BP in large arteries near heart
  - Pressure gradient provides driving force that keeps blood moving from higher to lower pressure areas

Physiology of Circulation: Definition of Terms

- **Resistance** (peripheral resistance)
  - Opposition to flow
  - Measure of amount of friction blood encounters with vessel walls, generally in peripheral (systemic) circulation
- Three important sources of resistance
  - Blood viscosity
  - Total blood vessel length
  - Blood vessel diameter

Resistance

- Factors that remain relatively constant:
  - Blood viscosity
    - The "stickiness" of blood due to formed elements and plasma proteins
    - Increased viscosity = increased resistance
  - Blood vessel length
    - Longer vessel = greater resistance encountered

Resistance

- Blood vessel diameter
  - Greatest influence on resistance
- Frequent changes alter peripheral resistance
- Varies inversely with fourth power of vessel radius
  - E.g., if radius is doubled, the resistance is 1/16 as much
  - E.g., Vasoconstriction → increased resistance

Resistance

- Small-diameter arterioles major determinants of peripheral resistance
- Abrupt changes in diameter or fatty plaques from atherosclerosis dramatically increase resistance
  - Disrupt laminar flow and cause turbulent flow
    - Irregular fluid motion → increased resistance

Relationship Between Blood Flow, Blood Pressure, and Resistance

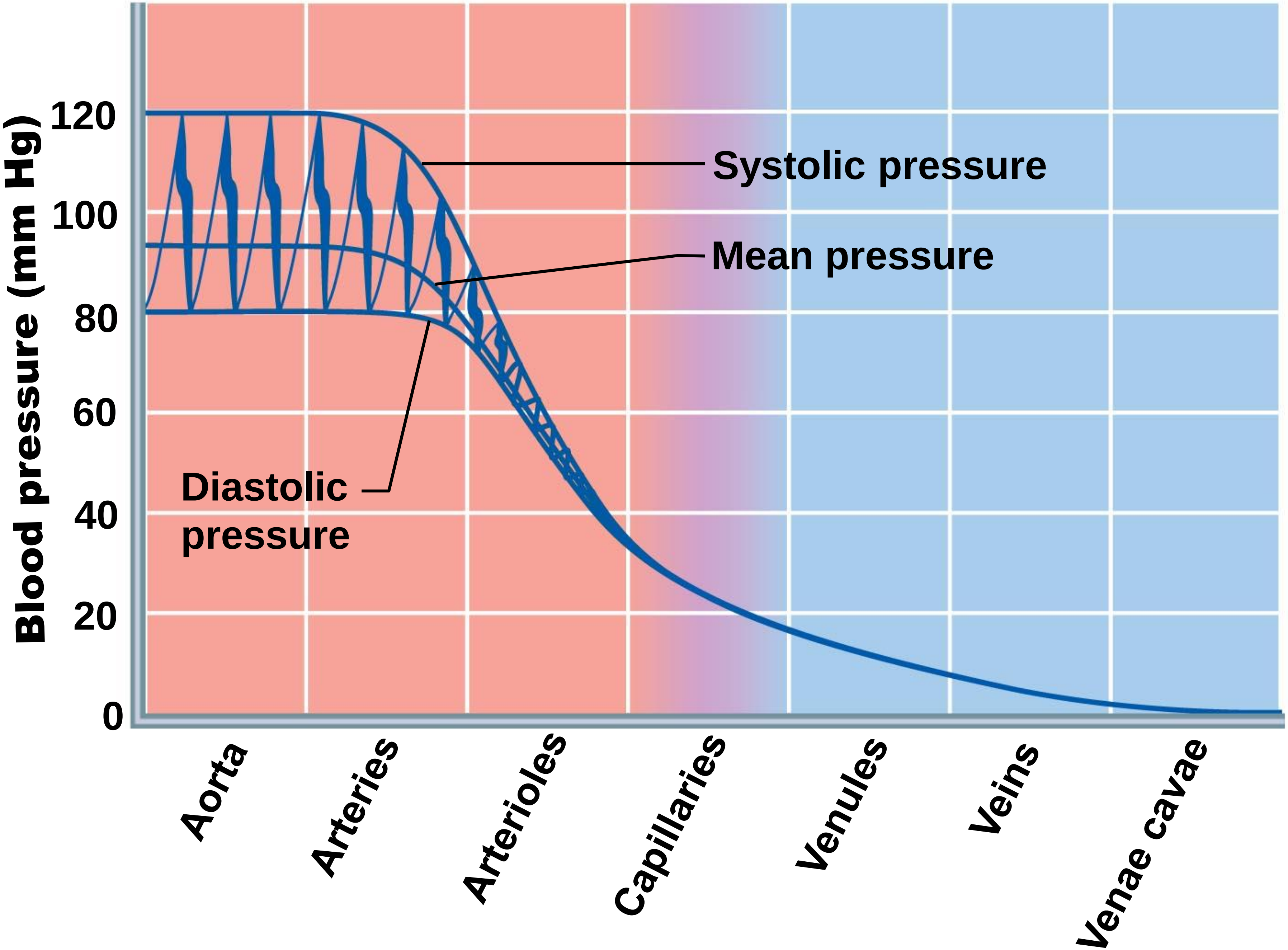
- Blood flow (F) directly proportional to blood pressure gradient (ΔP)
  - If ΔP increases, blood flow speeds up
- Blood flow inversely proportional to peripheral resistance (R)
  - If R increases, blood flow decreases:

    $F = \Delta P/R$
- R more important in influencing local blood flow because easily changed by altering blood vessel diameter

Systemic Blood Pressure

- Pumping action of heart generates blood flow
- Pressure results when flow is opposed by resistance
- Systemic pressure
  - Highest in aorta
  - Declines throughout pathway
  - 0 mm Hg in right atrium
- Steepest drop occurs in arterioles

Figure 19.6 Blood pressure in various blood vessels of the systemic circulation.



Arterial Blood Pressure

- Reflects two factors of arteries close to heart
  - Elasticity (compliance or distensibility)
  - Volume of blood forced into them at any time
- Blood pressure near heart is **pulsatile**

Arterial Blood Pressure

- **Systolic pressure**: pressure exerted in aorta during ventricular contraction
  – Averages 120 mm Hg in normal adult
- **Diastolic pressure**: lowest level of aortic pressure
- **Pulse pressure** = difference between systolic and diastolic pressure
  – Throbbing of arteries (pulse)

Arterial Blood Pressure

- Mean arterial pressure (MAP): pressure that propels blood to tissues
- MAP = diastolic pressure + 1/3 pulse pressure
- Pulse pressure and MAP both decline with increasing distance from heart
- Ex. BP = 120/80; MAP = 93 mm Hg

Capillary Blood Pressure

- Ranges from 17 to 35 mm Hg
- Low capillary pressure is desirable
  - High BP would rupture fragile, thin-walled capillaries
  - Most very permeable, so low pressure forces filtrate into interstitial spaces

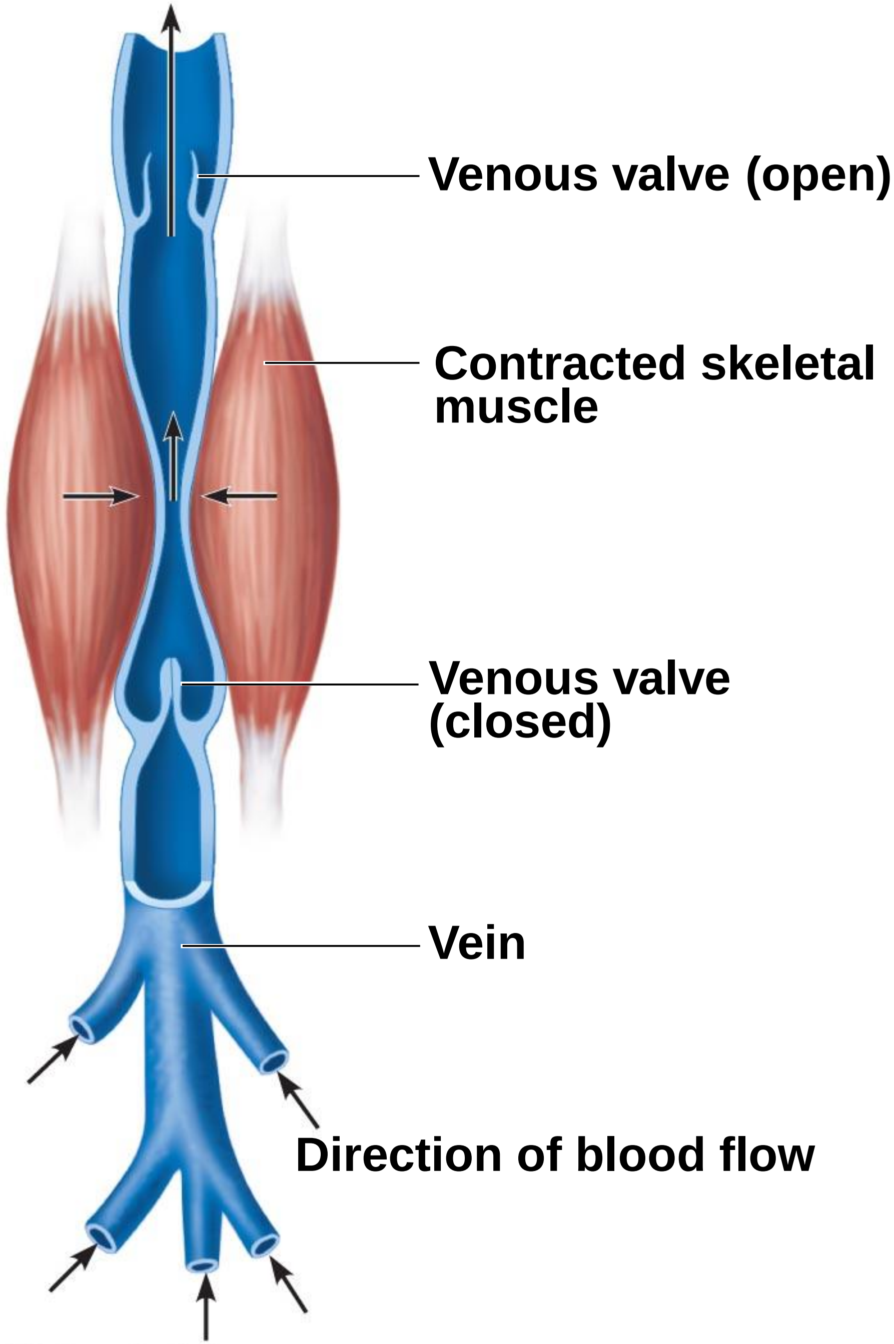
Venous Blood Pressure

- Changes little during cardiac cycle
- Small pressure gradient; about 15 mm Hg
- Low pressure due to cumulative effects of peripheral resistance
  - Energy of blood pressure lost as heat during each circuit

Factors Aiding Venous Return

1. **Muscular pump**: contraction of skeletal muscles "milks" blood toward heart; valves prevent backflow
2. **Respiratory pump**: pressure changes during breathing move blood toward heart by squeezing abdominal veins as thoracic veins expand
3. **Venoconstriction** under sympathetic control pushes blood toward heart

Figure 19.7 The muscular pump.



Maintaining Blood Pressure

- Requires
  - Cooperation of heart, blood vessels, and kidneys
  - Supervision by brain
- Main factors influencing blood pressure
  - Cardiac output (CO)
  - Peripheral resistance (PR)
  - Blood volume

Maintaining Blood Pressure

- $F = \Delta P/R$; $CO = \Delta P/R$; $\Delta P = CO \times R$
- Blood pressure = CO × PR (and CO depends on blood volume)
- Blood pressure varies directly with CO, PR, and blood volume
- Changes in one variable quickly compensated for by changes in other variables

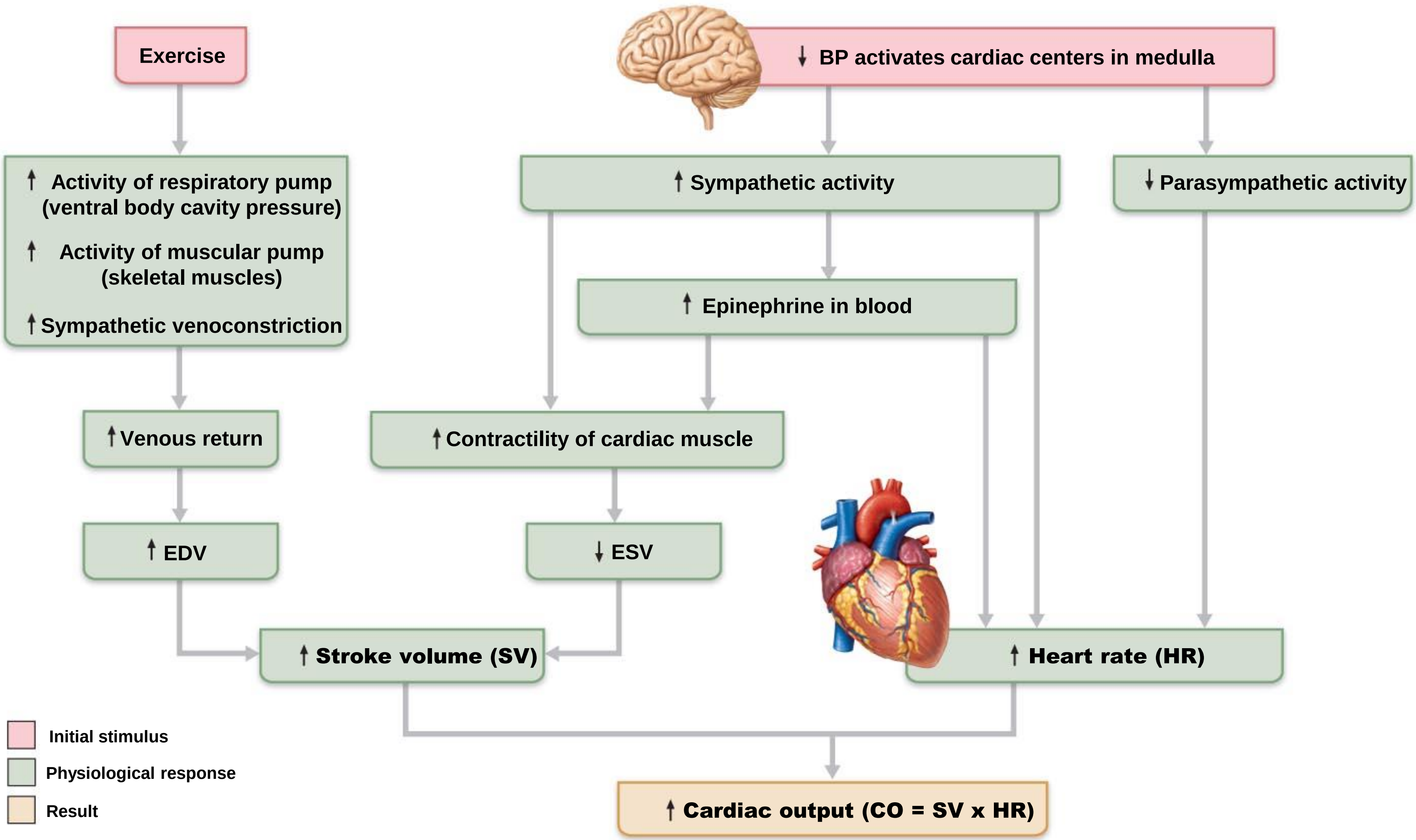
Cardiac Output (CO)

- $CO = SV \times HR$; normal = 5.0-5.5 L/min
- Determined by venous return, and neural and hormonal controls
- Resting heart rate maintained by cardioinhibitory center via parasympathetic vagus nerves
- Stroke volume controlled by venous return (EDV)

Cardiac Output (CO)

- During stress, cardioacceleratory center increases heart rate and stroke volume via sympathetic stimulation
  - ESV decreases and MAP increases

Figure 19.8 Major factors enhancing cardiac output.



Control of Blood Pressure

- Short-term neural and hormonal controls
  - Counteract fluctuations in blood pressure by altering peripheral resistance and CO
- Long-term renal regulation
  - Counteracts fluctuations in blood pressure by altering blood volume

Short-term Mechanisms: Neural Controls

- Neural controls of peripheral resistance
  - Maintain MAP by altering blood vessel diameter
    - If low blood volume all vessels constricted except those to heart and brain
  - Alter blood distribution to organs in response to specific demands

Short-term Mechanisms: Neural Controls

- Neural controls operate via **reflex arcs** that involve
  - **Baroreceptors**
  - Cardiovascular center of medulla
  - Vasomotor fibers to heart and vascular smooth muscle
  - Sometimes input from chemoreceptors and higher brain centers

The Cardiovascular Center

- Clusters of sympathetic neurons in medulla oversee changes in CO and blood vessel diameter
- Consists of cardiac centers and vasomotor center
- Vasomotor center sends steady impulses via sympathetic efferents to blood vessels → moderate constriction called **vasomotor tone**
- Receives inputs from baroreceptors, chemoreceptors, and higher brain centers

Short-term Mechanisms: Baroreceptor Reflexes

- **Baroreceptors** located in
  - Carotid sinuses
  - Aortic arch
  - Walls of large arteries of neck and thorax

Short-term Mechanisms: Baroreceptor Reflexes

- Increased blood pressure stimulates baroreceptors to increase input to vasomotor center
  - Inhibits vasomotor and cardioacceleratory centers, causing arteriolar dilation and venodilation
  - Stimulates cardioinhibitory center
  - → decreased blood pressure

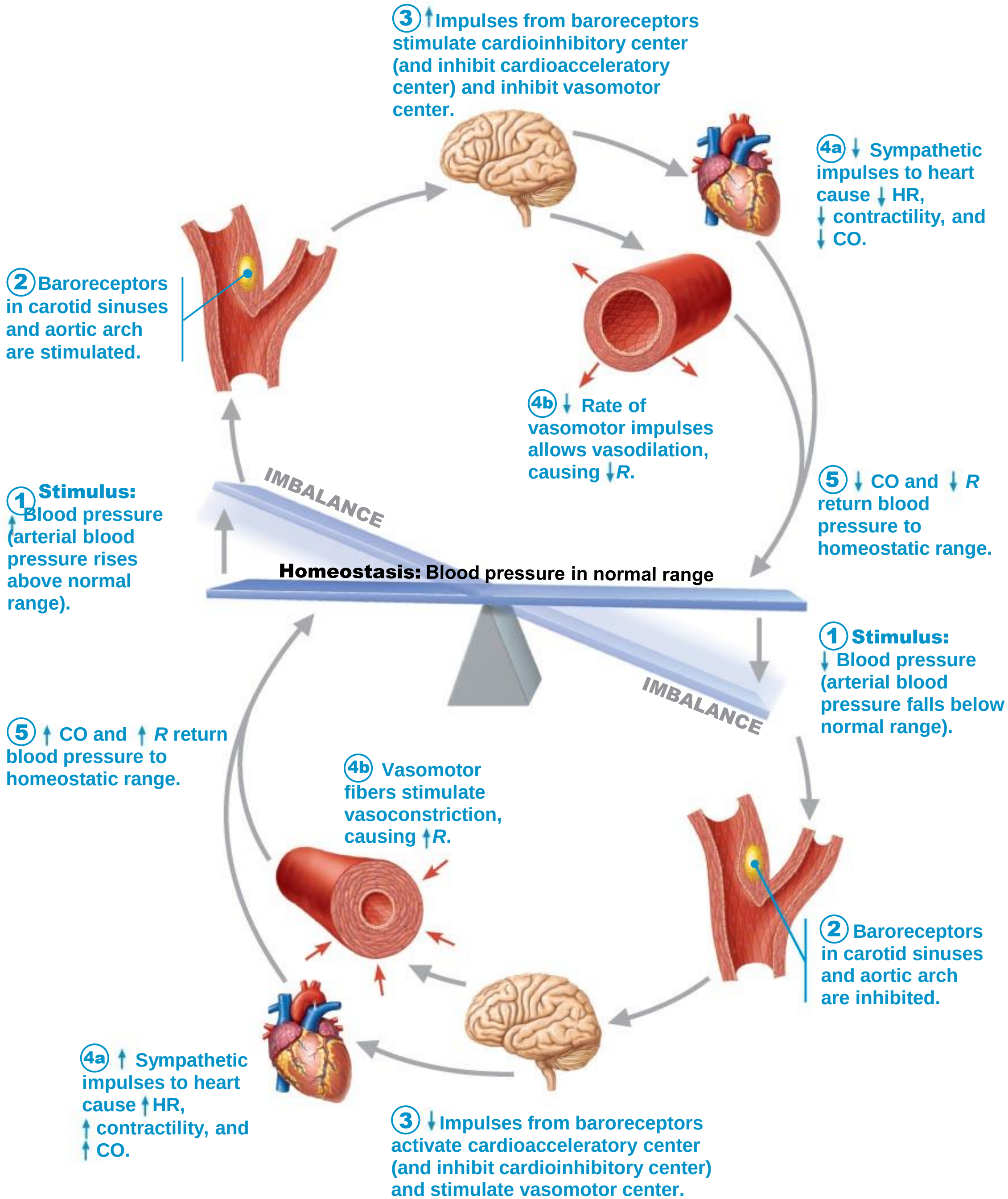
Short-term Mechanisms: Baroreceptor Reflexes

- Decrease in blood pressure due to
  - Arteriolar vasodilation
  - Venodilation
  - Decreased cardiac output

Short-term Mechanisms: Baroreceptor Reflexes

- If MAP low
  - → Reflex vasoconstriction → increased CO → increased blood pressure
  - Ex. Upon standing baroreceptors of **carotid sinus reflex** protect blood to brain; in systemic circuit as whole **aortic reflex** maintains blood pressure
- Baroreceptors ineffective if altered blood pressure sustained

Figure 19.9 Baroreceptor reflexes that help maintain blood pressure homeostasis.



Short-term Mechanisms: Chemoreceptor Reflexes

- Chemoreceptors in aortic arch and large arteries of neck detect increase in CO_2, or drop in pH or O_2
- Cause increased blood pressure by
  - Signaling cardioacceleratory center → increase CO
  - Signaling vasomotor center → increase vasoconstriction

Short-term Mechanisms: Influence of Higher Brain Centers

- Reflexes in medulla
- Hypothalamus and cerebral cortex can modify arterial pressure via relays to medulla
- Hypothalamus increases blood pressure during stress
- Hypothalamus mediates redistribution of blood flow during exercise and changes in body temperature

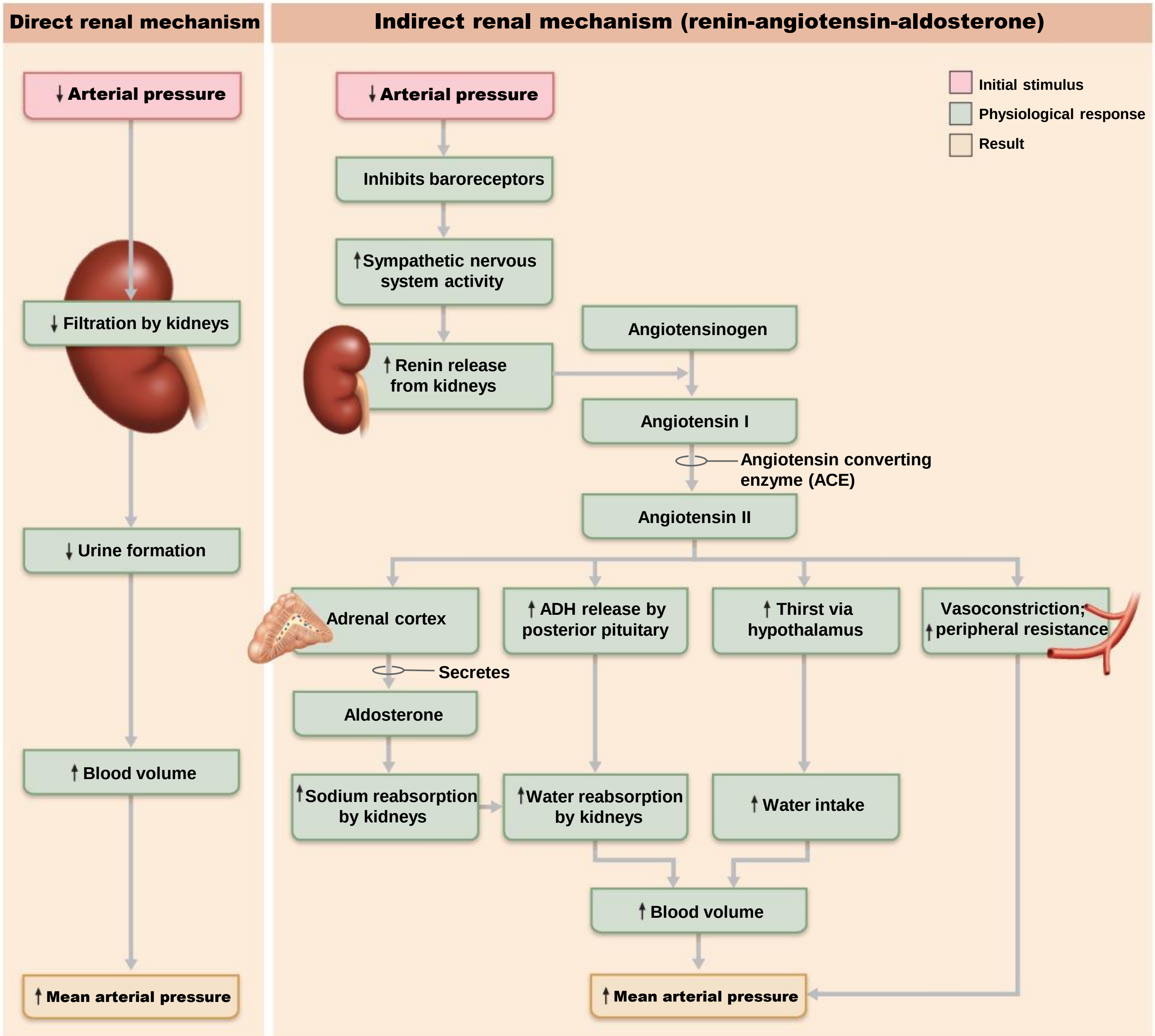
Short-term Mechanisms: Hormonal Controls

- Short term regulation via changes in peripheral resistance
- Long term regulation via changes in blood volume

Short-term Mechanisms: Hormonal Controls

- Cause increased blood pressure
  - Epinephrine and norepinephrine from adrenal gland → increased CO and vasoconstriction
  - Angiotensin II stimulates vasoconstriction
  - High ADH levels cause vasoconstriction
- Cause lowered blood pressure
  - Atrial natriuretic peptide causes decreased blood volume by antagonizing aldosterone

Figure 19.10 Direct and indirect (hormonal) mechanisms for renal control of blood pressure.



Long-term Mechanisms: Renal Regulation

- Baroreceptors quickly adapt to chronic high or low BP so are ineffective
- Long-term mechanisms control BP by altering blood volume via kidneys
- Kidneys regulate arterial blood pressure
  1. Direct renal mechanism
  2. Indirect renal (renin-angiotensin-aldosterone) mechanism

Direct Renal Mechanism

- Alters blood volume independently of hormones
  - Increased BP or blood volume causes elimination of more urine, thus reducing BP
  - Decreased BP or blood volume causes kidneys to conserve water, and BP rises

Indirect Mechanism

- The renin-angiotensin-aldosterone mechanism
  - $\downarrow$ Arterial blood pressure $\rightarrow$ release of renin
  - Renin catalyzes conversion of angiotensinogen from liver to angiotensin I
  - Angiotensin converting enzyme, especially from lungs, converts angiotensin I to angiotensin II

Functions of Angiotensin II

- Increases blood volume
  - Stimulates aldosterone secretion
  - Causes ADH release
  - Triggers hypothalamic thirst center
- Causes vasoconstriction directly increasing blood pressure

Figure 19.10 Direct and indirect (hormonal) mechanisms for renal control of blood pressure.

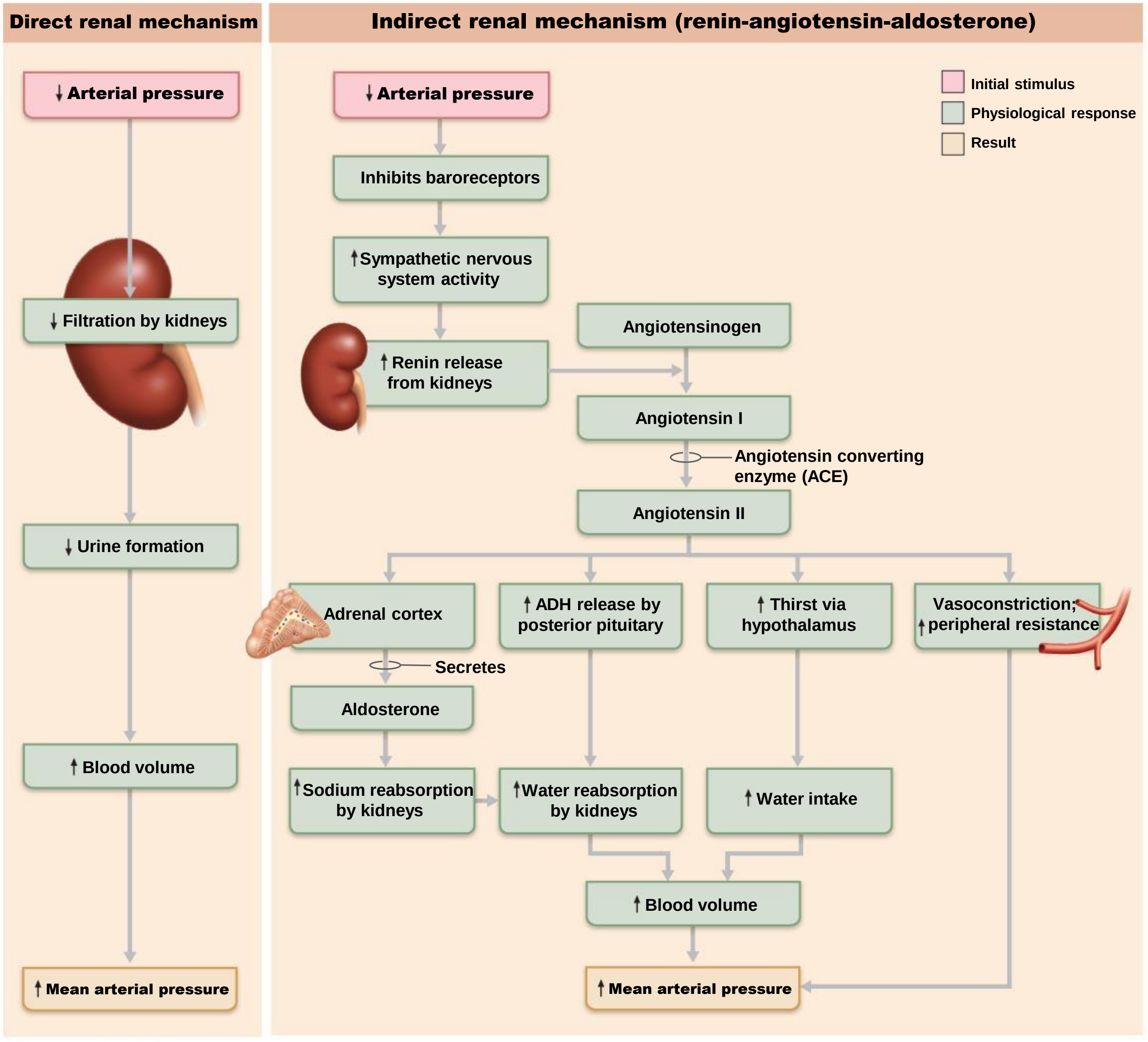
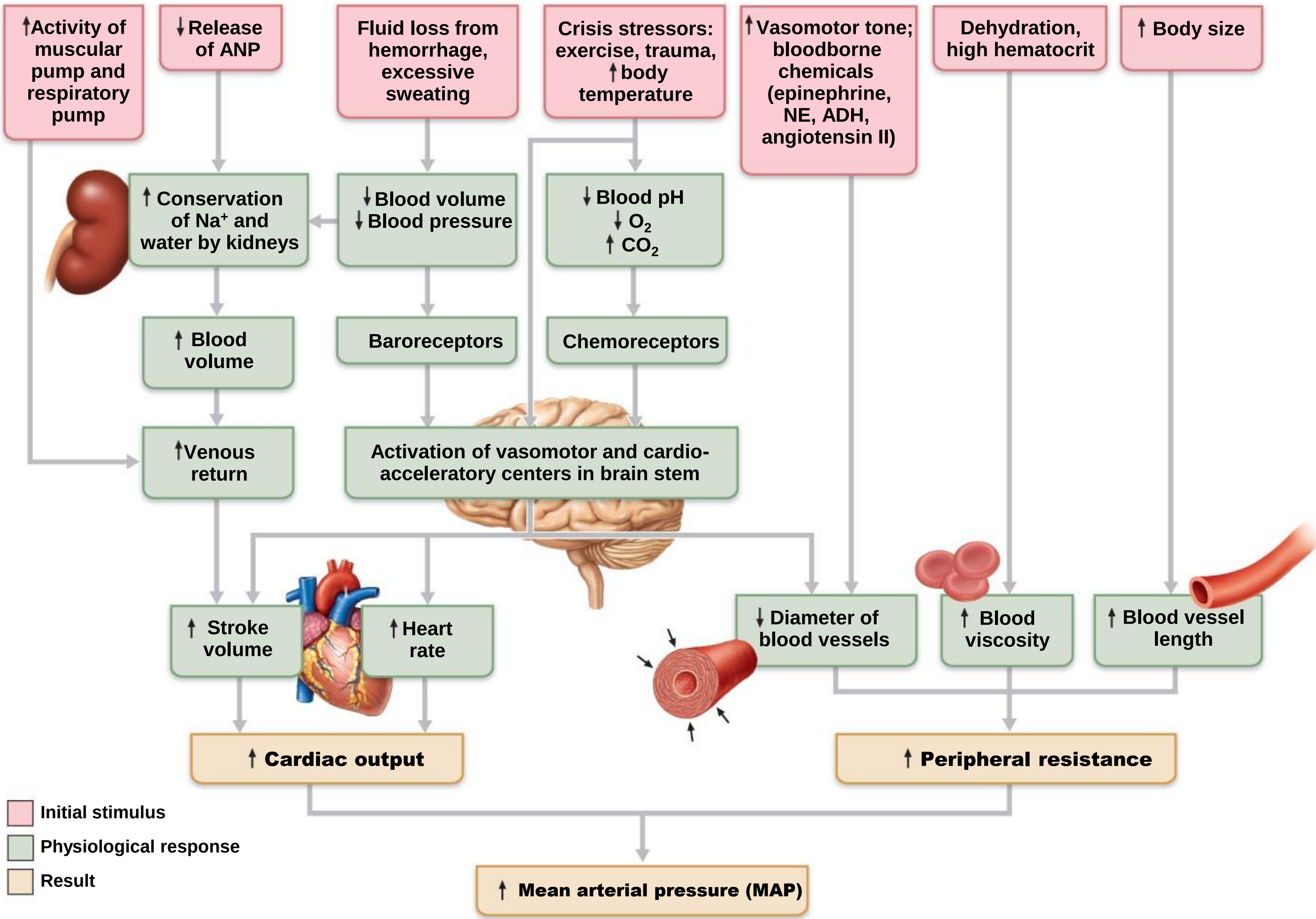


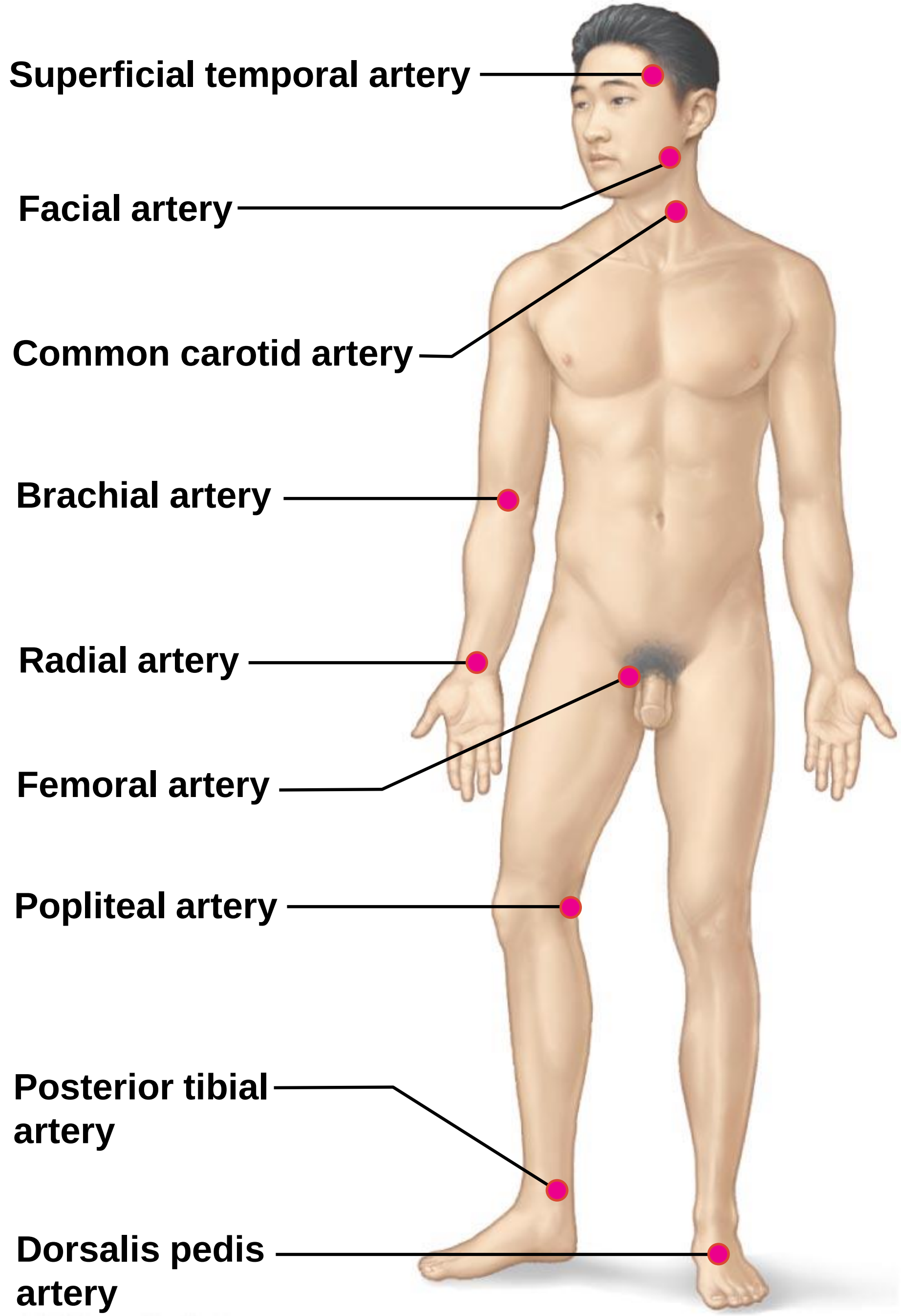
Figure 19.11 Factors that increase MAP.



Monitoring Circulatory Efficiency

- **Vital signs**: pulse and blood pressure, along with respiratory rate and body temperature
- **Pulse**: pressure wave caused by expansion and recoil of arteries
- **Radial pulse** (taken at the wrist) routinely used
- **Pressure points** where arteries close to body surface
  - Can be compressed to stop blood flow

Figure 19.12 Body sites where the pulse is most easily palpated.



Measuring Blood Pressure

- Systemic arterial BP
  - Measured indirectly by **auscultatory method** using a **sphygmomanometer**
  - Pressure increased in cuff until it exceeds systolic pressure in brachial artery
  - Pressure released slowly and examiner listens for **sounds of Korotkoff** with a stethoscope

Measuring Blood Pressure

- **Systolic pressure**, normally less than 120 mm Hg, is pressure when sounds first occur as blood starts to spurt through artery
- **Diastolic pressure**, normally less than 80 mm Hg, is pressure when sounds disappear because artery no longer constricted; blood flowing freely

Variations in Blood Pressure

- Transient elevations occur during changes in posture, physical exertion, emotional upset, fever.
- Age, sex, weight, race, mood, and posture may cause BP to vary

Alterations in Blood Pressure

- **Hypertension**: high blood pressure
  - Sustained elevated arterial pressure of 140/90 or higher
  - **Prehypertension** if values elevated but not yet in hypertension range
    - May be transient adaptations during fever, physical exertion, and emotional upset
    - Often persistent in obese people

Homeostatic Imbalance: Hypertension

- Prolonged hypertension major cause of heart failure, vascular disease, renal failure, and stroke
  - Heart must work harder → myocardium enlarges, weakens, becomes flabby
  - Also accelerates atherosclerosis

Primary or Essential Hypertension

- 90% of hypertensive conditions
- No underlying cause identified
  - Risk factors include heredity, diet, obesity, age, diabetes mellitus, stress, and smoking
- No cure but can be controlled
  - Restrict salt, fat, cholesterol intake
  - Increase exercise, lose weight, stop smoking
  - Antihypertensive drugs

Homeostatic Imbalance: Hypertension

- **Secondary hypertension** less common
  - Due to identifiable disorders including obstructed renal arteries, kidney disease, and endocrine disorders such as hyperthyroidism and Cushing's syndrome
  - Treatment focuses on correcting underlying cause

Alterations in Blood Pressure

- **Hypotension**: low blood pressure
  - Blood pressure below 90/60 mm Hg
  - Usually not a concern
    - Only if leads to inadequate blood flow to tissues
  - Often associated with long life and lack of cardiovascular illness

Homeostatic Imbalance: Hypotension

- **Orthostatic hypotension**: temporary low BP and dizziness when suddenly rising from sitting or reclining position
- **Chronic hypotension**: hint of poor nutrition and warning sign for Addison's disease or hypothyroidism
- **Acute hypotension**: important sign of circulatory shock; threat for surgical patients and those in ICU

Circulatory Shock

- **Hypovolemic shock**: results from large-scale blood loss
- **Vascular shock**: results from extreme vasodilation and decreased peripheral resistance
- **Cardiogenic shock** results when an inefficient heart cannot sustain adequate circulation

Figure 19.18 Events and signs of hypovolemic shock.

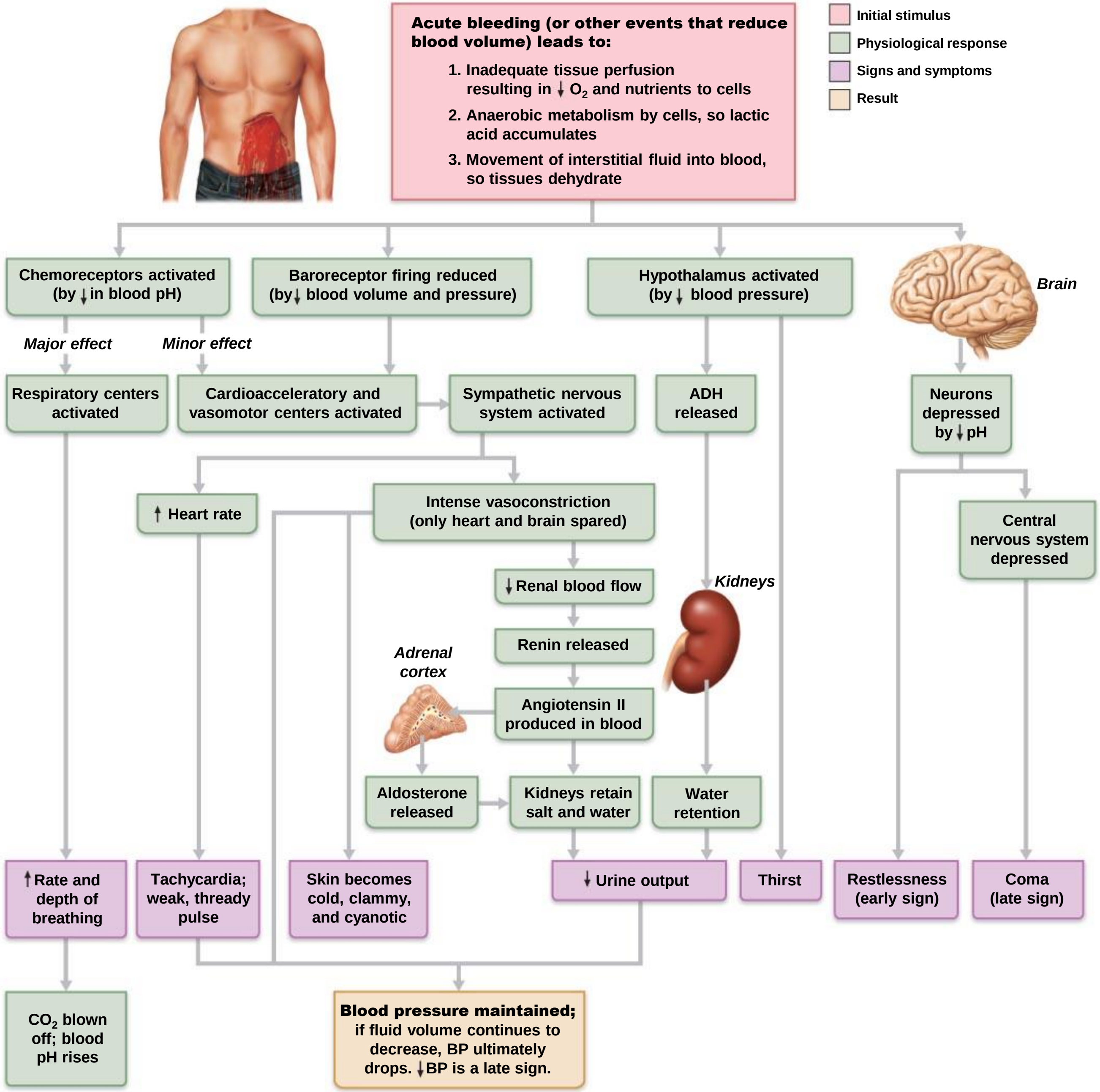
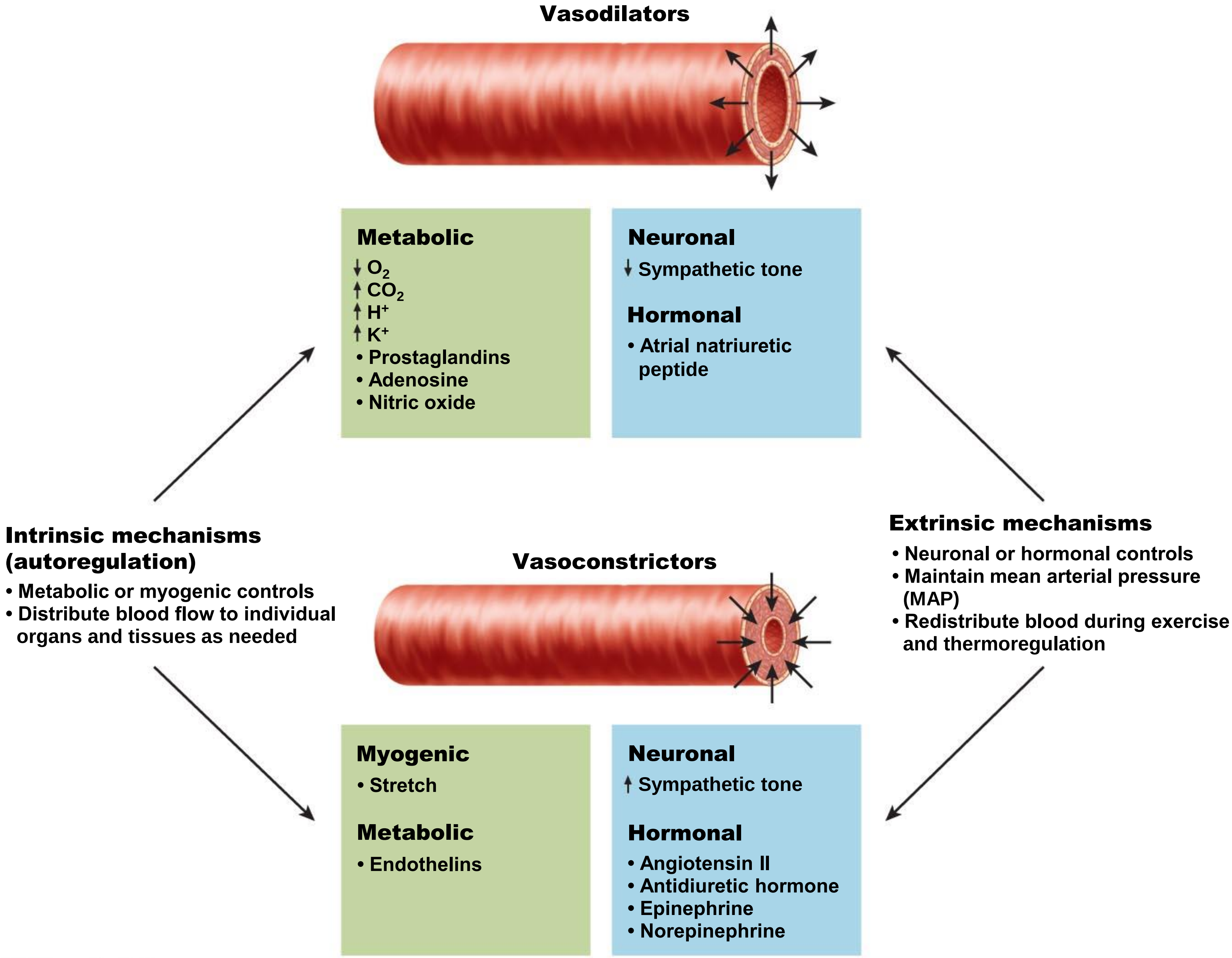


Figure 19.15 Intrinsic and extrinsic control of arteriolar smooth muscle in the systemic circulation.



Hydrostatic Pressures

- **Capillary hydrostatic pressure** (HP_c) (capillary blood pressure)
  - Tends to force fluids through capillary walls
  - Greater at arterial end (35 mm Hg) of bed than at venule end (17 mm Hg)
- **Interstitial fluid hydrostatic pressure** (HP_{if})
  - Pressure that would push fluid into vessel
  - Usually assumed to be zero because of lymphatic vessels

Colloid Osmotic Pressures

- **Capillary colloid osmotic pressure (oncotic pressure)** (OP_c)
  - Created by nondiffusible plasma proteins, which draw water toward themselves
  - ~26 mm Hg
- Interstitial fluid osmotic pressure (OP_{if})
  - Low (~1 mm Hg) due to low protein content

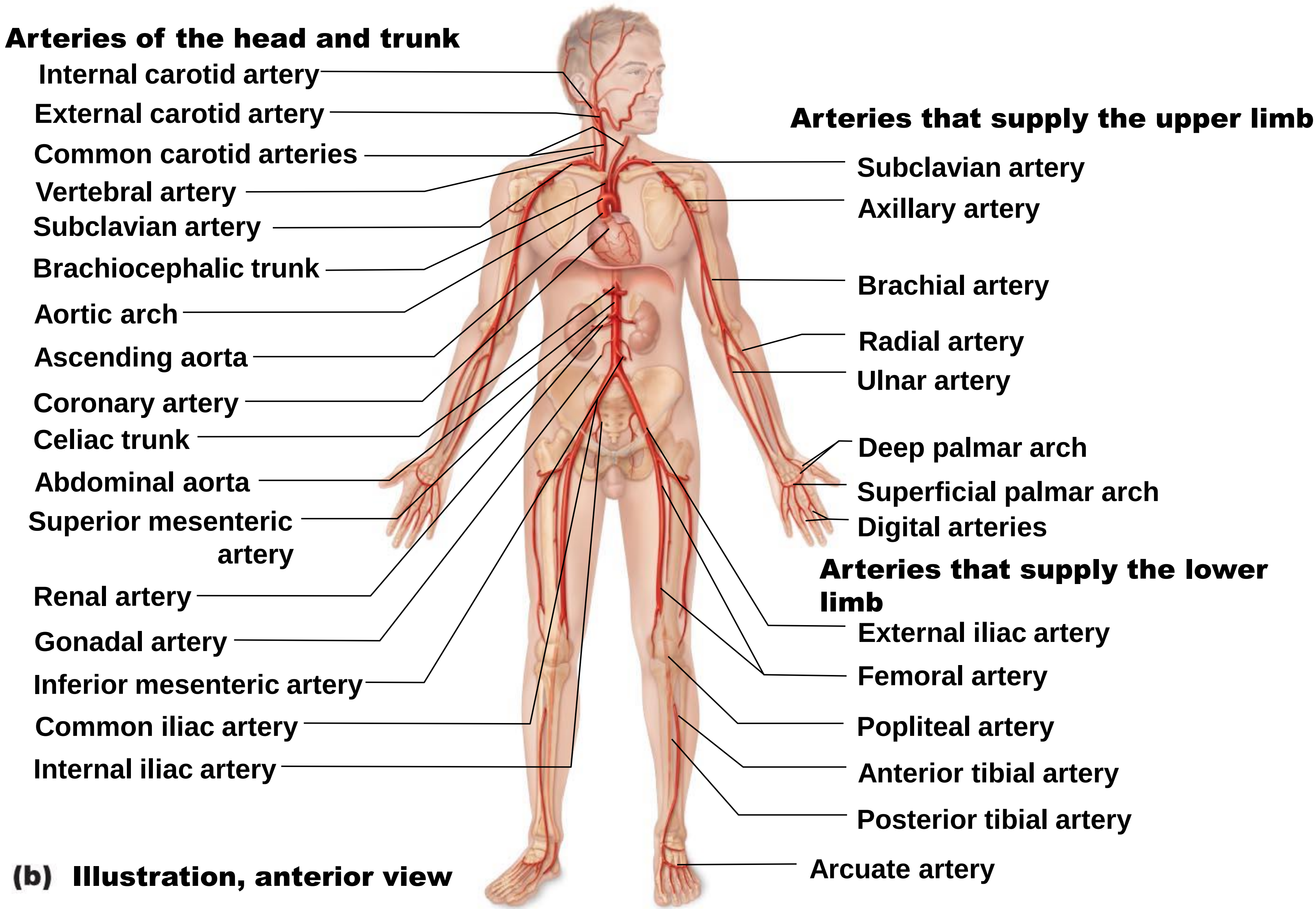
Hydrostatic-osmotic Pressure Interactions: Net Filtration Pressure (NFP)

- NFP—comprises all forces acting on capillary bed
  - $NFP = (HP_c + OP_{if}) - (HP_{if} + OP_c)$
- Net fluid flow out at arterial end
- Net fluid flow in at venous end
- More leaves than is returned
  - Excess fluid returned to blood via lymphatic system

Capillary Exchange of Respiratory Gases and Nutrients

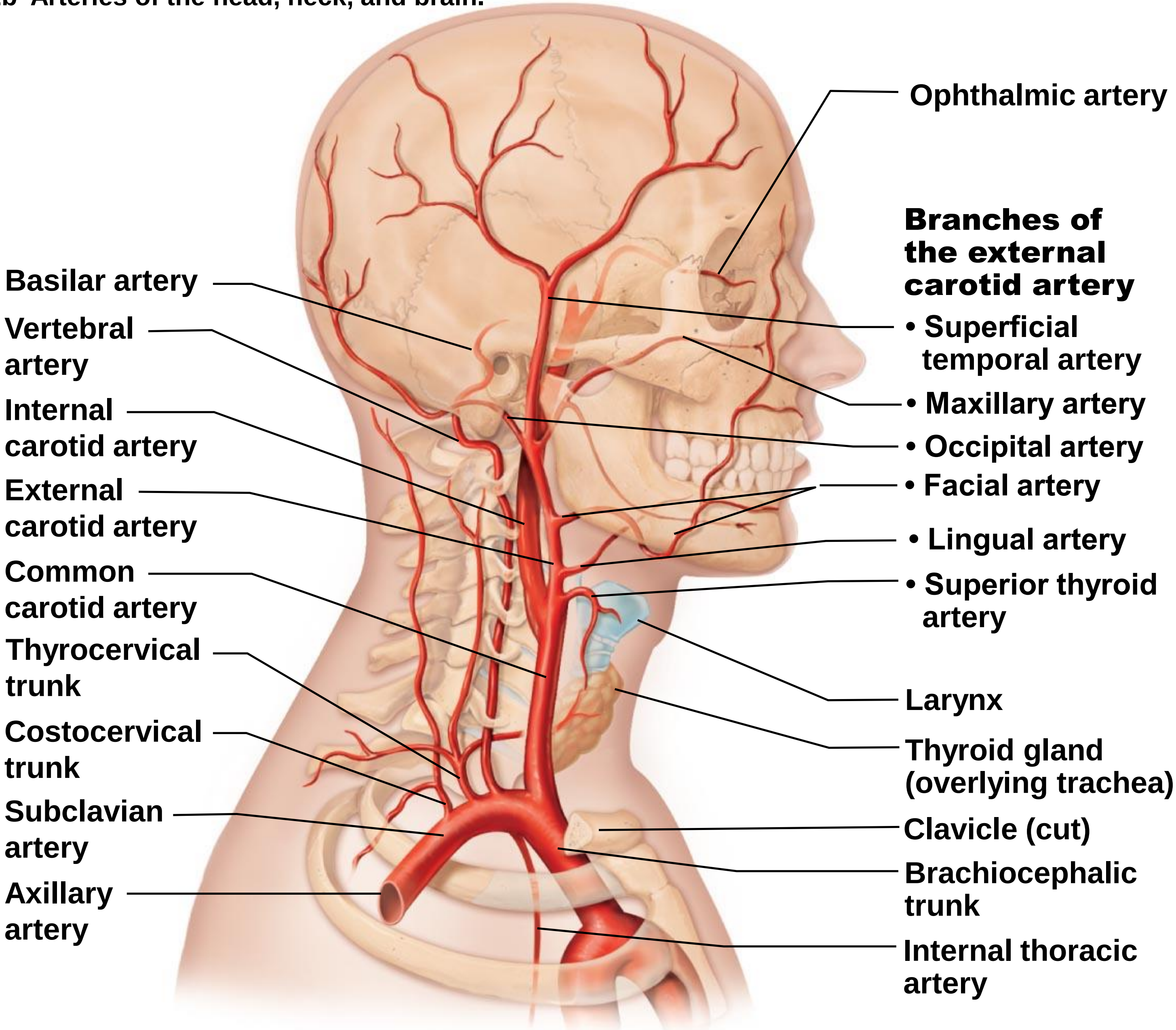
- Diffusion down concentration gradients
  - O_2 and nutrients from blood to tissues
  - CO_2 and metabolic wastes from tissues to blood
- Lipid-soluble molecules diffuse directly through endothelial membranes
- Water-soluble solutes pass through clefts and fenestrations
- Larger molecules, such as proteins, are actively transported in pinocytotic vesicles or caveolae

Figure 19.21b Major arteries of the systemic circulation.



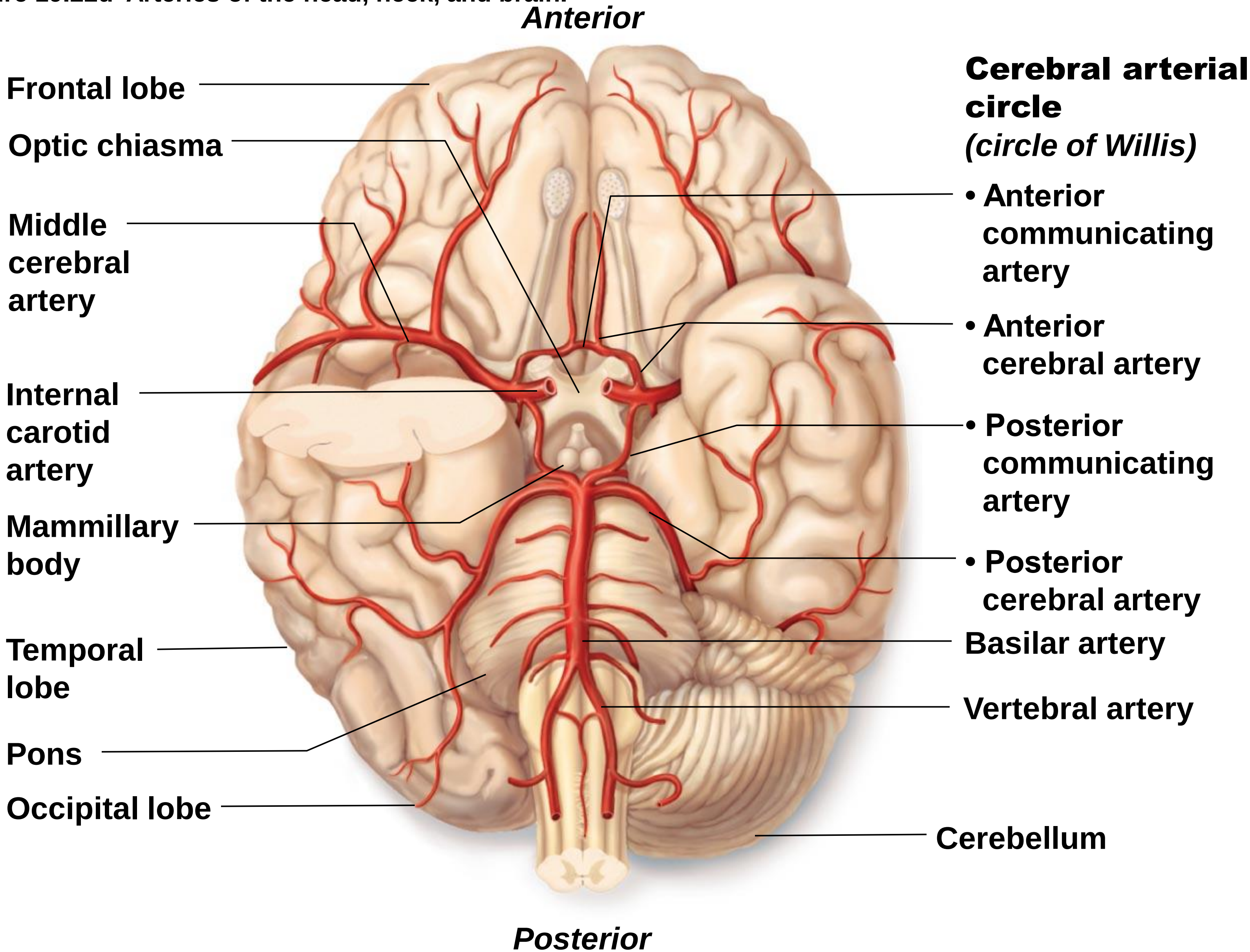
(b) Illustration, anterior view

Figure 19.22b Arteries of the head, neck, and brain.



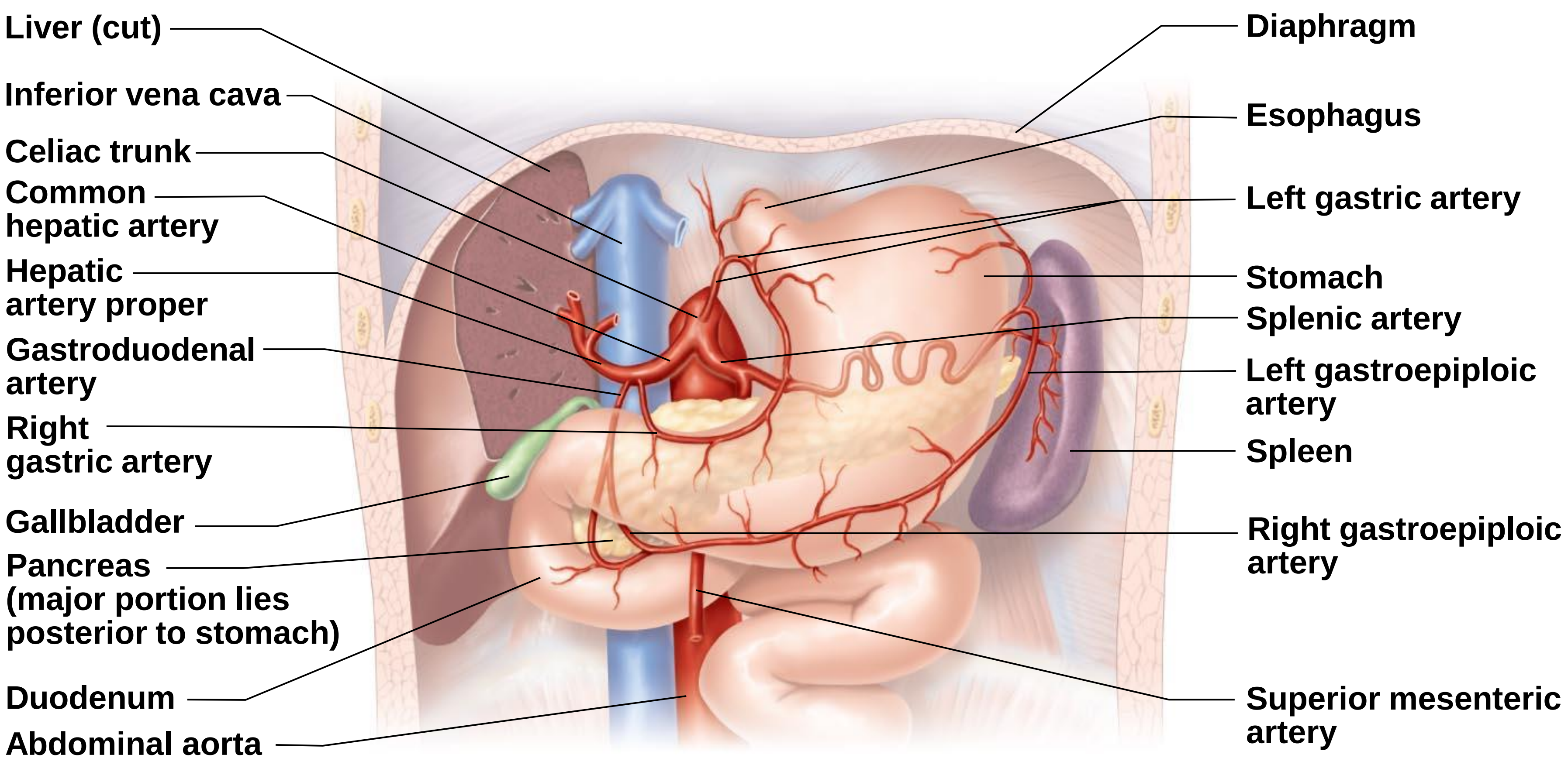
(b) Arteries of the head and neck, right aspect

Figure 19.22d Arteries of the head, neck, and brain.



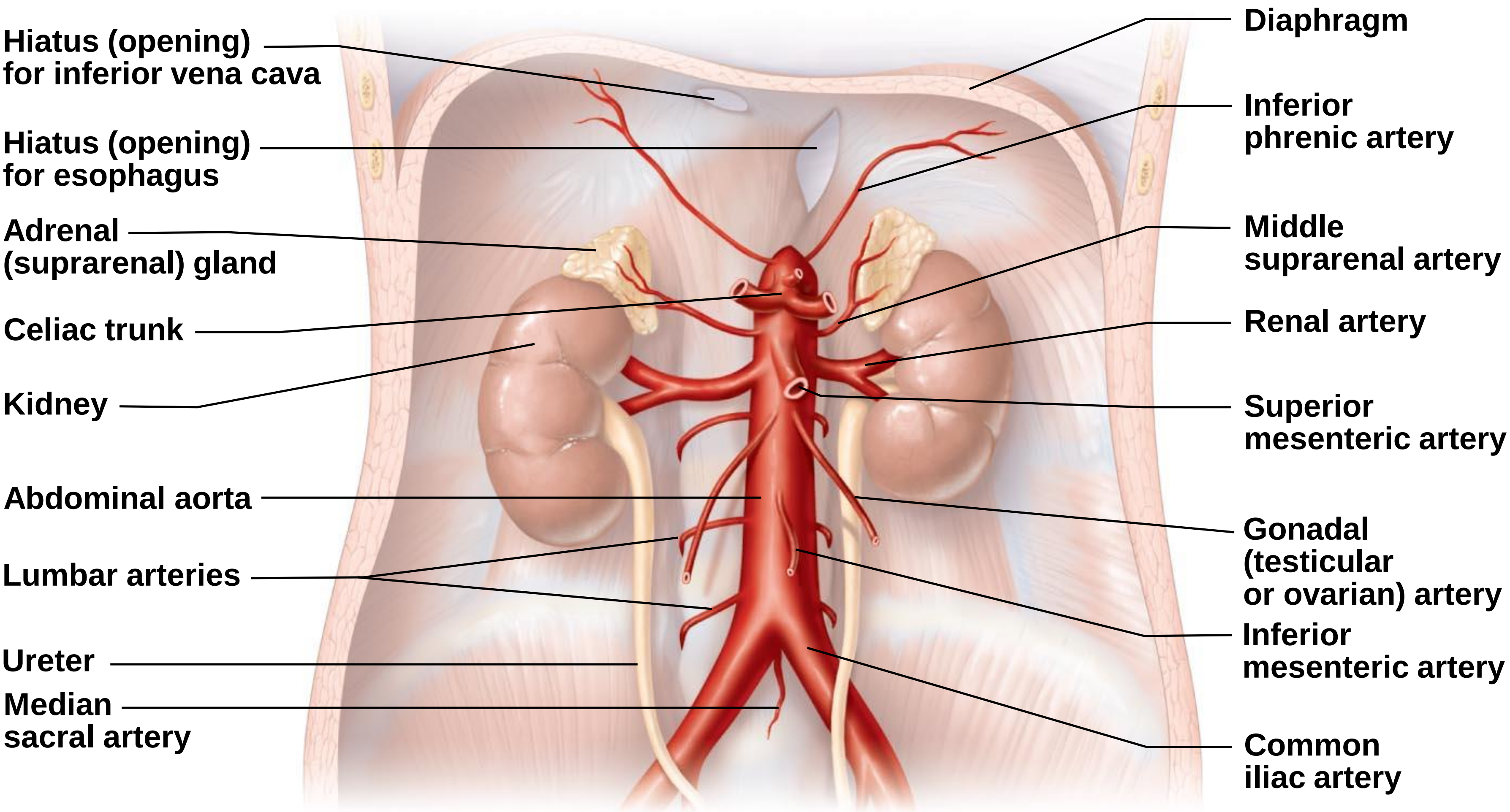
(d) Major arteries serving the brain (inferior view, right side of cerebellum and part of right temporal lobe removed)

Figure 19.24b Arteries of the abdomen.



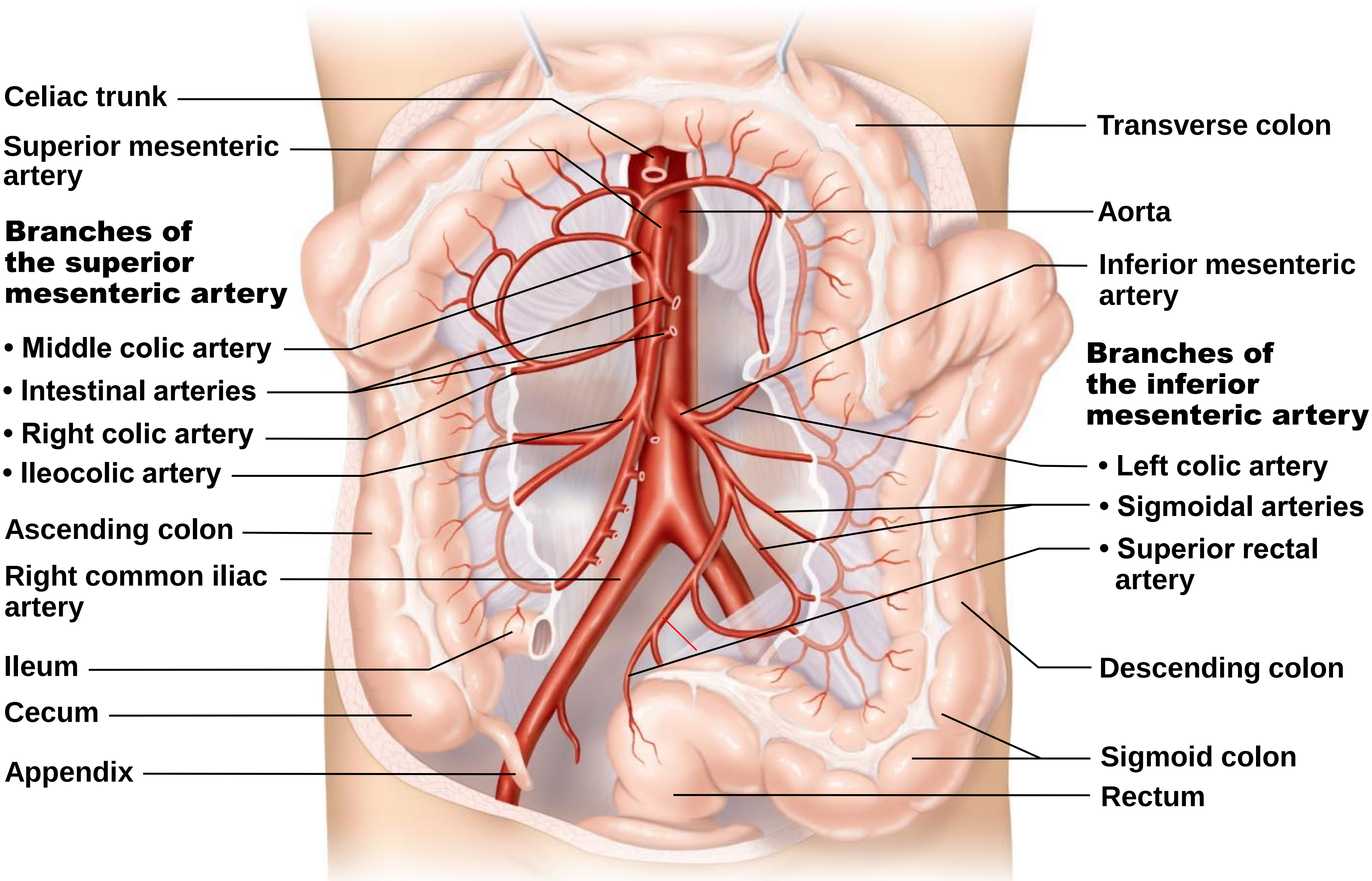
(b) The celiac trunk and its major branches. The left half of the liver has been removed.

Figure 19.24c Arteries of the abdomen.



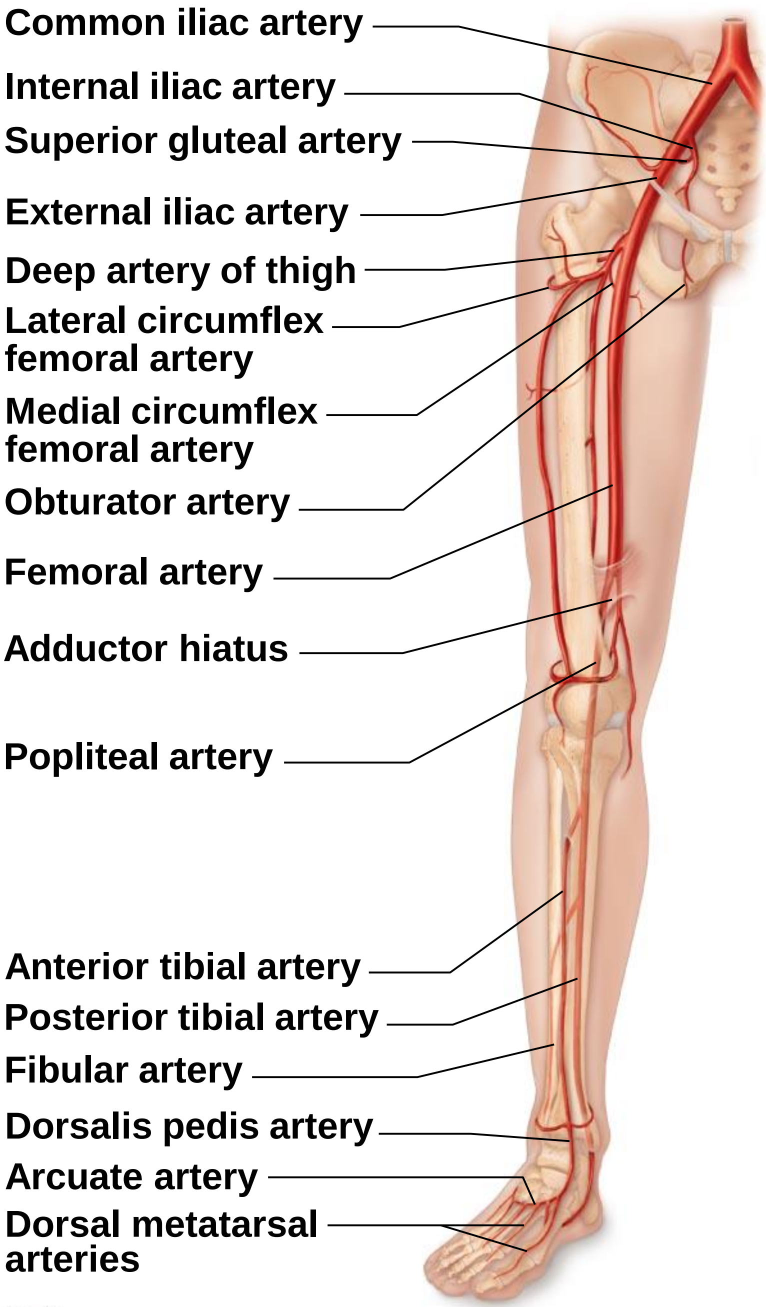
(c) Major branches of the abdominal aorta.

Figure 19.24d Arteries of the abdomen.



(d) Distribution of the superior and inferior mesenteric arteries. The transverse colon has been pulled superiorly.

Figure 19.25b Arteries of the right pelvis and lower limb.



(b) Anterior view

Figure 19.25c Arteries of the right pelvis and lower limb.

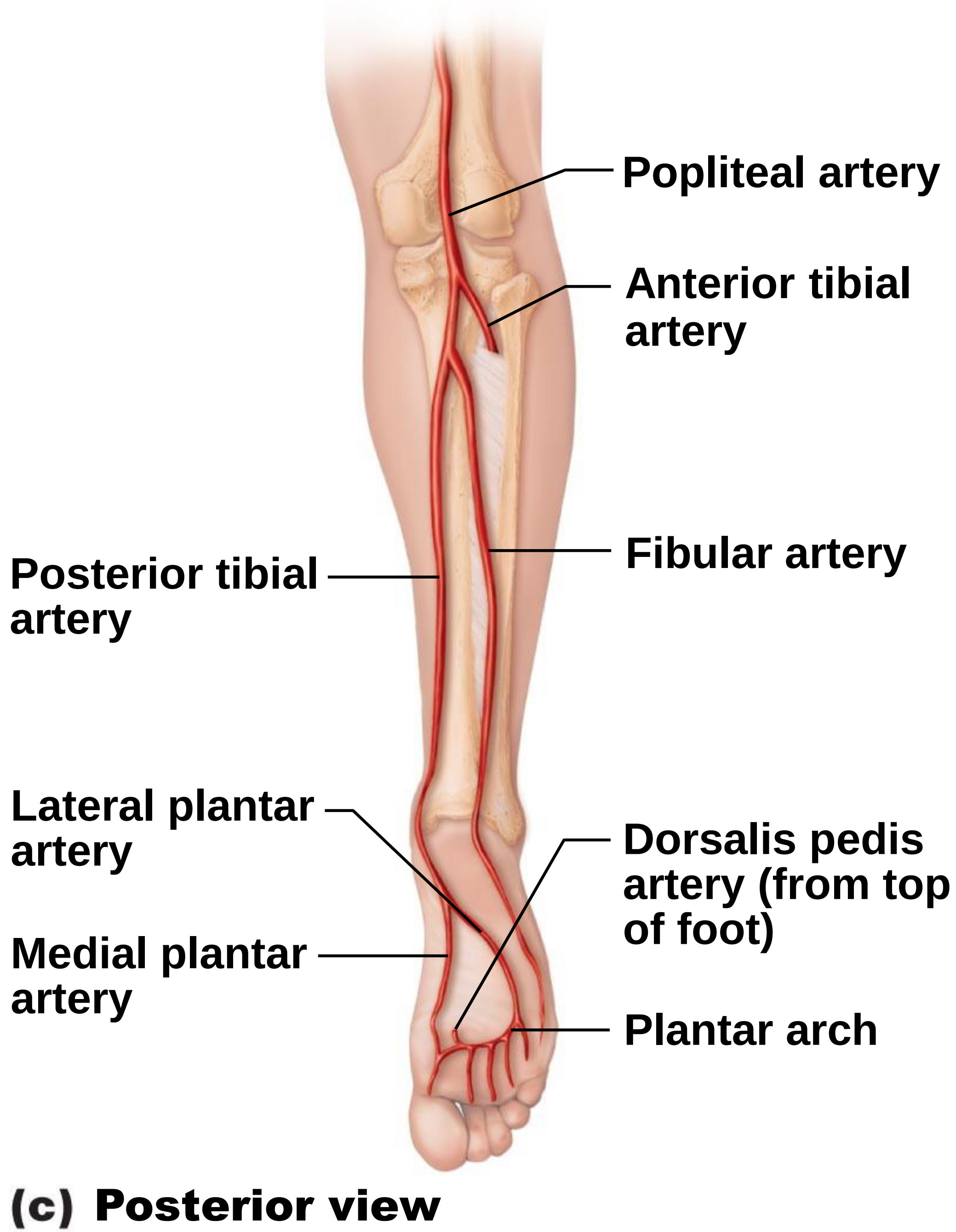
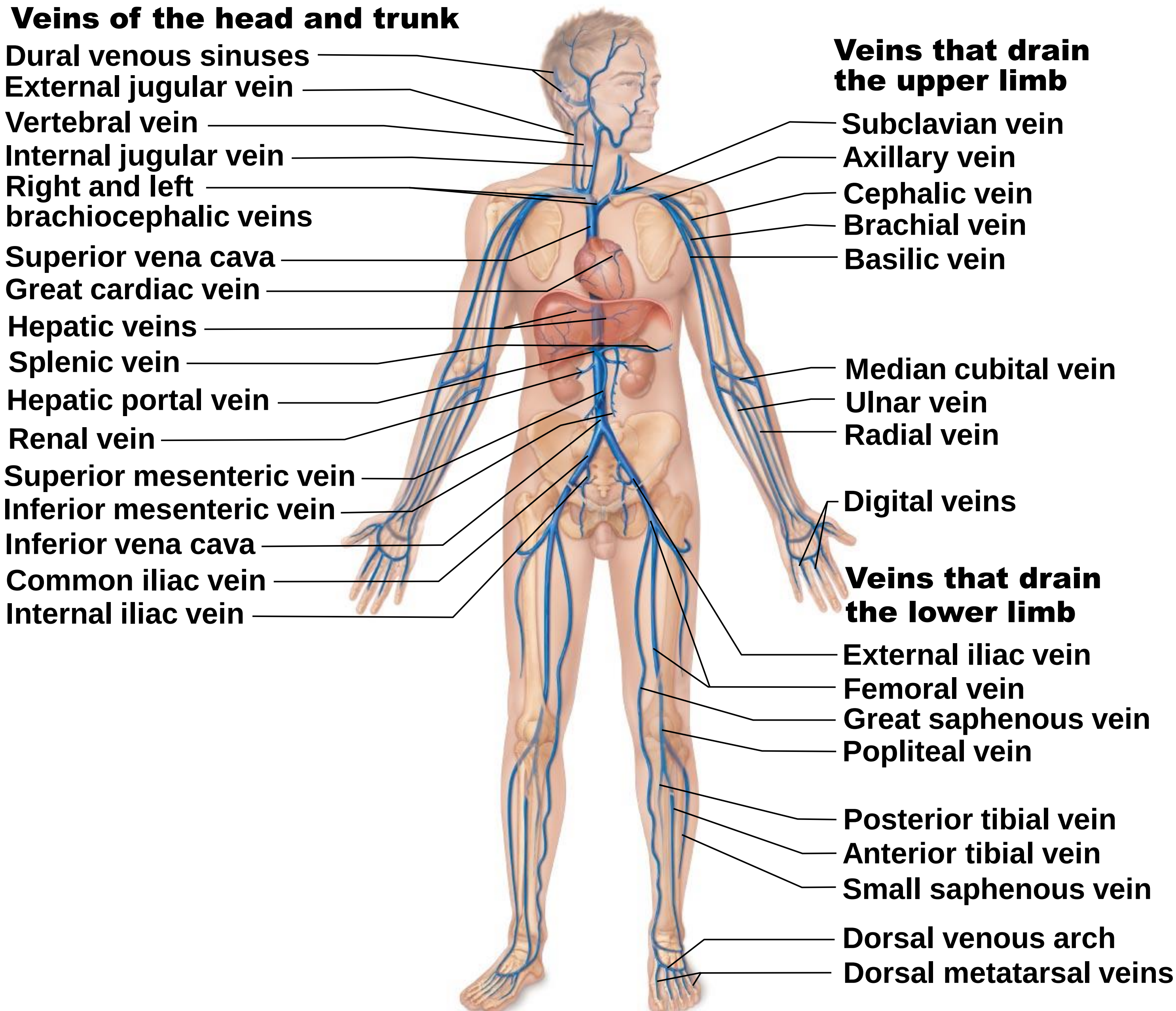
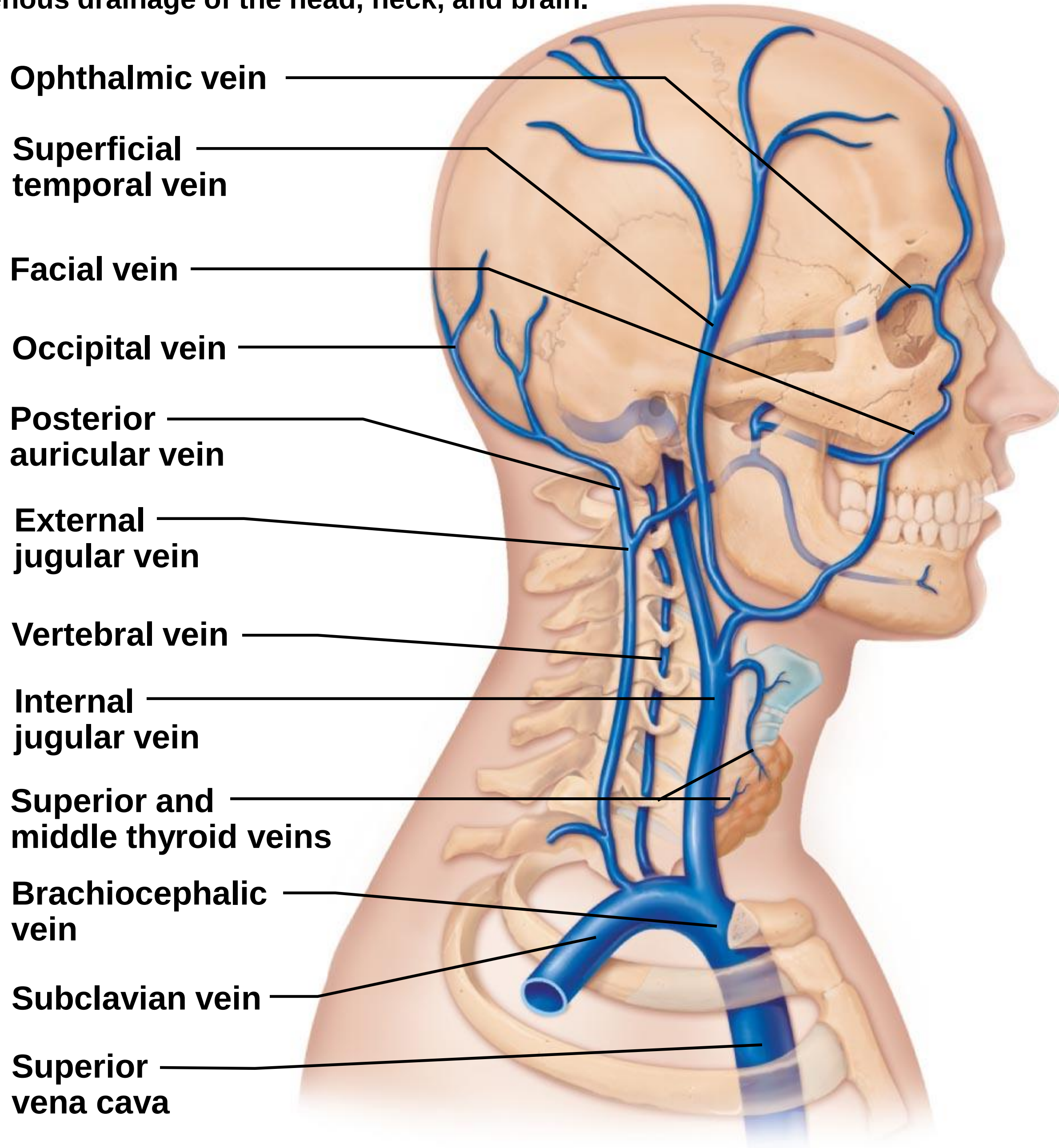


Figure 19.26b Major veins of the systemic circulation.



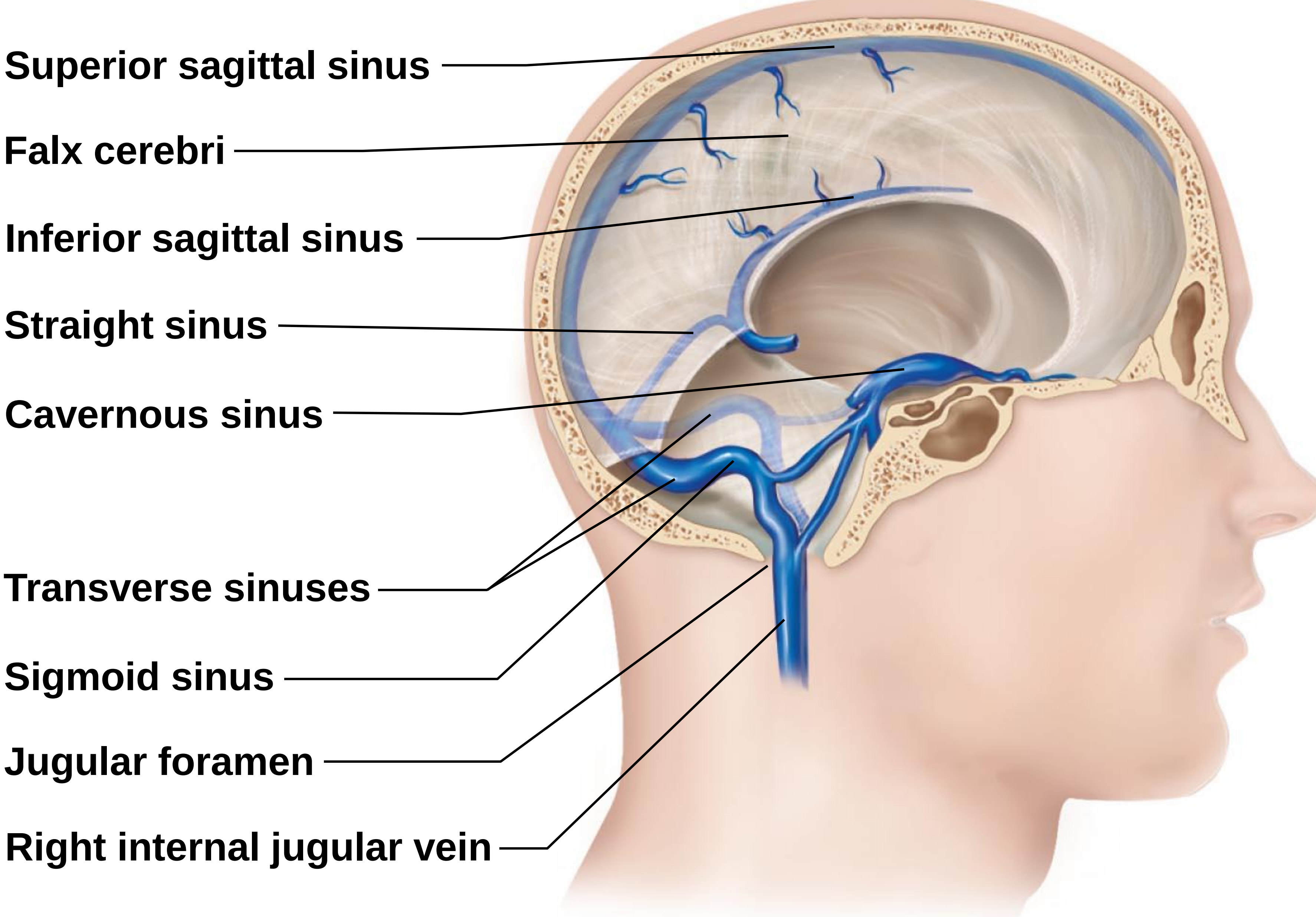
(b) Illustration, anterior view. The vessels of the pulmonary circulation are not shown.

Figure 19.27b Venous drainage of the head, neck, and brain.



(b) Veins of the head and neck, right superficial aspect

Figure 19.27c Venous drainage of the head, neck, and brain.



(c) Dural venous sinuses of the brain

Figure 19.28b Veins of the thorax and right upper limb.

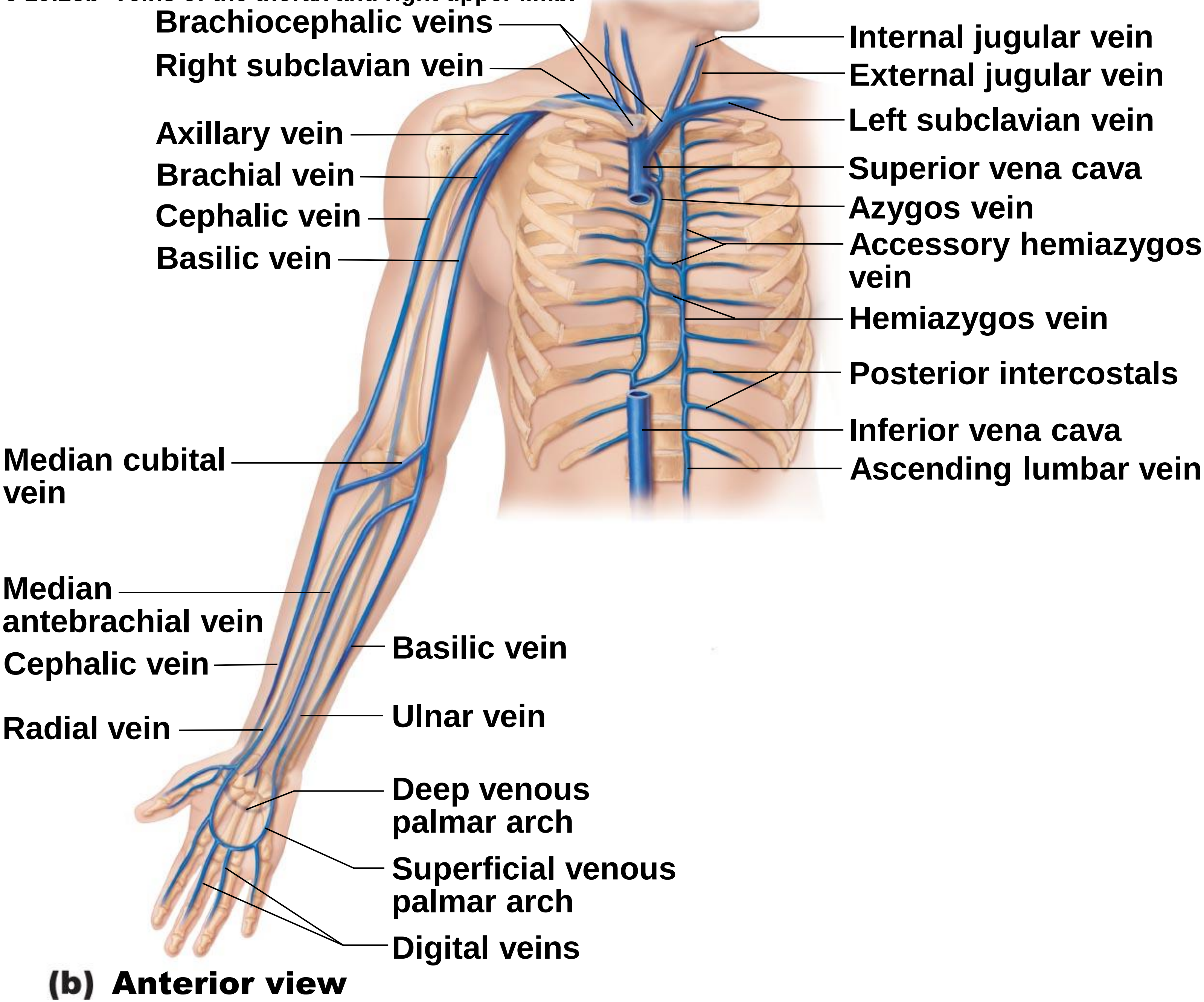
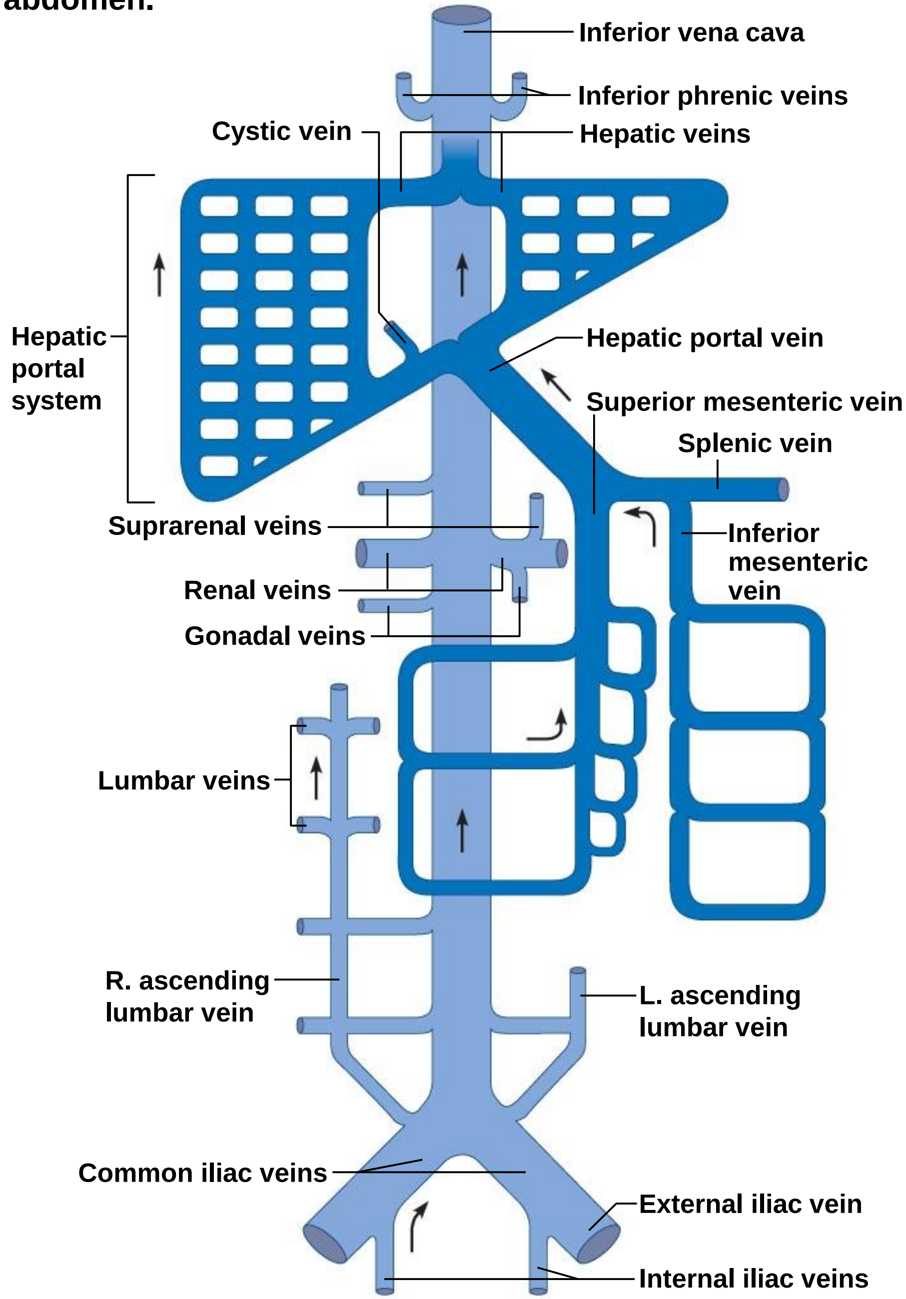
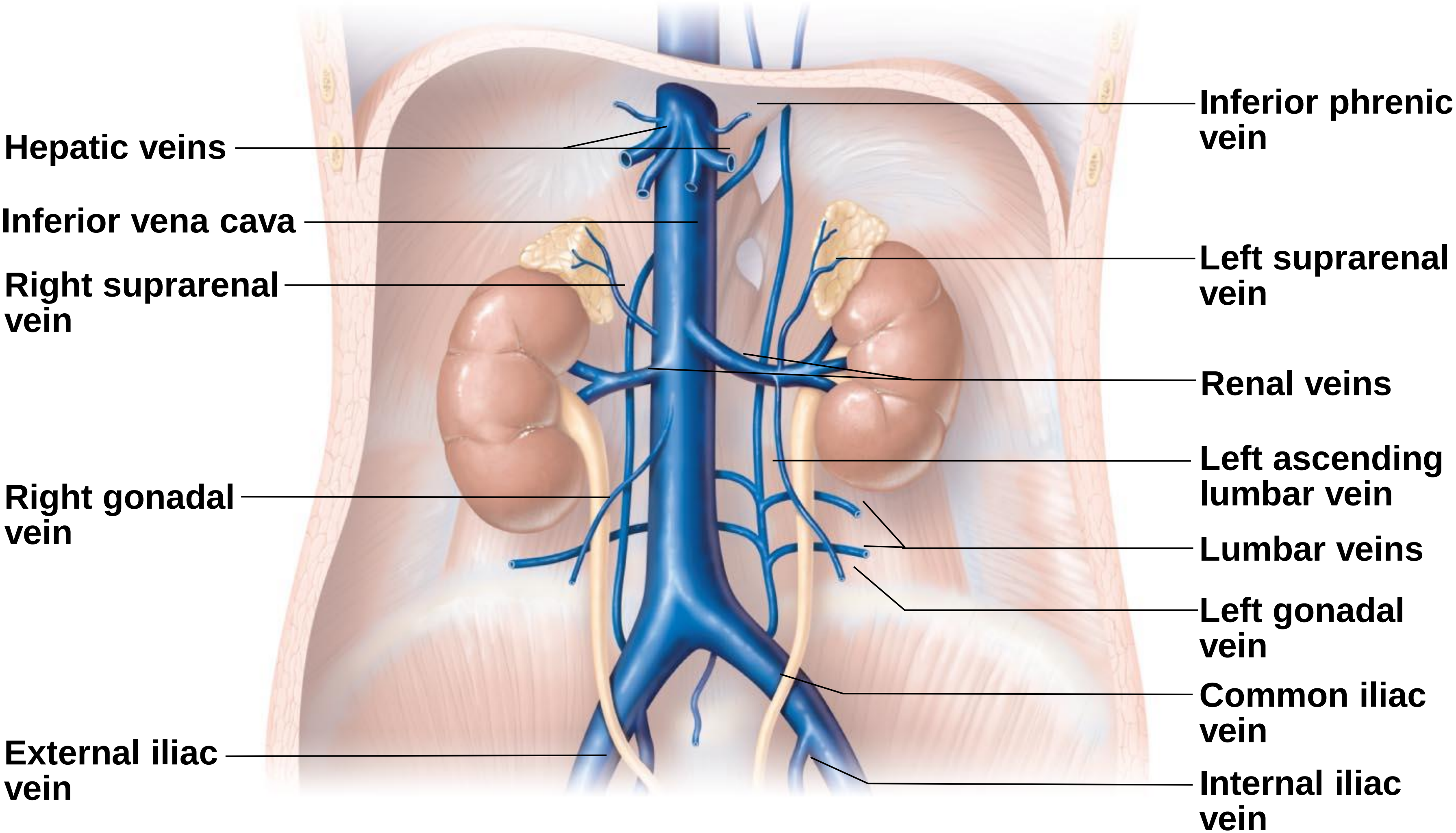


Figure 19.29a Veins of the abdomen.



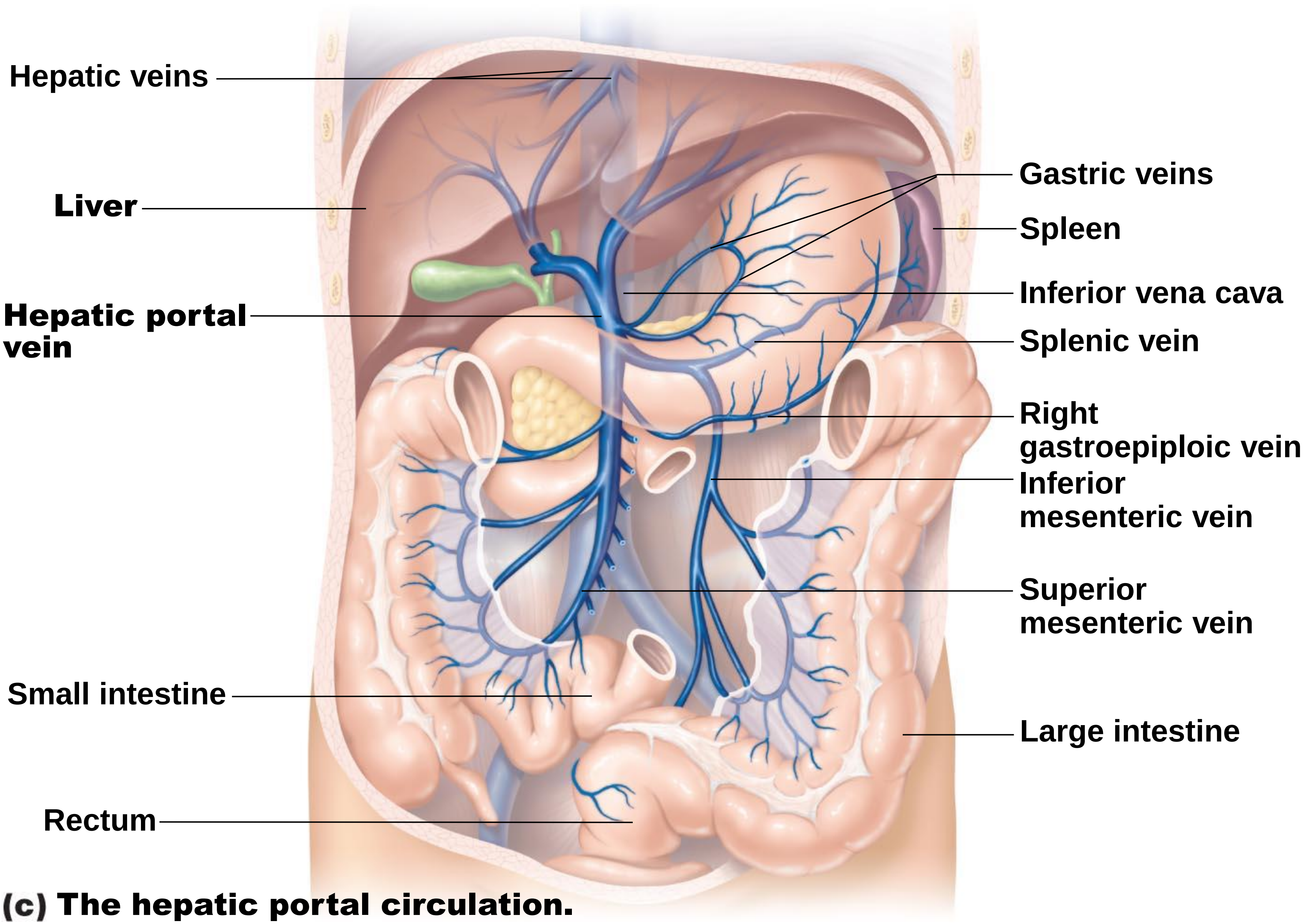
(a) Schematic flowchart.

Figure 19.29b Veins of the abdomen.



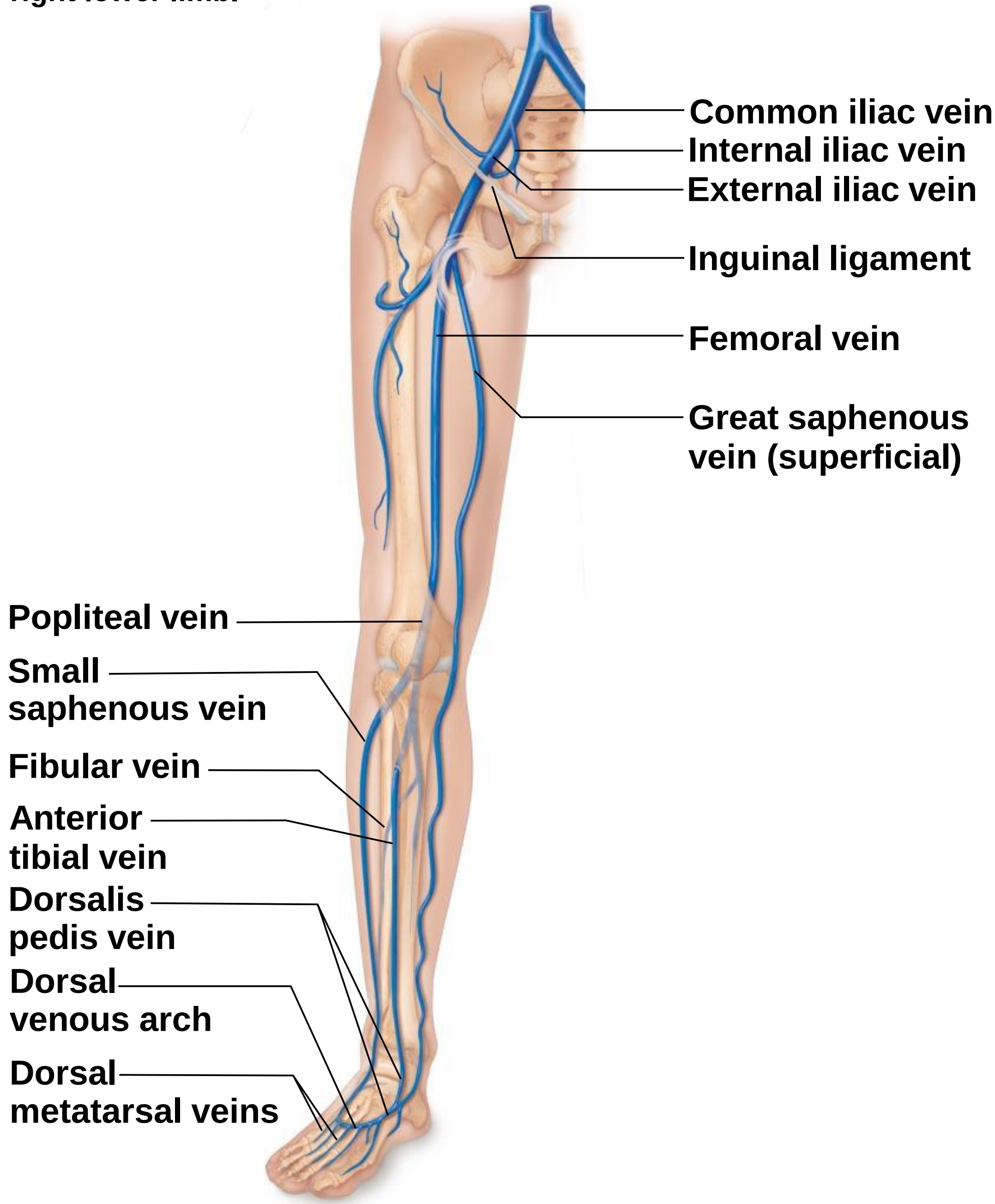
(b) Tributaries of the inferior vena cava.
Venous drainage of abdominal organs not drained by the hepatic portal vein.

Figure 19.29c Veins of the abdomen.



(c) The hepatic portal circulation.

Figure 19.30b Veins of the right lower limb.



(b) Anterior view