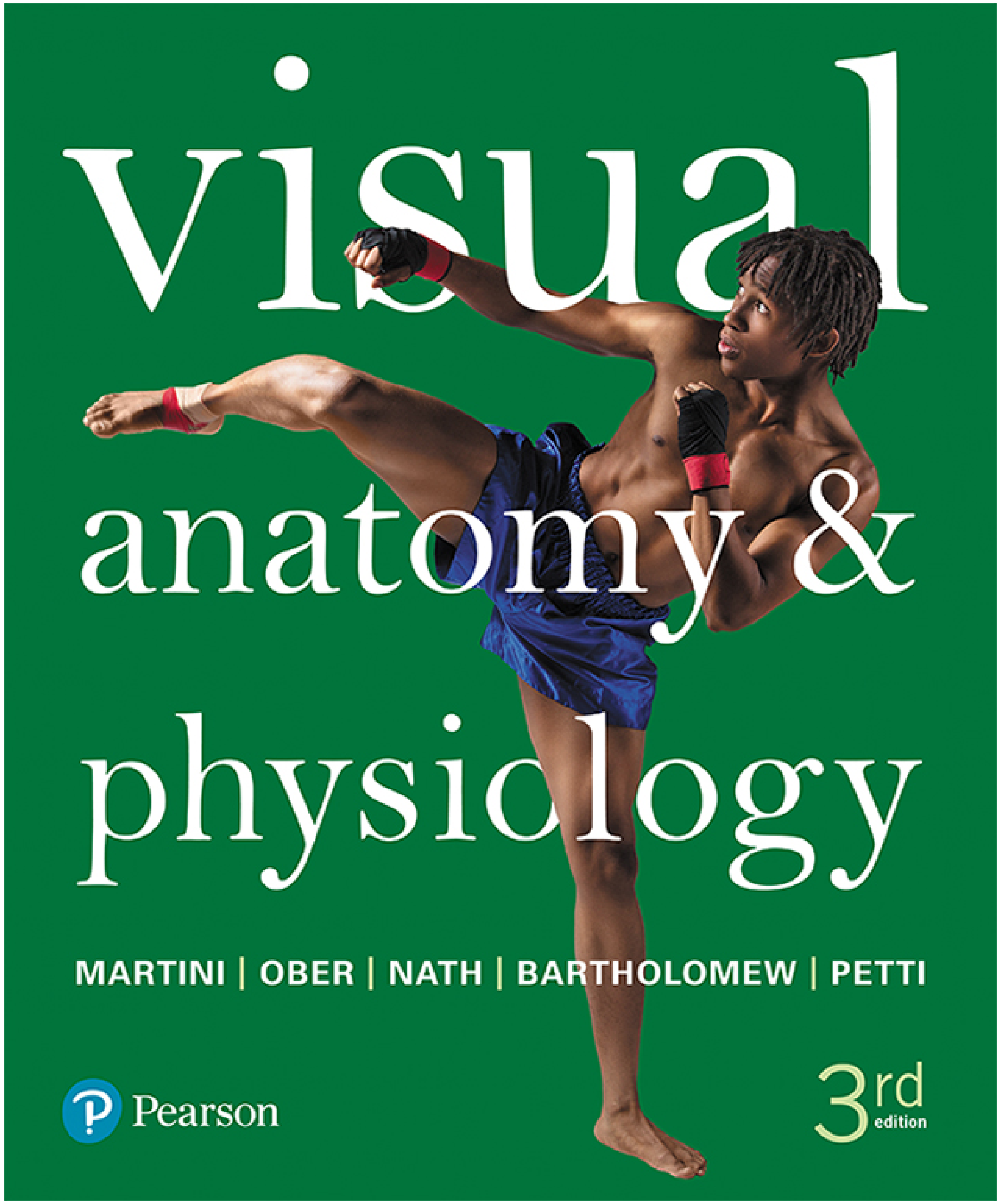


19

Blood Vessels and Circulation

Lecture Presentation by
Lori Garrett

Section 1: Functional Anatomy of Blood Vessels

Learning Outcomes

19.1 Distinguish between the pulmonary and systemic circuits, and identify afferent and efferent blood vessels.

19.2 Distinguish among the types of blood vessels on the basis of their structure and function.

19.3 Describe the structures of capillaries and their functions in the exchange of dissolved materials between blood and interstitial fluid.

19.4 Describe the venous system, and indicate the distribution of blood within the cardiovascular system.

Module 19.1: The heart pumps blood, in sequence, through the arteries, capillaries, and veins of the pulmonary and systemic circuits

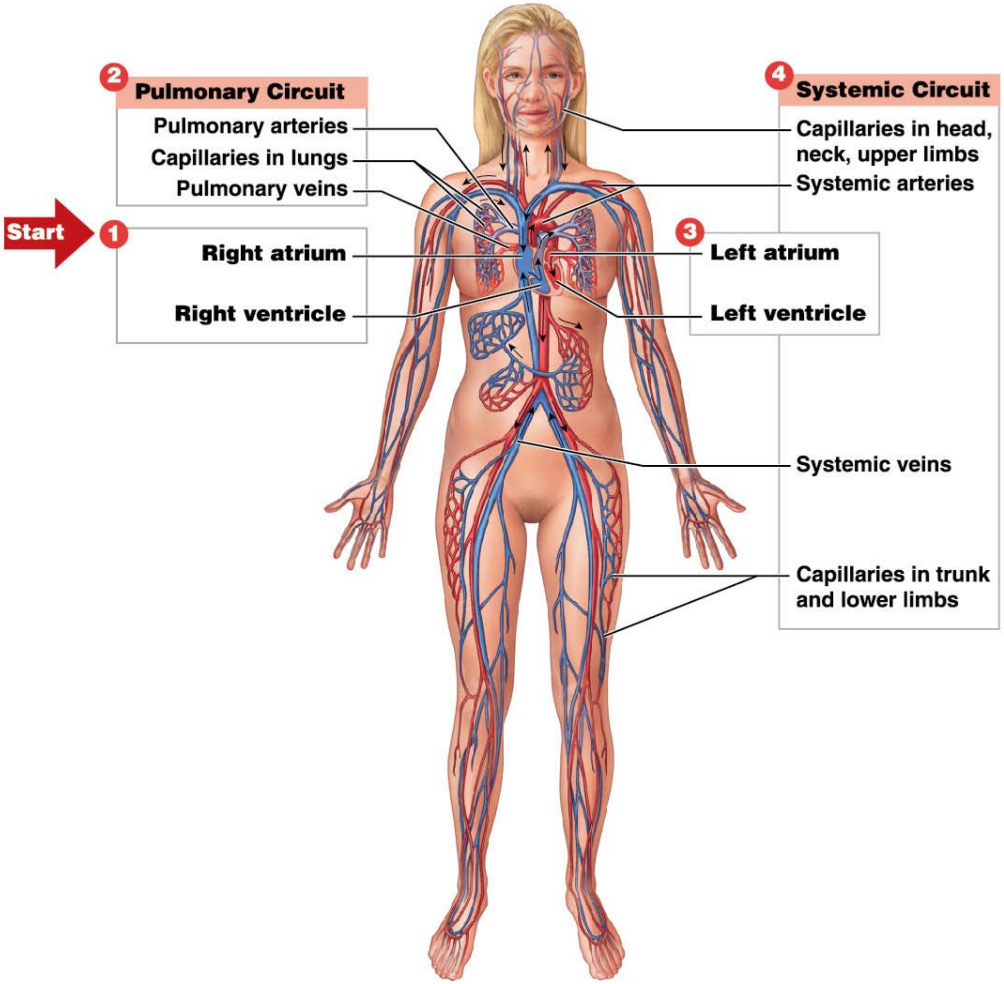
Blood vessels

- Blood vessels conduct blood between the heart and peripheral tissues
- **Arteries** (carry blood away from the heart)
  - Also called *efferent vessels*
- **Veins** (carry blood to the heart)
  - Also called *afferent vessels*
- **Capillaries** (exchange substances between blood and tissues)
  - Interconnect smallest arteries and smallest veins

Module 19.1: Blood vessels and circuits

Two circuits

1. **Pulmonary circuit**
   - To and from gas exchange surfaces in the lungs
2. **Systemic circuit**
   - To and from rest of body



Module 19.1: Blood vessels and circuits

Circulation pathway through circuits

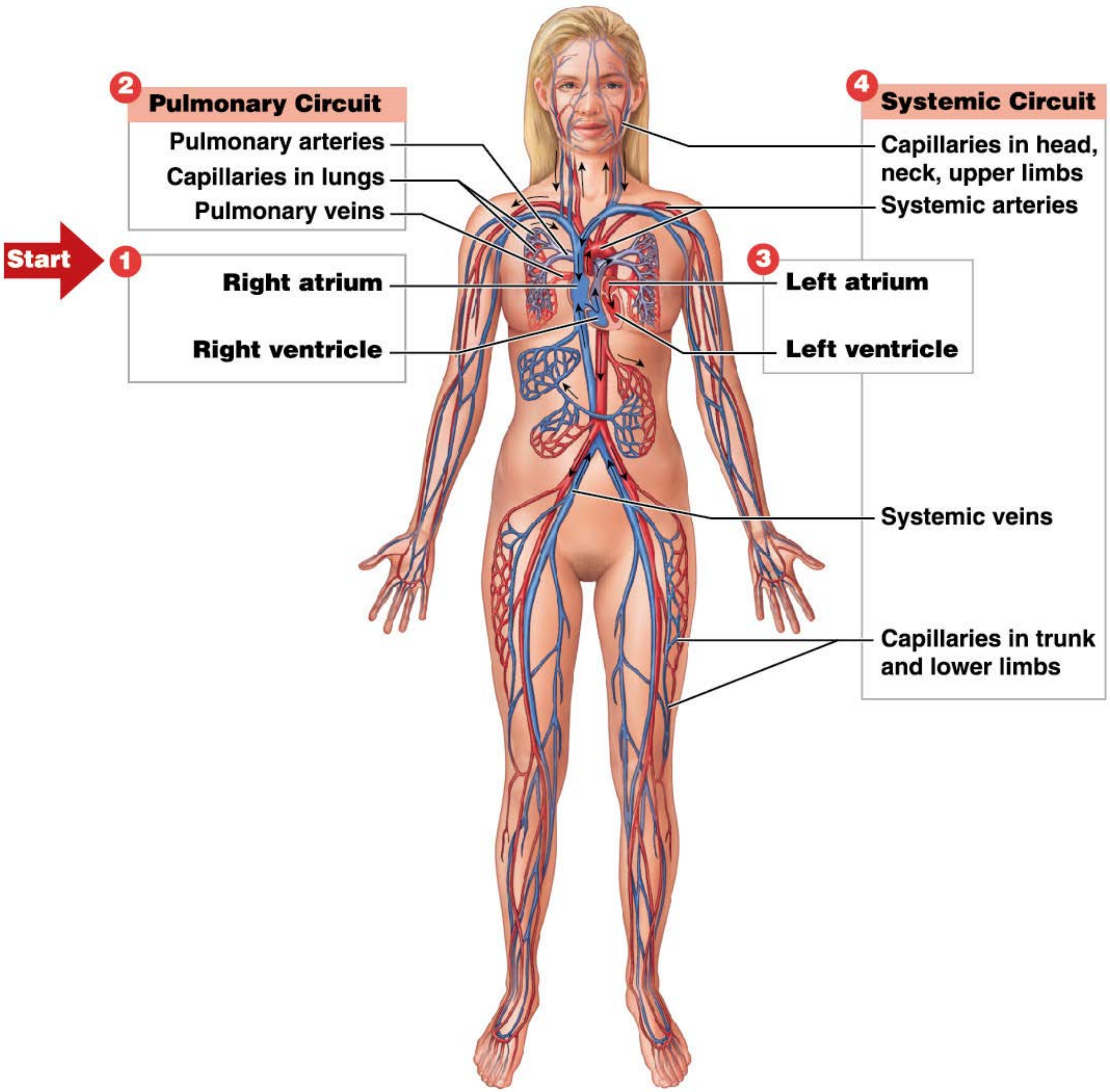
1. **Right atrium** (entry chamber)
   - Collects blood from systemic circuit
   - To **right ventricle** to pulmonary circuit
2. **Pulmonary circuit**
   - Pulmonary arteries to pulmonary capillaries to pulmonary veins

Module 19.1: Blood vessels and circuits

Circulation pathway through circuits (continued)

3. **Left atrium**
   - Receives blood from pulmonary circuit
   - To **left ventricle** to systemic circuit
4. **Systemic circuit**
   - Systemic arteries to systemic capillaries to systemic veins

Circulation pathway through the circuits



Module 19.1: Review

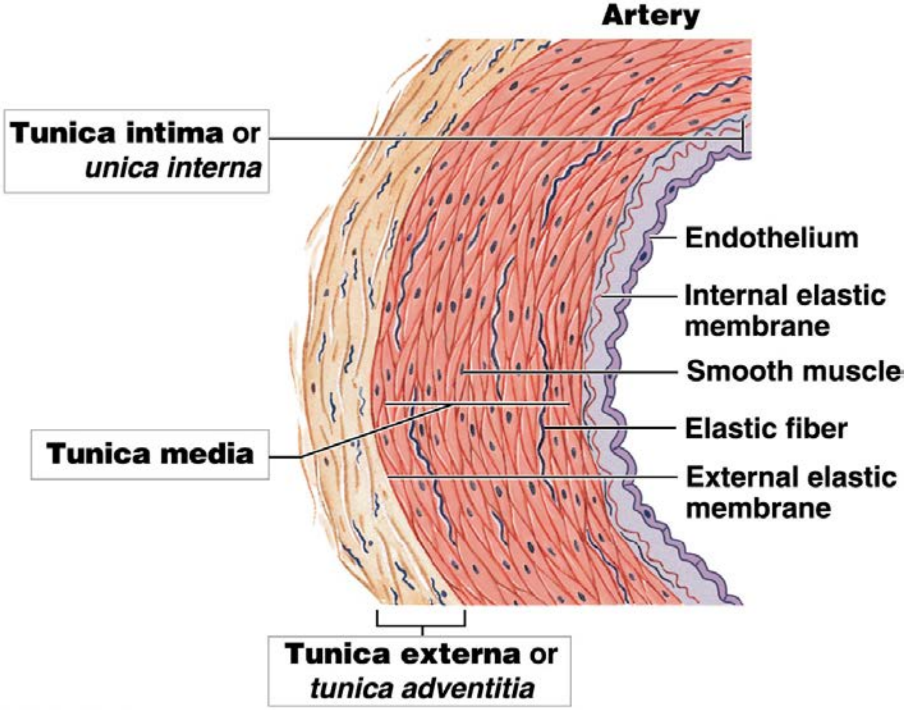
A. Describe the pulmonary circuit.
B. Describe the systemic circuit.
C. Which chamber of the heart receives blood from the systemic circuit?
D. Distinguish among efferent vessels, afferent vessels, and exchange vessels.

Learning Outcome: Distinguish between the pulmonary and systemic circuits, and identify afferent and efferent blood vessels.

Module 19.2: Arteries and veins differ in the structure and thickness of their walls

Three layers of arteries and veins

1. **Tunica intima**, or *tunica interna*
   - Innermost layer
   - Endothelial cells with connective tissue with elastic fibers
     - In arteries, outer margin has layer of elastic fibers (**internal elastic membrane**)



Module 19.2: Arteries and veins

Three layers of arteries and veins (continued)

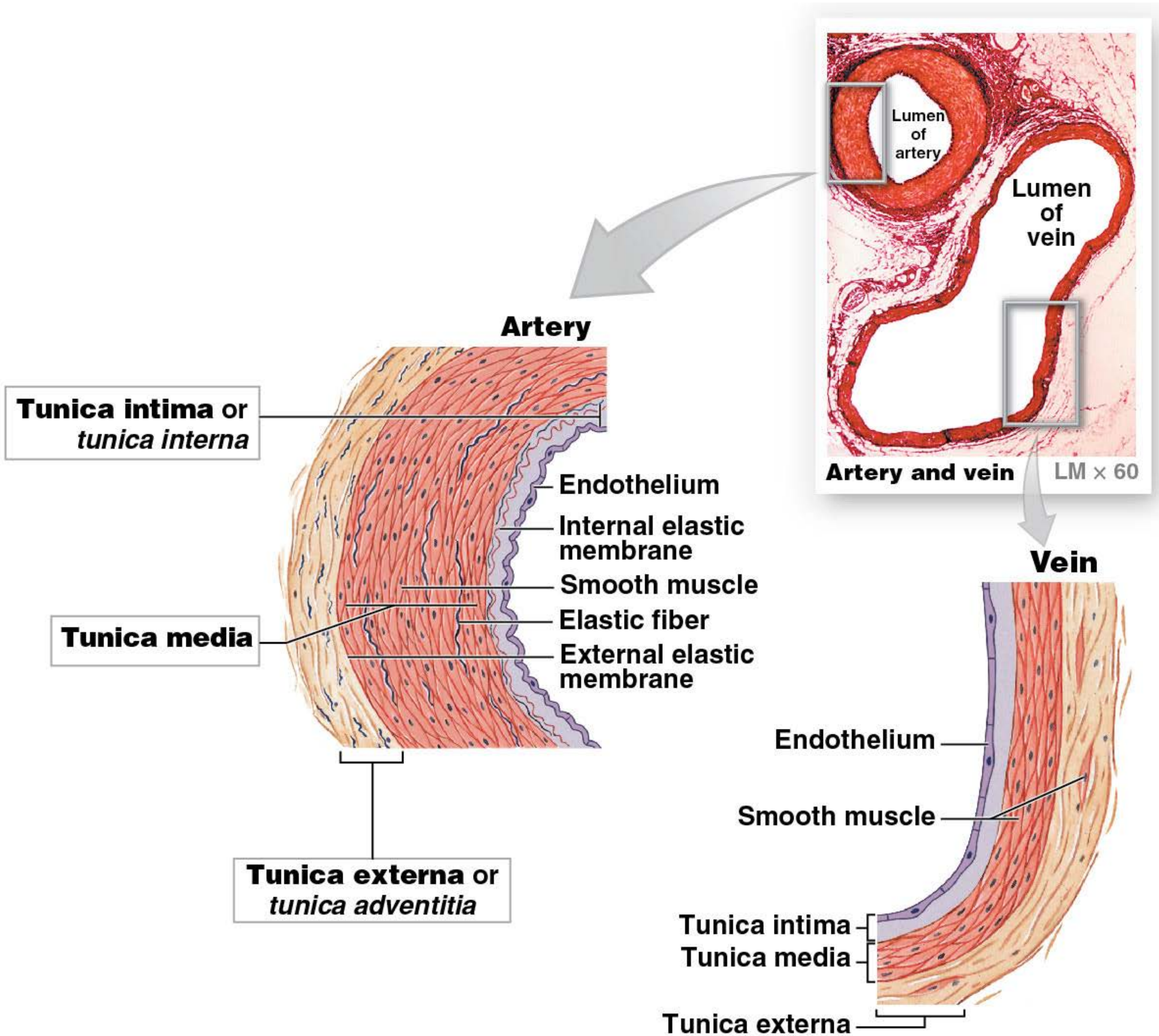
2. **Tunica media**
   - Middle layer
   - Contains concentric sheets of smooth muscle
     - Contraction causes a decrease in vessel diameter, or **vasoconstriction**
     - Relaxation causes an increase in vessel diameter, or **vasodilation**
   - Separated from the tunica externa by the **external elastic membrane**

Module 19.2: Arteries and veins

Three layers of arteries and veins (continued)

3. **Tunica externa**, or *tunica adventitia*
   - Outermost layer
   - Connective tissue sheath
     - In arteries, contains collagen and scattered elastic fibers
     - In veins, generally thicker than the tunica media
       - Contains networks of elastic fibers and bundles of smooth muscle cells
   - Anchors vessel to surrounding tissues

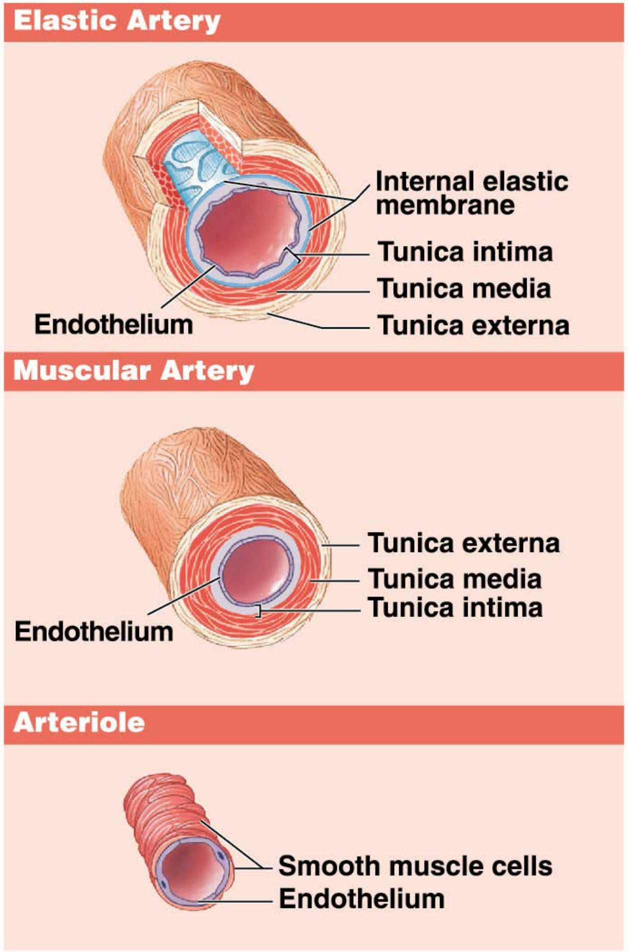
Blood vessel layers



Module 19.2: Arteries and veins

Five general blood vessel classes

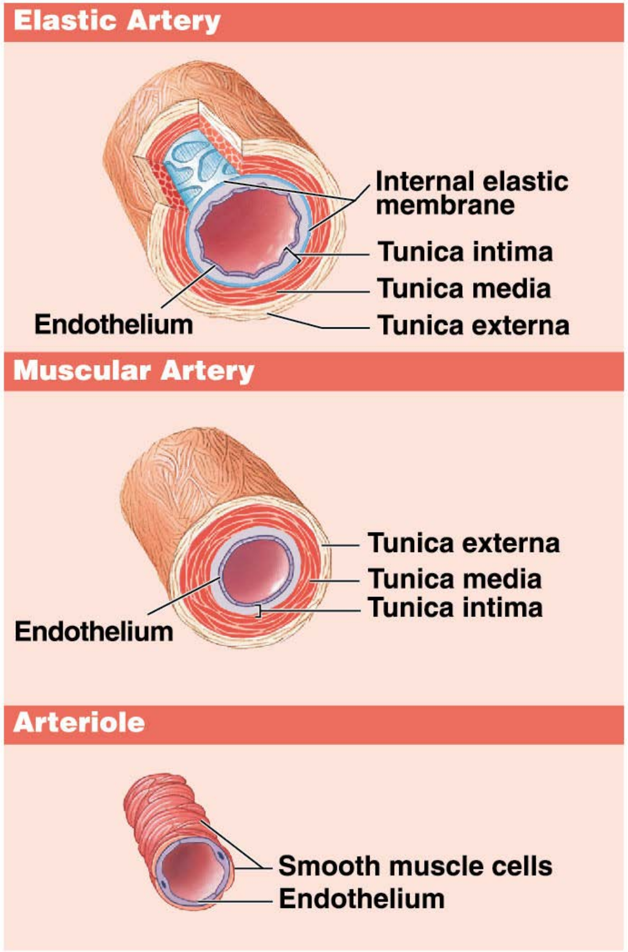
1. **Arteries**
   - **Elastic arteries**
     – Large vessels close to the heart that stretch and recoil when heart beats
     – Include pulmonary trunk, aorta, and branches
   - **Muscular arteries**
     – Medium-sized arteries
     – Distribute blood to skeletal muscles and internal organs



Module 19.2: Arteries and veins

Five general blood vessel classes (continued)

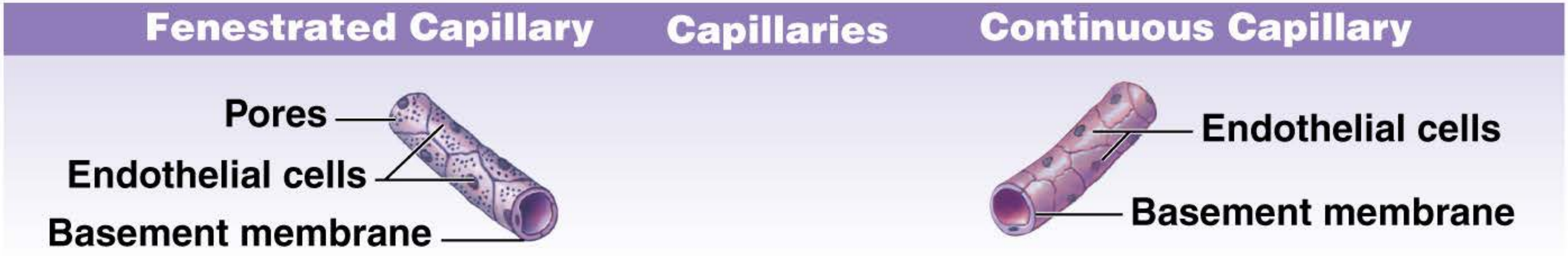
2. **Arterioles**
   - Poorly defined tunica externa
   - Tunica media is only 1–2 smooth muscle cells thick



Module 19.2: Arteries and veins

Five general blood vessel classes (continued)

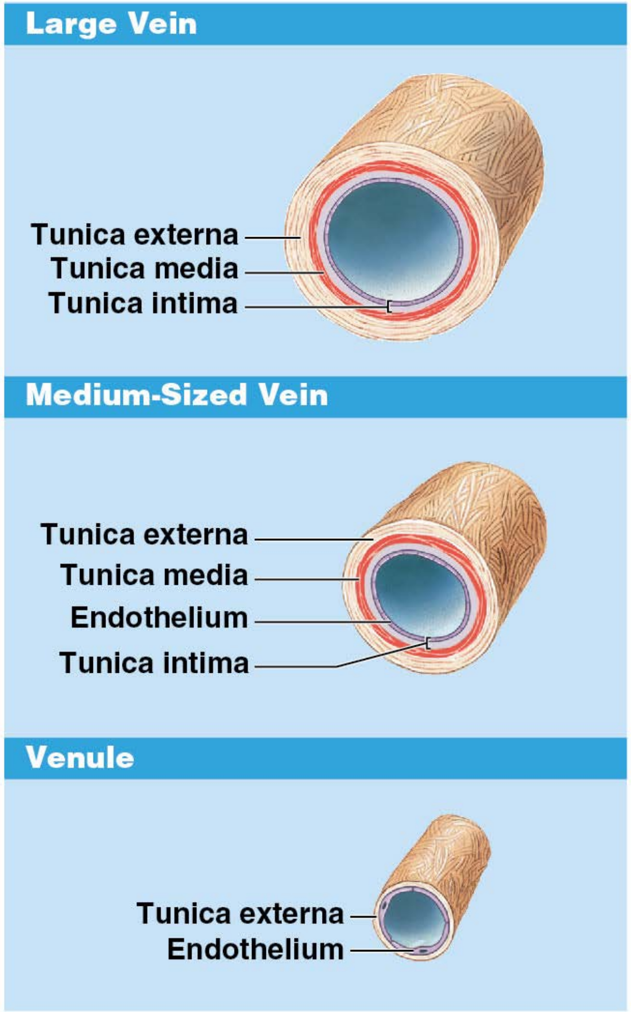
3. **Capillaries**
   - Only blood vessels to allow exchange between blood and interstitial fluid
   - Very thin walls allow easy diffusion



Module 19.2: Arteries and veins

Five general blood vessel classes (continued)

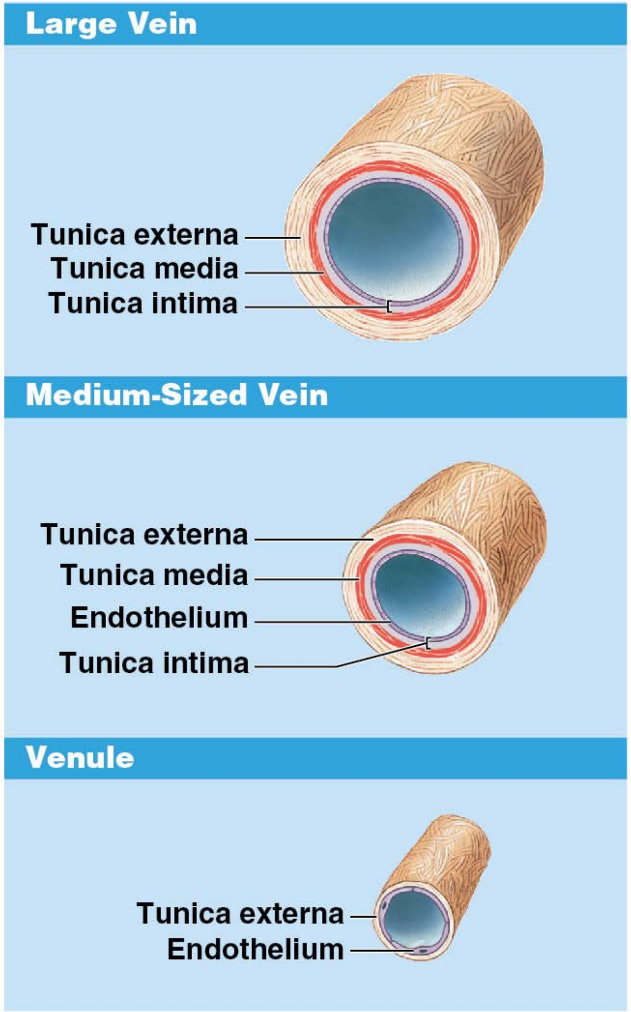
4. **Venules**
   - Small veins
     - Those smaller than 50 µm lack a tunica media and resemble expanded capillaries
   - Collect blood from capillaries



Module 19.2: Arteries and veins

Five general blood vessel classes (continued)

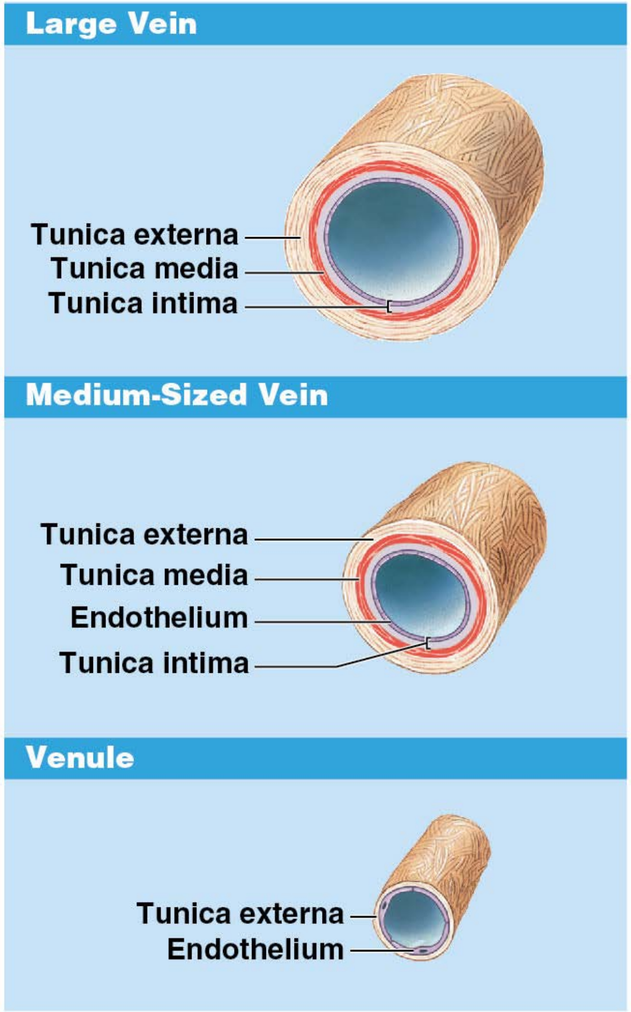
5. **Veins**
   - **Medium-sized veins**
     - Range from 2 to 9 mm in internal diameter
     - Thin tunica media with smooth muscle cells and collagen fibers
     - Thickest layer is tunica externa with longitudinal collagen and elastic fibers



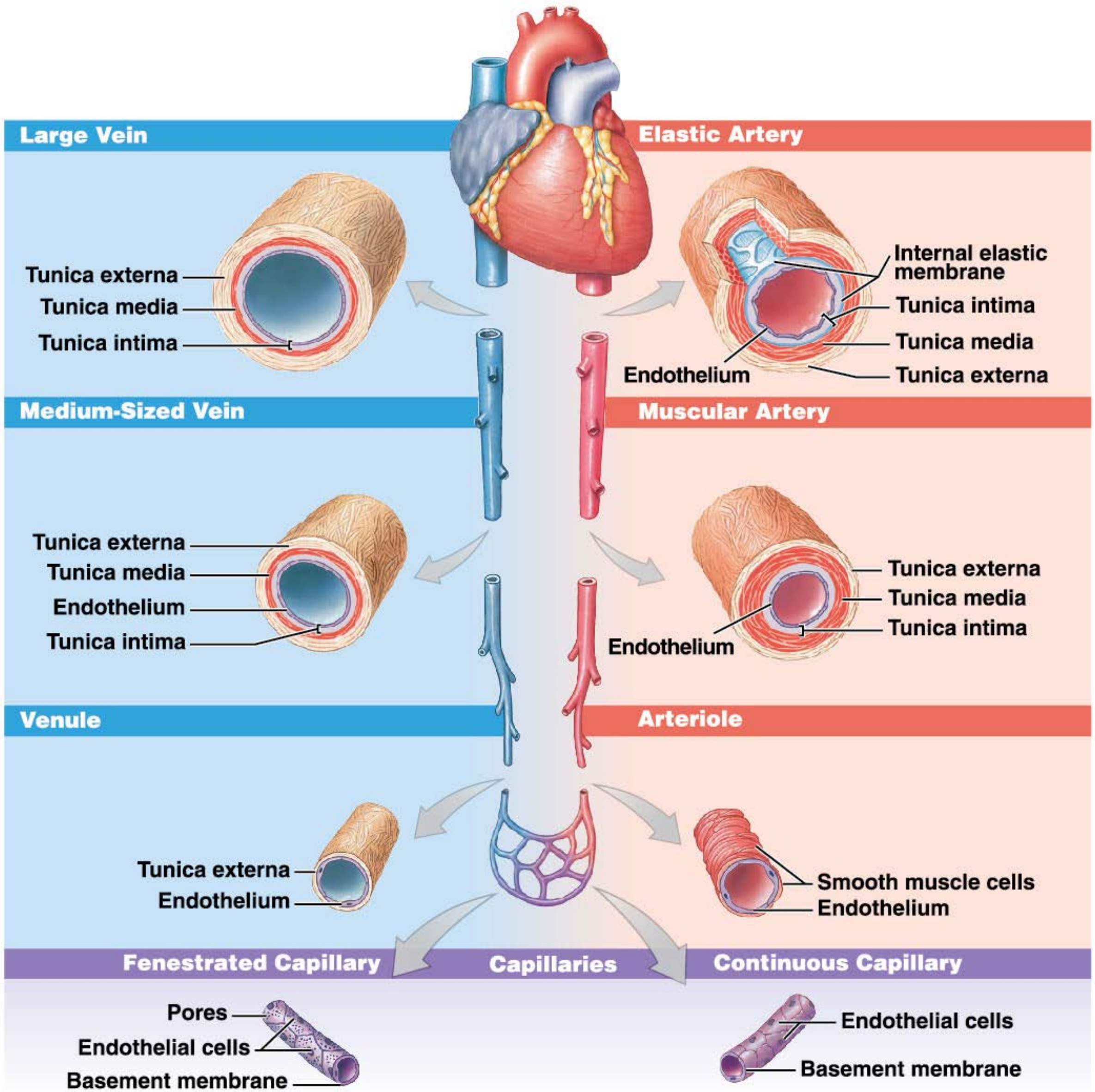
Module 19.2: Arteries and veins

Five general blood vessel classes (continued)

5. **Veins** (continued)
   - **Large veins**
     - Contain all three vessel wall layers
       - Thin tunica media surrounded by thick tunica externa
     - Include superior and inferior venae cavae and tributaries



Blood vessels



Features of Typical (Medium-Sized) Arteries and Veins

Feature	Typical Artery	Typical Vein
General appearance in sectional view	Usually round, with relatively thick wall Small lumen	Usually flattened or collapsed, with relatively thin wall Large lumen
Tunica intima		
Endothelium	Usually rippled because of vessel constriction	Often smooth
Internal elastic membrane	Present	Absent
Tunica media	Thick, dominated by smooth muscle cells and elastic fibers	Thin, dominated by smooth muscle cells and collagen fibers
External elastic membrane	Present	Absent
Tunica externa	Collagen and elastic fibers	Collagen, elastic fibers, and smooth muscle cells

Module 19.2: Arteries and veins

Large vessel walls

- Contain small arteries and veins for nourishment
  - **Vasa vasorum**, “vessels of vessels”

Module 19.2: Review

A. List the five general classes of blood vessels.
B. Describe a capillary.

Learning Outcome: Distinguish among the types of blood vessels on the basis of their structure and function.

Module 19.3: Capillary structure and capillary blood flow affect the rates of exchange between the blood and interstitial fluid

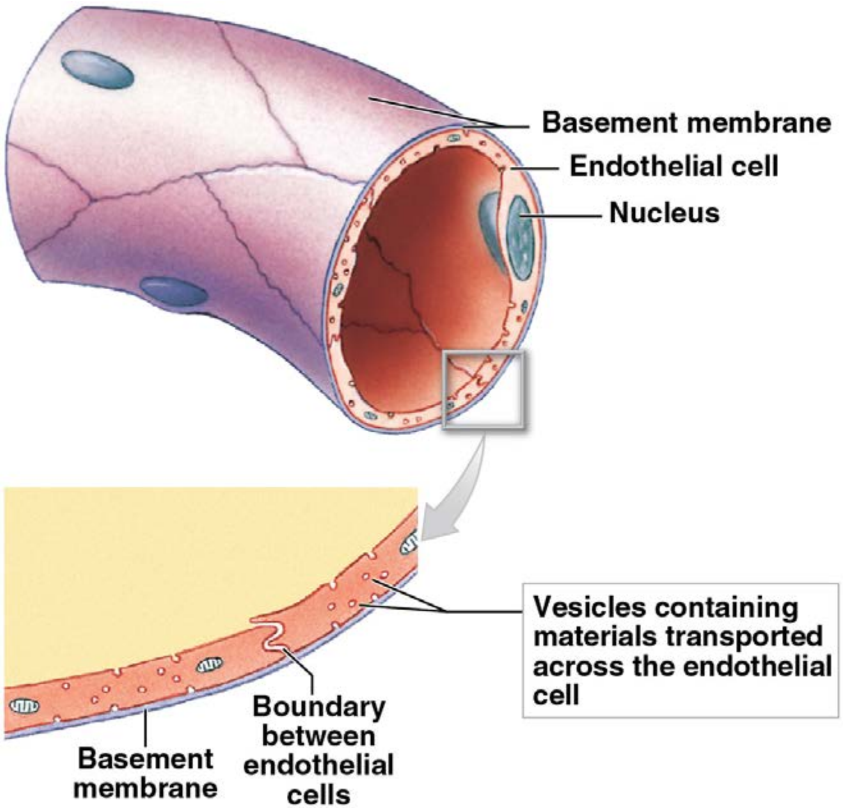
Typical capillary

- Consists of a tube of endothelial cells with delicate basement membrane
  - Lacking both tunica media and tunica externa
- Average diameter = 8 µm
  - About the same as a single RBC
- Two major types
  1. **Continuous capillaries**
  2. **Fenestrated capillaries**

Module 19.3: Capillaries

Continuous capillary

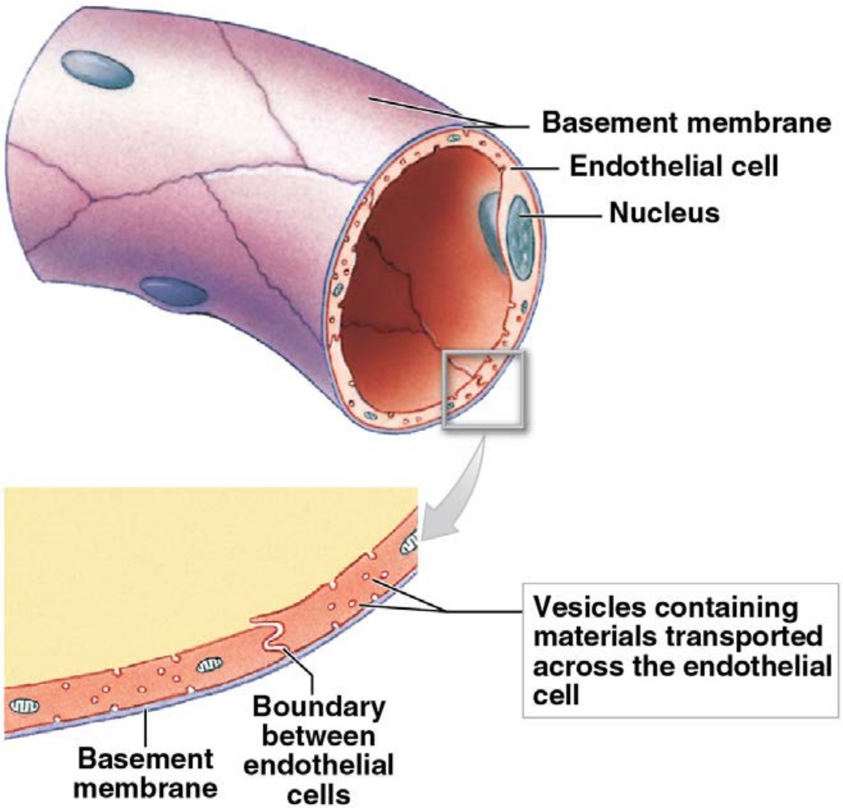
- Endothelium is a complete lining
- Located throughout body in all tissues except epithelia and cartilage
- Permits diffusion of water, small solutes, and lipid-soluble materials
  - Prevents loss of blood cells and plasma proteins
  - Some selective vesicular transport



Module 19.3: Capillaries

Continuous capillary (continued)

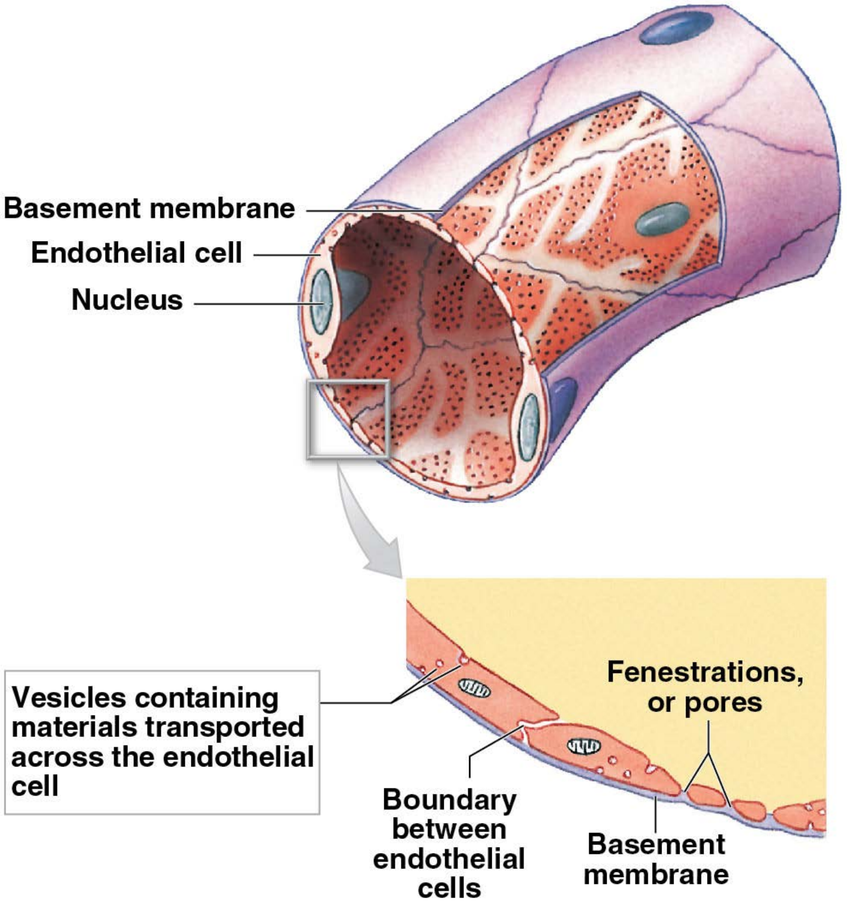
- Specialized continuous capillaries in CNS and thymus have endothelial tight junctions
  - Enables restricted and regulated permeability



Module 19.3: Capillaries

Fenestrated (*fenestra*, window) capillary

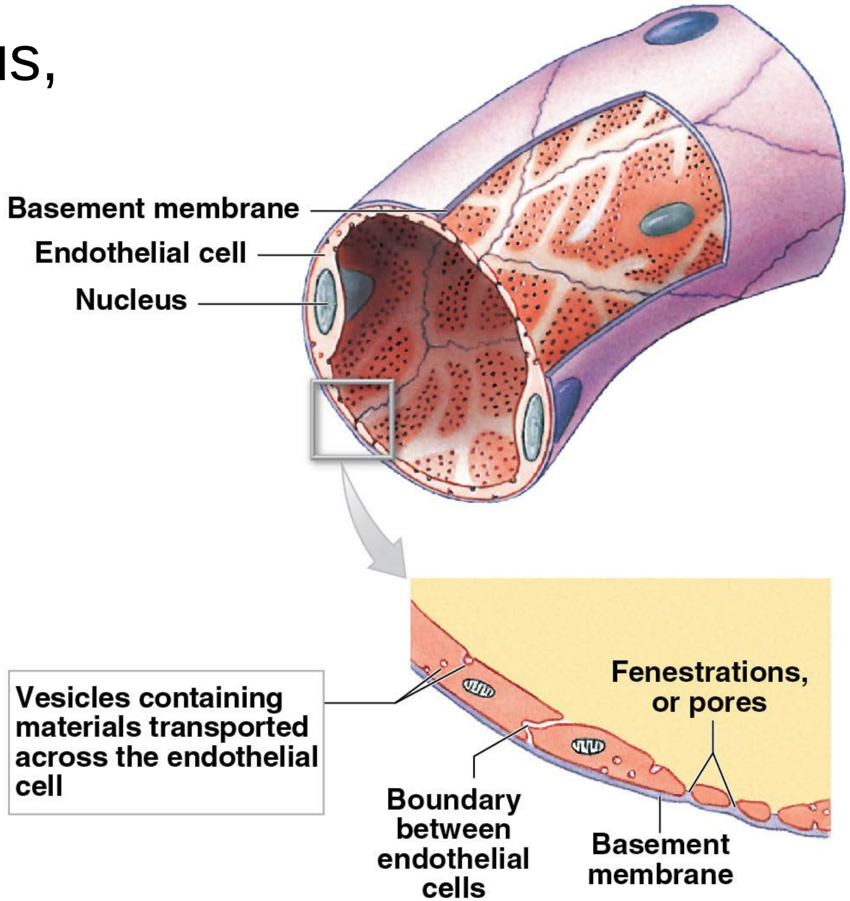
- Contains "windows," or pores, penetrating endothelial lining
- Permits rapid exchange of water and larger solutes



Module 19.3: Capillaries

Fenestrated capillary (continued)

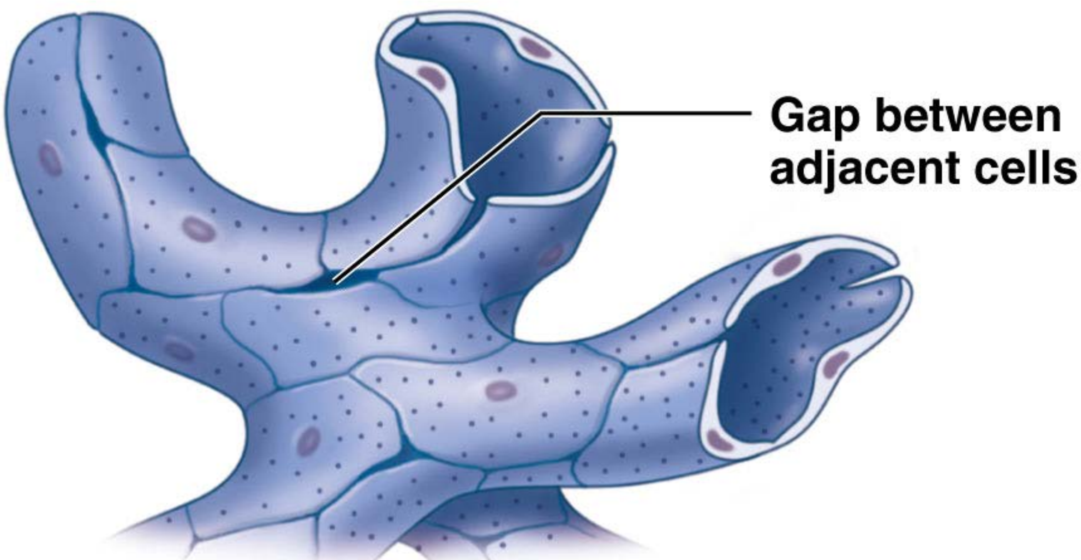
- Examples found in:
  - Choroid plexus of brain
  - Capillaries of hypothalamus, pituitary, pineal, and thyroid glands
  - Absorptive areas of intestinal tract
  - Kidney filtration sites



Module 19.3: Capillaries

Sinusoids (**sinusoidal capillaries**)

- Resemble fenestrated capillaries that are flattened and irregularly shaped
- Commonly have gaps between endothelial cells
- Basement membrane is thin or absent

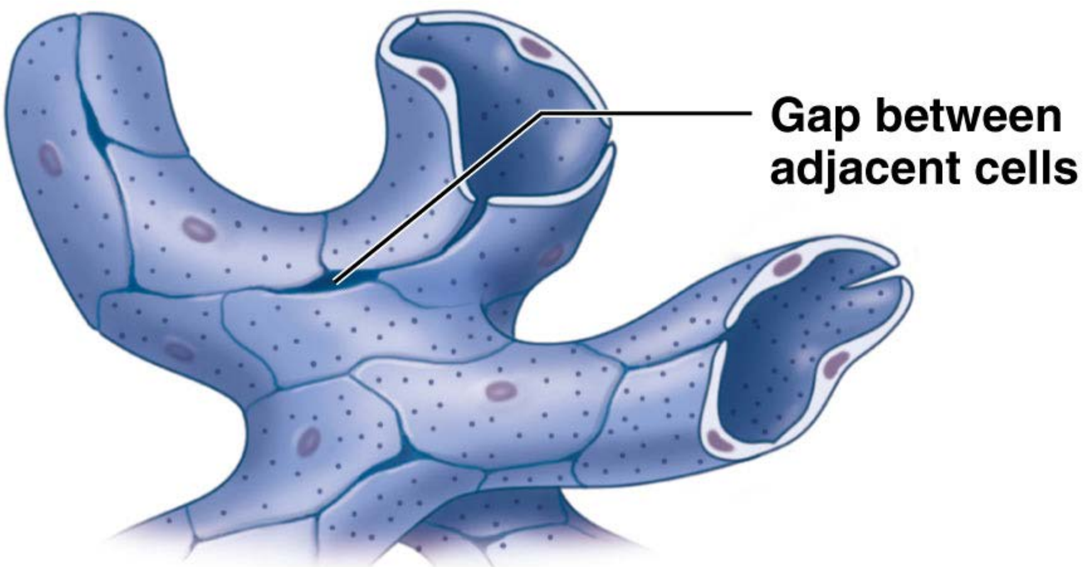


Sinusoids

Module 19.3: Capillaries

Sinusoids (continued)

- Permit more water and solute (plasma proteins) exchange
- Occur in liver, bone marrow, spleen, and many endocrine organs

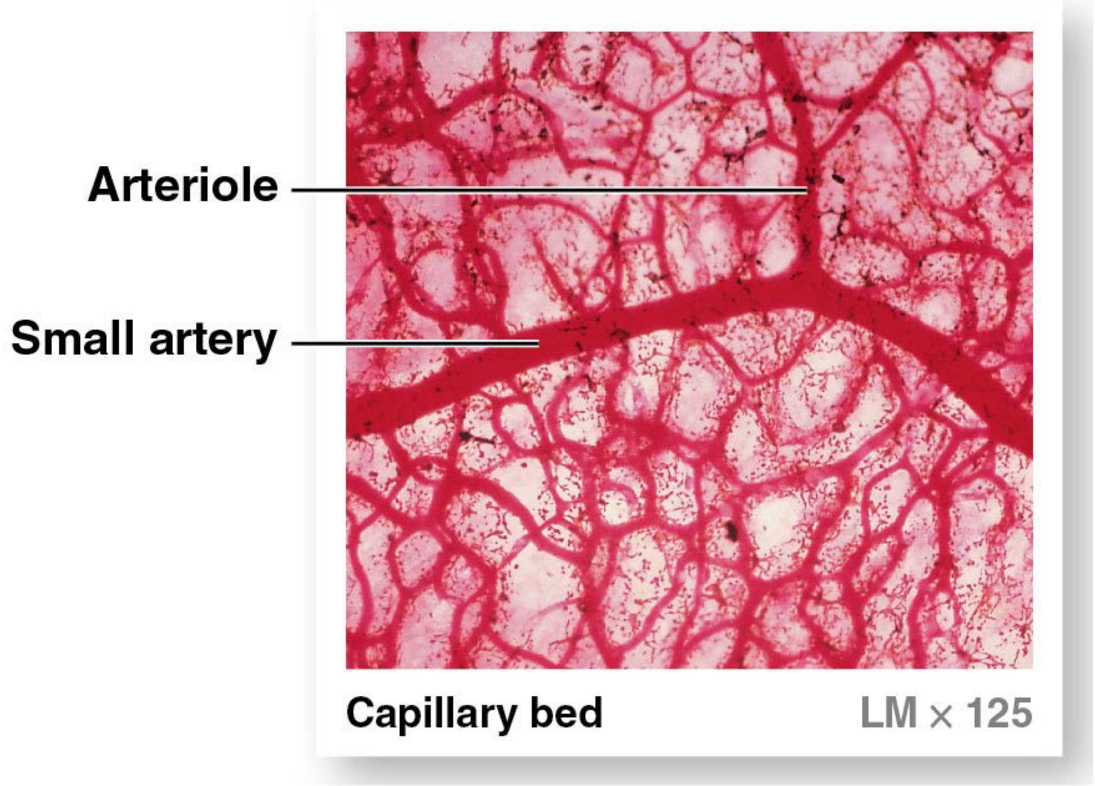


Sinusoids

Module 19.3: Capillaries

Capillary bed

- Interconnected network of capillaries
  - Contains several connections between arterioles and venules



Capillary bed

Module 19.3: Capillaries

Capillary bed (continued)

- May be supplied by more than one artery
  - Multiple arteries called **collaterals**
  - Fuse before giving rise to arterioles
  - Fusion is an example of **arterial anastomosis**
    - *Anastomosis* is joining of blood vessels
  - Allows continuous delivery of blood to capillary bed even if one artery is blocked or compressed

Module 19.3: Capillaries

Capillary bed (continued)

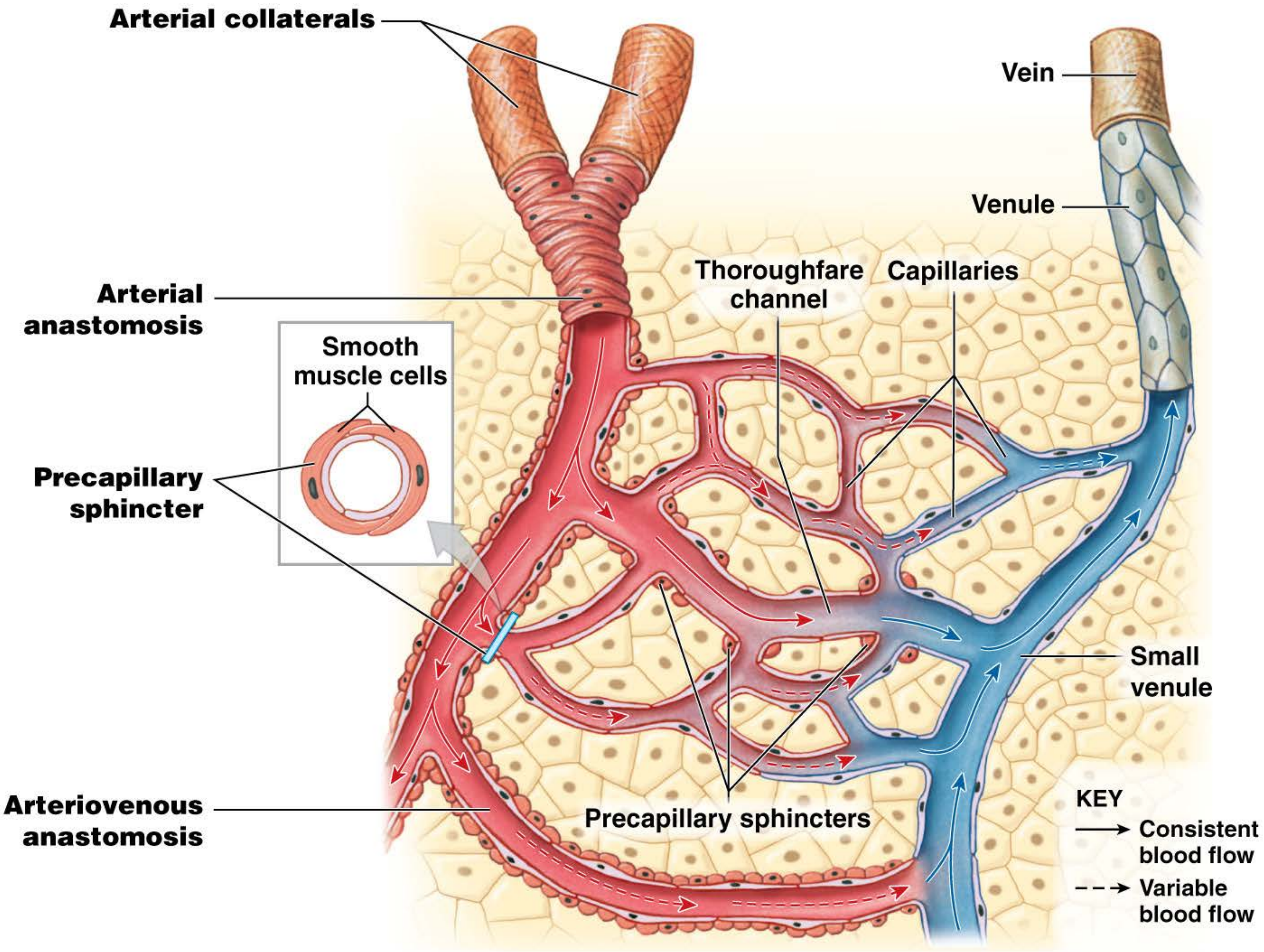
- Can be bypassed by **arteriovenous anastomosis** that directly connects arteriole to venule
  - Regulated by sympathetic innervation
- **Metarteriole**, or **precapillary arteriole**
  - Initial segment of the connection passageway
  - Contains smooth muscle that can change the vessel's diameter and adjust flow rate

Module 19.3: Capillaries

Capillary bed (continued)

- **Thoroughfare channel**
  - Most direct passageway through capillary bed
- **Precapillary sphincters**
  - Bands of smooth muscle that contract and relax to control flow into the capillary bed
- **Vasomotion**
  - Cycles of contraction and relaxation

Capillary bed



Module 19.3: Review

A. Identify the two types of capillaries with a complete endothelium.

B. At what sites in the body are fenestrated capillaries located?

Learning Outcome: Describe the structures of capillaries and their functions in the exchange of dissolved materials between blood and interstitial fluid.

Module 19.4: The venous system has low pressures and contains almost two-thirds of the body's blood volume

Pressure and blood flow in veins

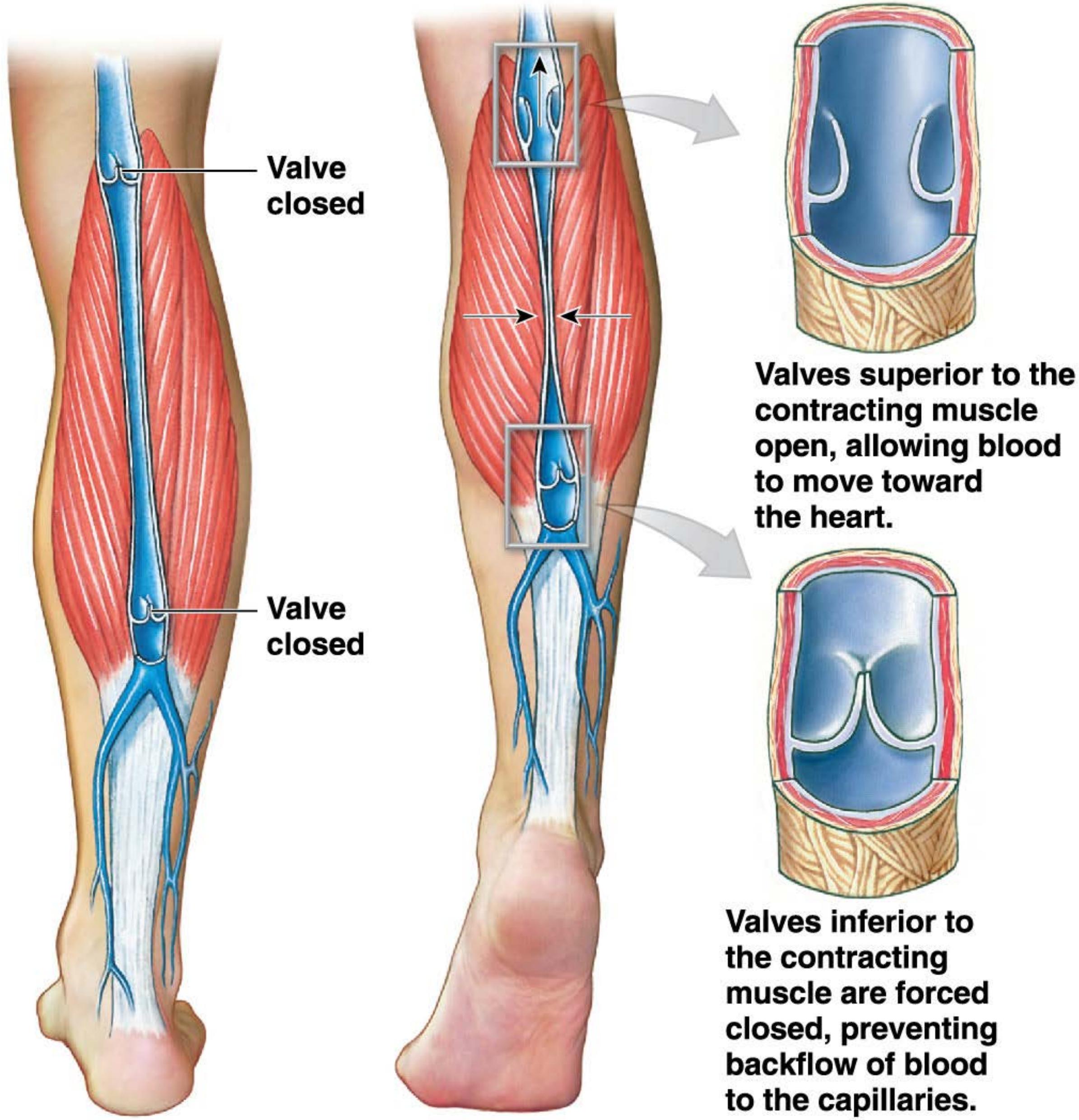
- Blood pressure in peripheral venules is <10 percent of that in ascending aorta (largest artery)
- Mechanisms are needed to maintain flow of blood in veins against force of gravity
  - **Valves**
    - Folds of tunica intima projecting from vessel wall and pointing in the direction of blood flow
    - Ensure one-way flow of blood toward heart
  - Contraction of skeletal muscles

Module 19.4: The venous system

Process of maintaining blood flow in veins

- Contraction of skeletal muscles squeezes veins (and the blood within them)
  - Valves permit blood flow in one direction and prevent backflow of blood toward capillaries
  - If valves do not work properly, blood can pool in veins, causing distention and a range of effects
    - Mild discomfort and cosmetic problems, as with **varicose veins** (in thighs and legs)
    - Painful distortion of adjacent tissues, as in **hemorrhoids** (form in the venous networks of the anal canal)

Veins have valves

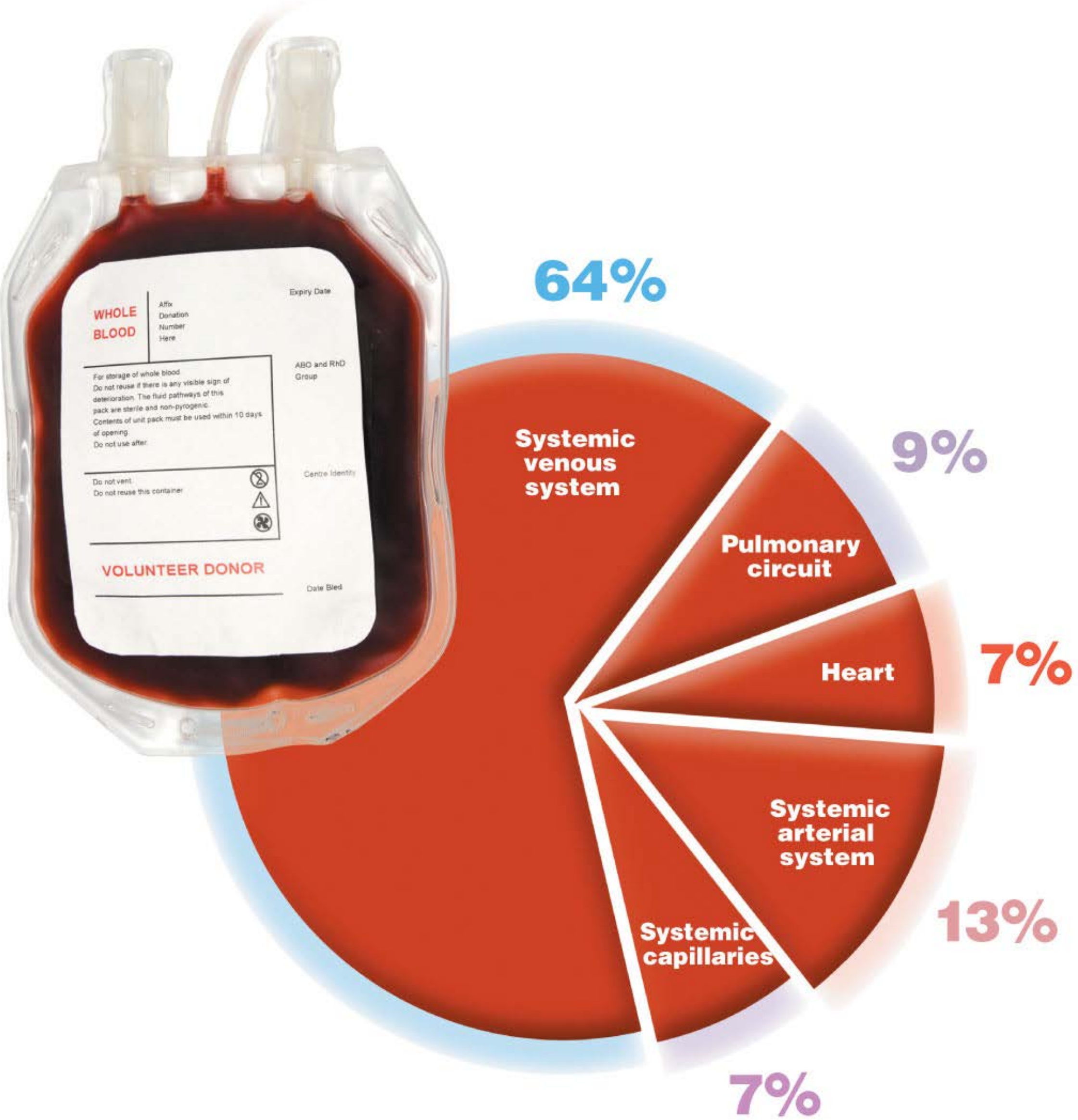


Module 19.4: The venous system

Total blood volume distribution

- Uneven distribution among arteries, veins, and capillaries
- Systemic venous system contains 64 percent of total blood volume (~3.5 L)
  - Of that , ~1 L is in venous networks carrying blood from digestive organs to liver
  - Act as **blood reservoirs**
- Systemic arteries contain 13 percent total blood volume
- The remaining blood is in the systemic capillaries, heart, and pulmonary circuit

Distribution of body's blood

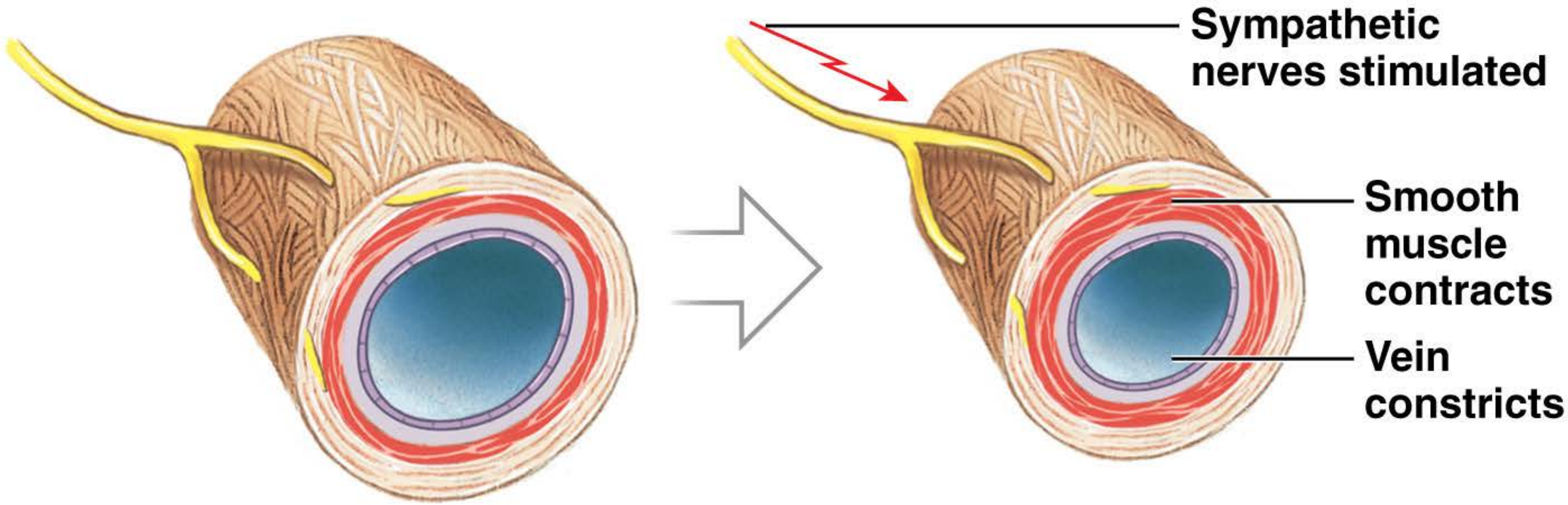


Module 19.4: The venous system

Venoconstriction

- Contraction of smooth muscle fibers in veins
  - Reduces diameter of the veins and the amount of blood in the venous system
- Method of maintaining blood volume in the arterial system even with a significant blood loss
  - Controlled by the vasomotor center in the medulla oblongata
  - Sympathetic nerves stimulate smooth muscles in medium-sized veins

Venoconstriction



Module 19.4: Review

A. Why are valves located in veins but not in arteries?
B. How is blood pressure maintained in veins to counter the force of gravity?
C. Describe the distribution of total blood volume in the body.
D. What factors are involved in the formation of varicose veins?

Learning Outcome: Describe the venous system, and indicate the distribution of blood within the cardiovascular system.

Section 2: Coordination of Cardiac Output and Blood Flow

Learning Outcomes

19.5 Explain the effects of pressure, resistance, and venous return on cardiac output.

19.6 Describe the factors that influence total peripheral resistance.

19.7 Describe the factors that determine blood flow.

19.8 Describe the movement of fluids between capillaries and interstitial spaces.

Section 2: Coordination of Cardiac Output and Blood Flow

Learning Outcomes (continued)

19.9 Explain central regulation, autoregulation, and baroreceptor reflexes in response to changes in blood pressure and blood composition.

19.10 Explain the hormonal regulation of blood pressure and blood volume.

19.11 Describe the role of chemoreceptor reflexes in adjusting cardiovascular activity.

Section 2: Coordination of Cardiac Output and Blood Flow

Learning Outcomes (continued)

19.12 Explain how the cardiovascular system responds to the demands of exercise.

19.13 **Clinical Module:** Explain the body's response to blood loss.

Module 19.5: Pressure, resistance, and venous return affect cardiac output

Cardiovascular regulation

- Accomplished by adjusting both:
  - **Cardiac output**
    - Must generate enough pressure to force blood through miles of peripheral capillaries
  - Blood flow regulation within systemic and pulmonary circuits

Module 19.5: Cardiovascular regulation

Cardiovascular regulation (continued)

- **Autoregulation** acts locally
- **Central regulation**
  - Involves neural and endocrine mechanisms
  - Makes coordinated adjustments to heart rate, stroke volume, peripheral resistance, and venous pressure so cardiac output is sufficient

Module 19.5: Cardiovascular regulation

Cardiovascular regulation (continued)

- Pulsing of the heart generates pressure
- **Blood pressure**
  - Pressure within the cardiovascular system as a whole
    - **Arterial pressure** is much higher than **venous pressure**
      - Must push blood greater distance through smaller vessels

Module 19.5: Cardiovascular regulation

Cardiovascular regulation (continued)

- Flow through blood vessels is influenced by **resistance**
  - Force that opposes movement
  - **Peripheral resistance**
    - Resistance of the arterial system as a whole
    - Increases as vessels get smaller

Module 19.5: Cardiovascular regulation

Cardiovascular regulation (continued)

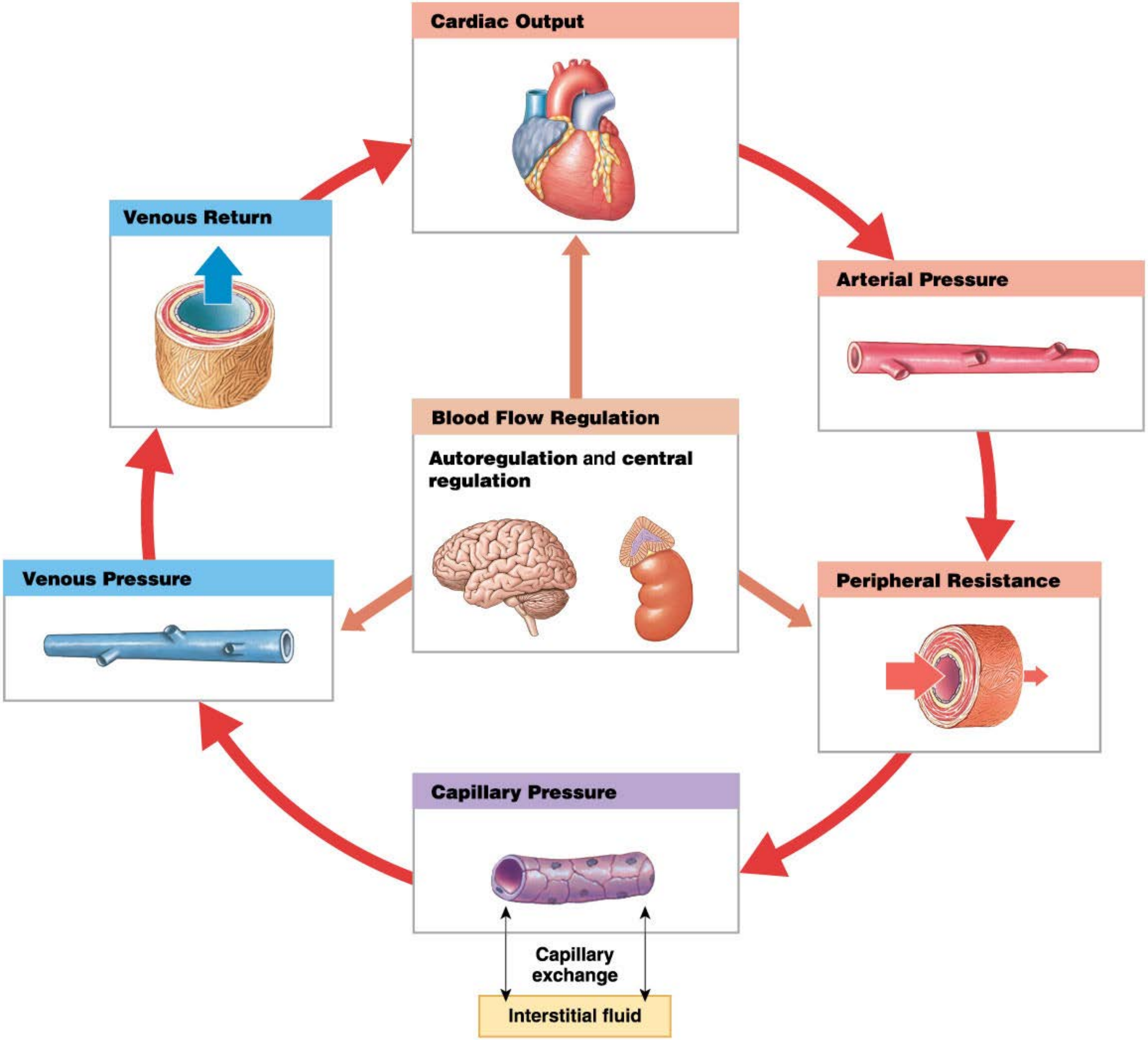
- Blood flow in capillaries is very slow
  - Capillary pressure is very low
  - Allows plenty of time for **capillary exchange**
    - Diffusion between blood and interstitial fluid

Module 19.5: Cardiovascular regulation

Cardiovascular regulation (continued)

- Blood pressure in veins is maintained by:
  - Valves
  - Muscular compression of peripheral veins
- As blood moves toward the heart, vessels get larger, and resistance decreases
- **Venous return**
  - Amount of blood arriving at the right atrium each minute
  - On average, equal to the cardiac output

Cardiovascular regulation



Module 19.5: Review

A. Neural and endocrine regulatory mechanisms influence which factors?
B. Which is greater: arterial pressure or venous pressure?
C. Why is it beneficial for capillary pressure to be very low?

Learning Outcome: Explain the effects of pressure, resistance, and venous return on cardiac output.

Module 19.6: Vessel luminal diameter is the main source of resistance within the cardiovascular system

Total peripheral resistance

- Resistance of entire cardiovascular system
  - Must be overcome by sufficient pressure from the heart in order for circulation to occur
  - Depends on three factors
    1. *Vascular resistance*
    2. *Viscosity*
    3. *Turbulence*

Module 19.6: Factors affecting peripheral resistance

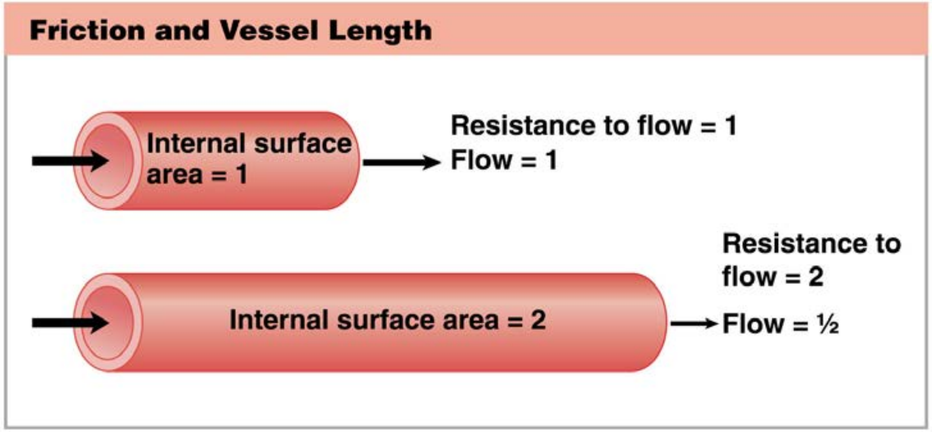
Total peripheral resistance (continued)

1. **Vascular resistance**
   - Opposition to blood flow in vessels
     - Largest component of total peripheral resistance
     - Primarily results from friction between blood and vessel walls
     - Amount of friction depends on two factors
       1. Vessel length
       2. Vessel diameter

Module 19.6: Factors affecting peripheral resistance

Total peripheral resistance (continued)

1. **Vascular resistance** (continued)
   1. Vessel length
      – Friction occurs between vessel walls and moving blood
      – Increase in vessel length = increased surface area = increased in friction or resistance
      – Largest change occurs between birth and maturity

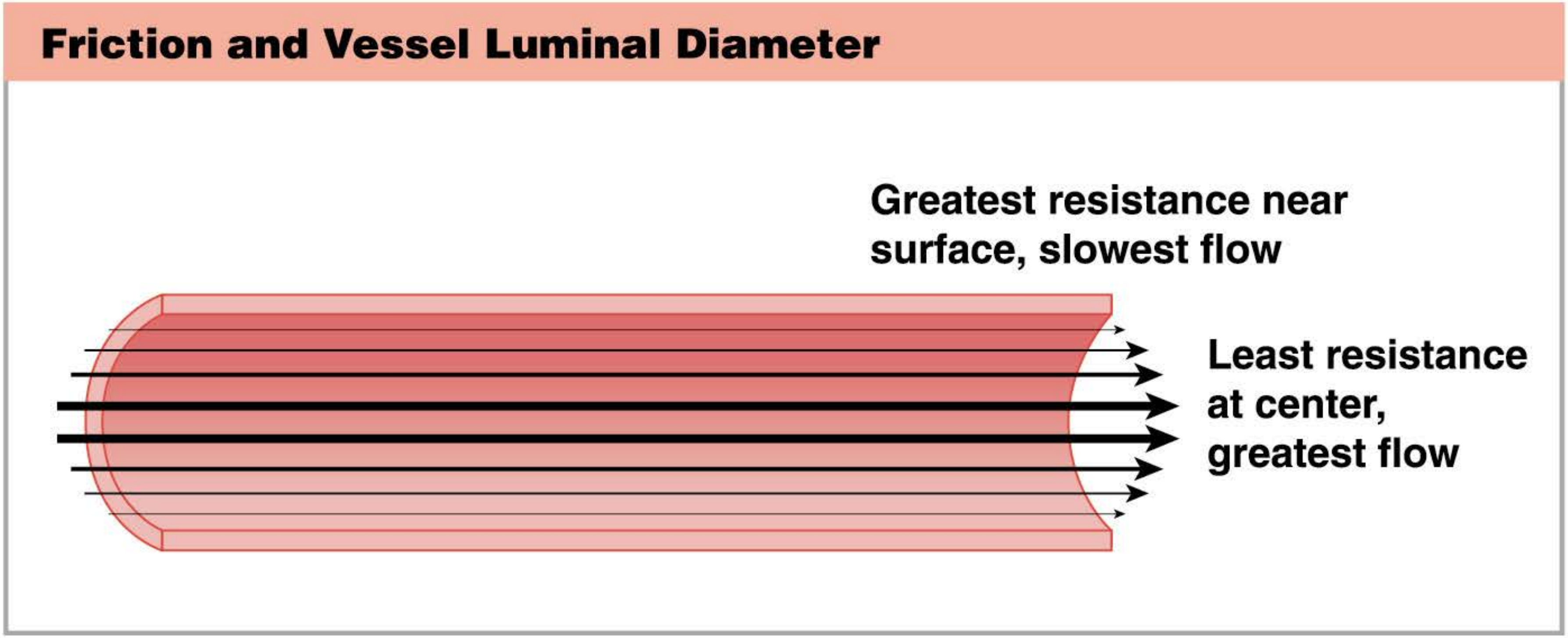


Module 19.6: Factors affecting peripheral resistance

Total peripheral resistance (continued)

1. **Vascular resistance** (continued)
   2. Vessel luminal diameter
      - Friction occurs between moving fluid layers
        - Layer closest to vessel wall is slowed most because of friction with endothelial surface
        - Effect gradually diminishes away from wall
      - In smaller vessels, more fluid volume is near wall, so higher resistance
      - In larger vessels, central region unaffected, so lower resistance

Friction and vessel luminal diameter

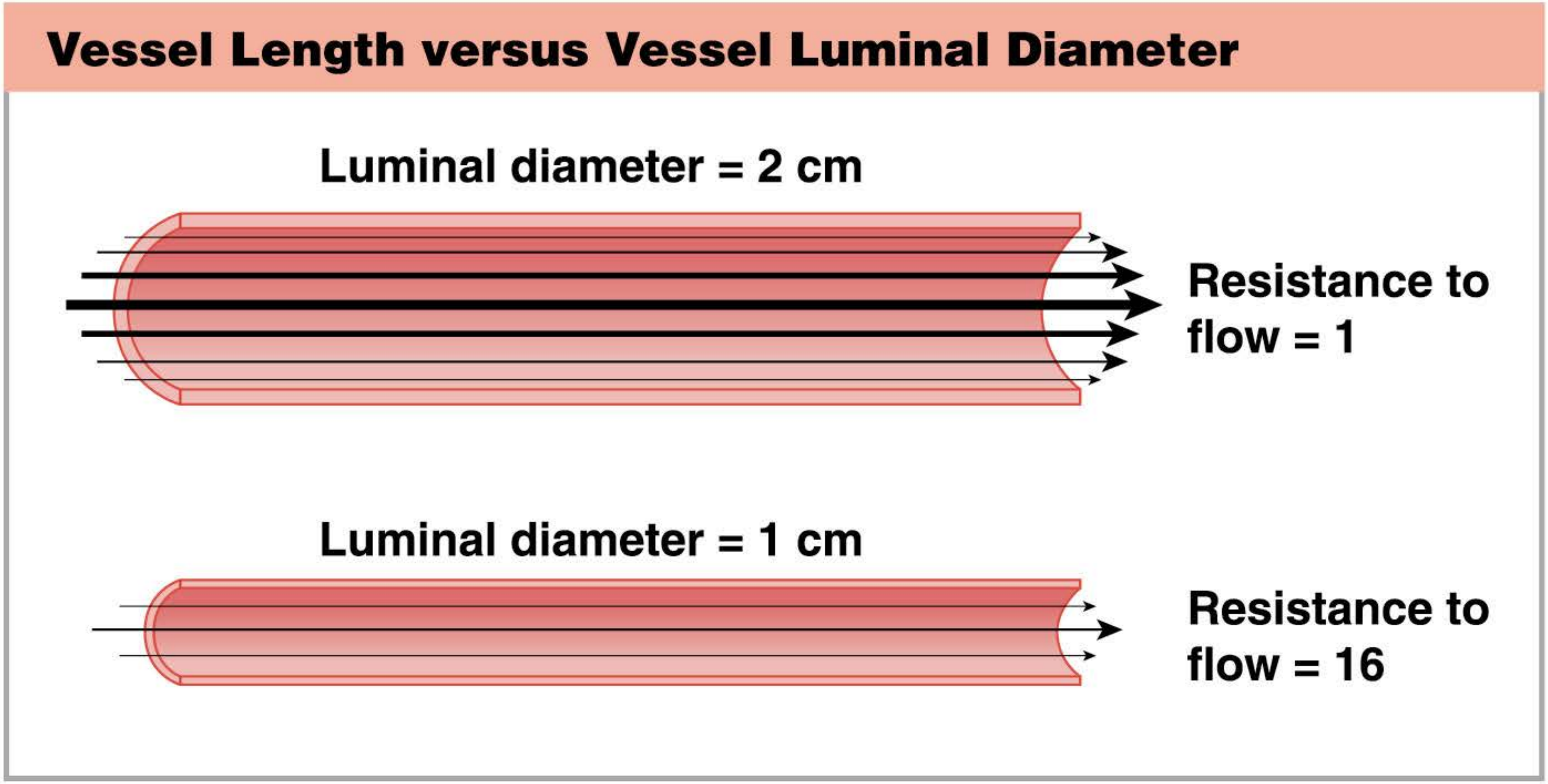


Module 19.6: Factors affecting peripheral resistance

Total peripheral resistance (continued)

1. **Vascular resistance** (continued)
   2. Vessel diameter (continued)
      – Diameter has a much larger effect on resistance compared to vessel length
         - o $R = 1/r^4$
            - • Change in radius (r) affects resistance (R) to 4th power
      – Small change in diameter produces a large change in resistance
      – Vasomotor center controls peripheral resistance primarily by altering diameters of arterioles

Vessel length versus vessel luminal diameter



Module 19.6: Factors affecting peripheral resistance

Total peripheral resistance (continued)

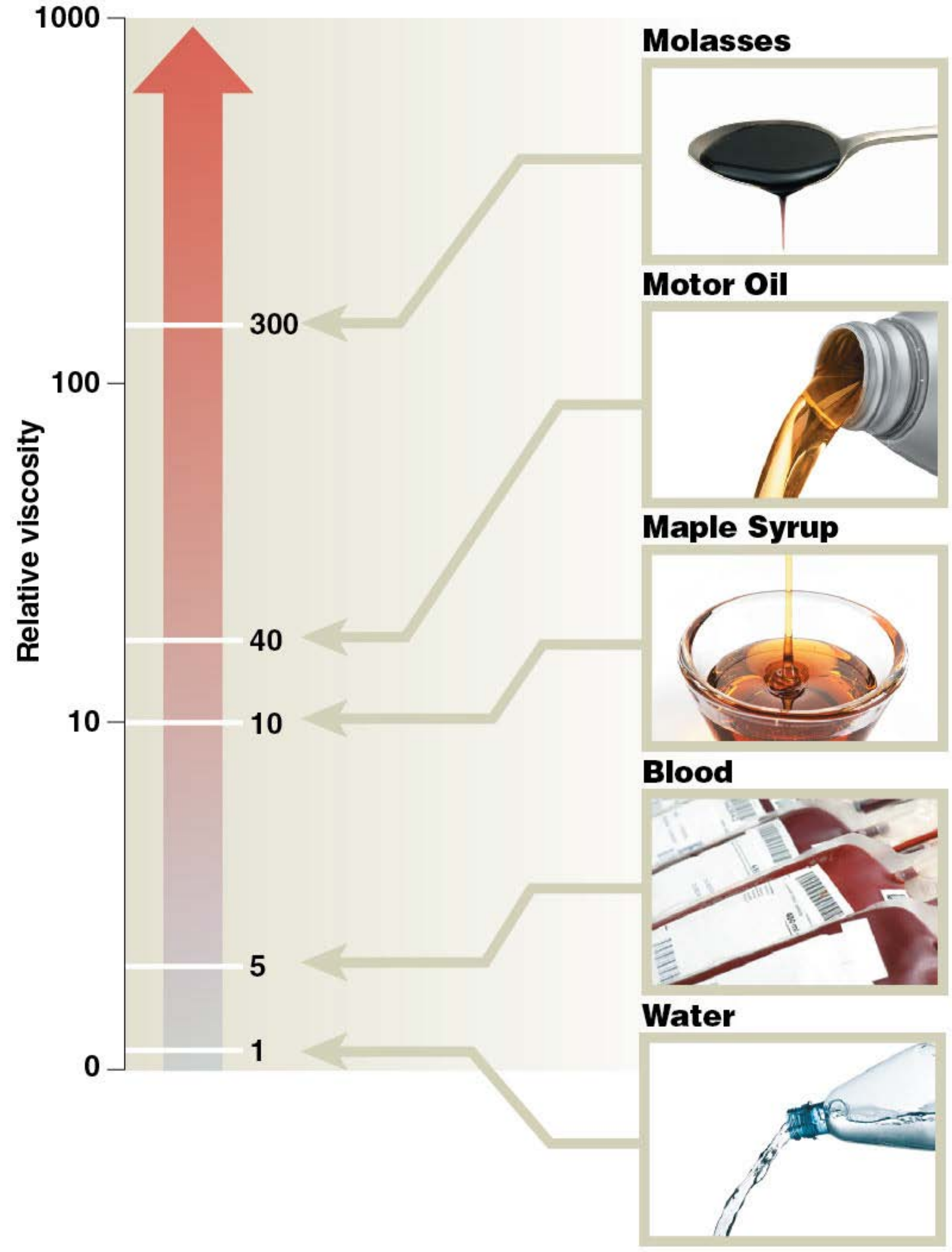
2. **Viscosity**
   - Resistance to flow caused by interactions among molecules and suspended materials in a liquid
   - Low-viscosity fluids have lower resistance, so flow at low pressures
     – *Example:* water (viscosity 1.0)
   - High-viscosity fluids have higher resistance, so flow only at high pressures
     – *Example:* molasses (viscosity 300)

Module 19.6: Factors affecting peripheral resistance

Total peripheral resistance (continued)

2. **Viscosity** (continued)
   - Blood viscosity is about five times that of water
     - Due to cells and plasma proteins
     - Viscosity is normally stable
       - Disorders affecting hematocrit or plasma composition change viscosity and affect peripheral resistance

Viscosity



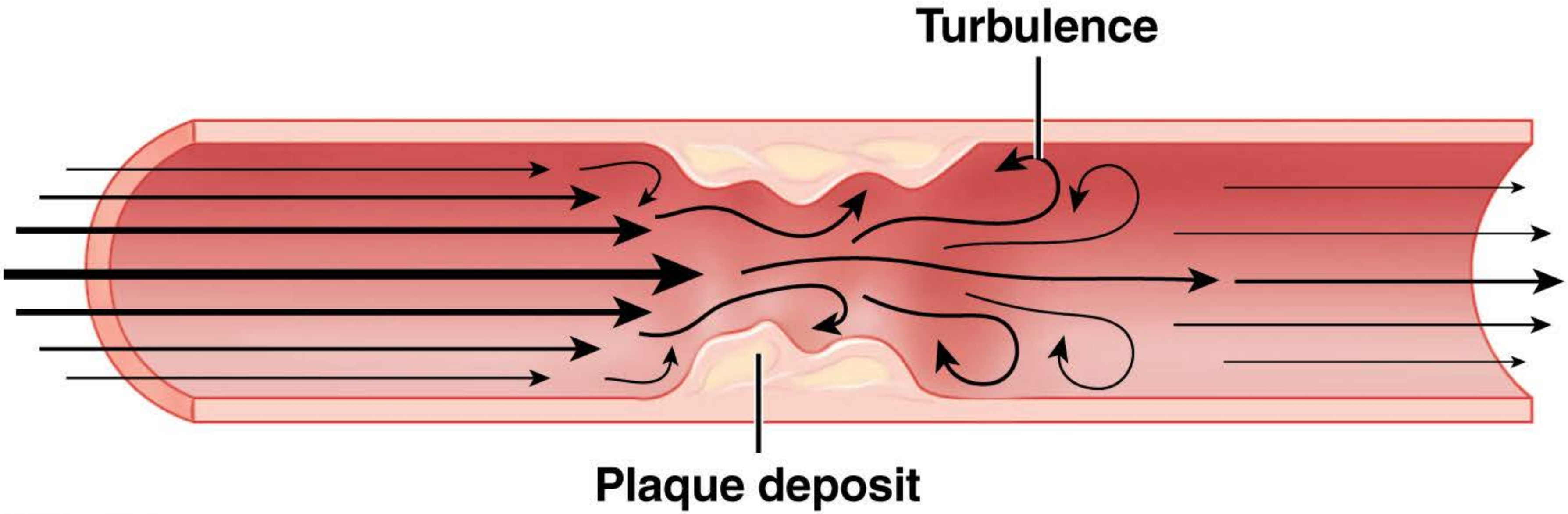
1000
100
10
0
Relative viscosity
300
40
10
5
1
Molasses
Motor Oil
Maple Syrup
Blood
Water

Module 19.6: Factors affecting peripheral resistance

Total peripheral resistance (continued)

3. **Turbulence**
   - Type of fluid flow with eddies and swirls
   - Caused by high flow rates, irregular surfaces, and sudden changes in vessel diameter
   - Responsible for production of third and fourth heart sounds
     - Normal turbulent flow in the heart
   - Increased turbulence = increased resistance = slow blood flow

Turbulence



Module 19.6: Review

A. List the factors that contribute to total peripheral resistance.

B. Explain the equation $R \propto 1/r^4$.

C. Which would reduce peripheral resistance: an increase in vessel length or an increase in vessel diameter?

Learning Outcome: Describe the factors that influence total peripheral resistance.

Module 19.7: Blood flow is determined by the interplay between arterial pressure and peripheral resistance

Blood flow

- Volume of blood flowing per unit of time through a vessel or group of vessels
- Directly proportional to **arterial pressure**
- Inversely proportional to **peripheral resistance**
- More important than absolute pressure is the **pressure gradient**
  - Difference in pressure from one end of vessel to other
  - Largest gradient from base of the aorta and proximal end of capillary beds

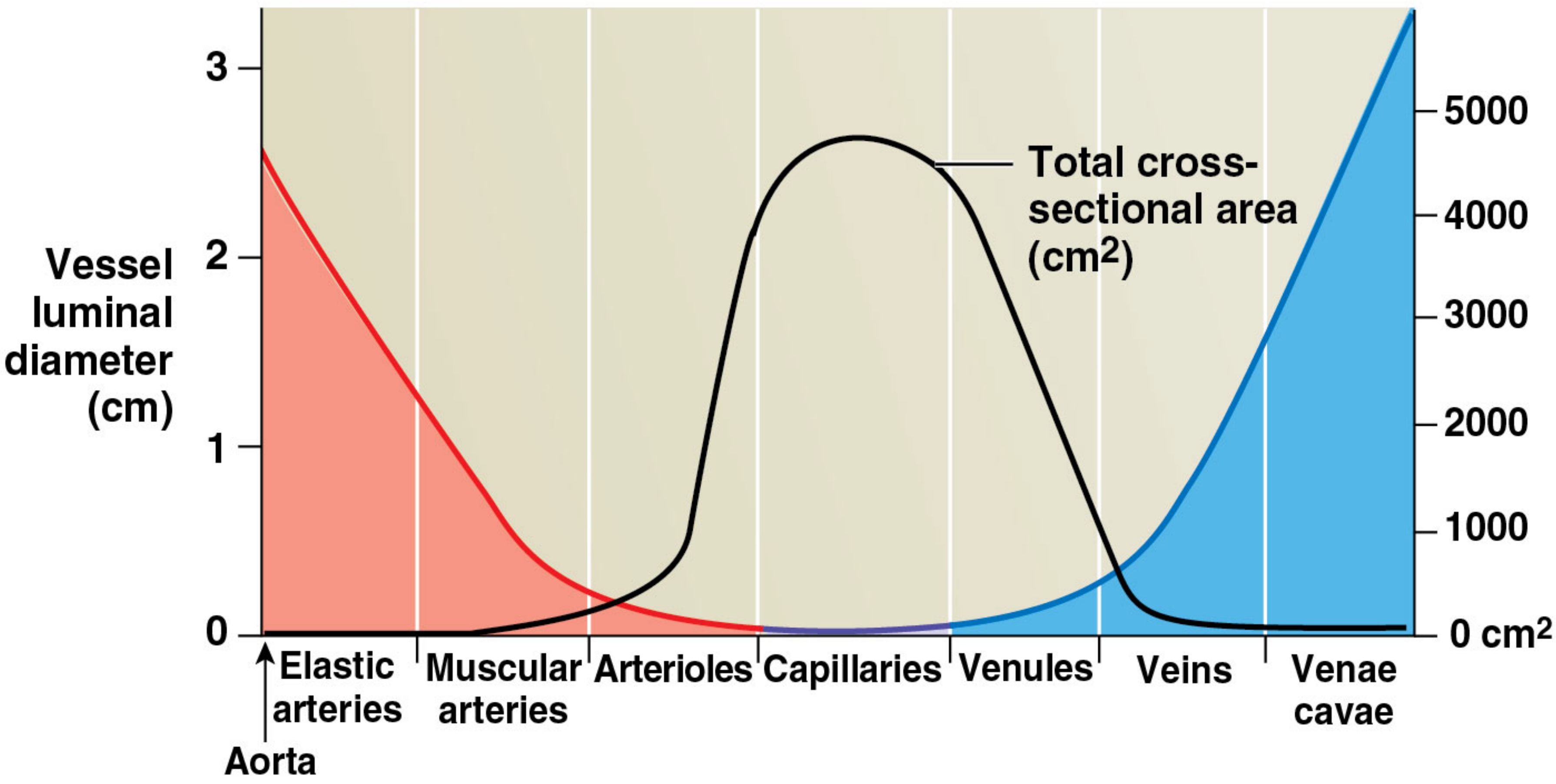
Module 19.7: Factors affecting blood flow

Blood flow (continued)

Changes in diameter

- From aorta to capillaries:
  - Blood vessels diverge and branch
  - Decreasing diameter increases resistance = decreased pressure = decreased flow
- From capillaries to venae cavae:
  - Blood vessels converge to form larger vessels
  - Increasing diameter decreases resistance = increased flow

Vessel luminal diameter and cross-sectional area

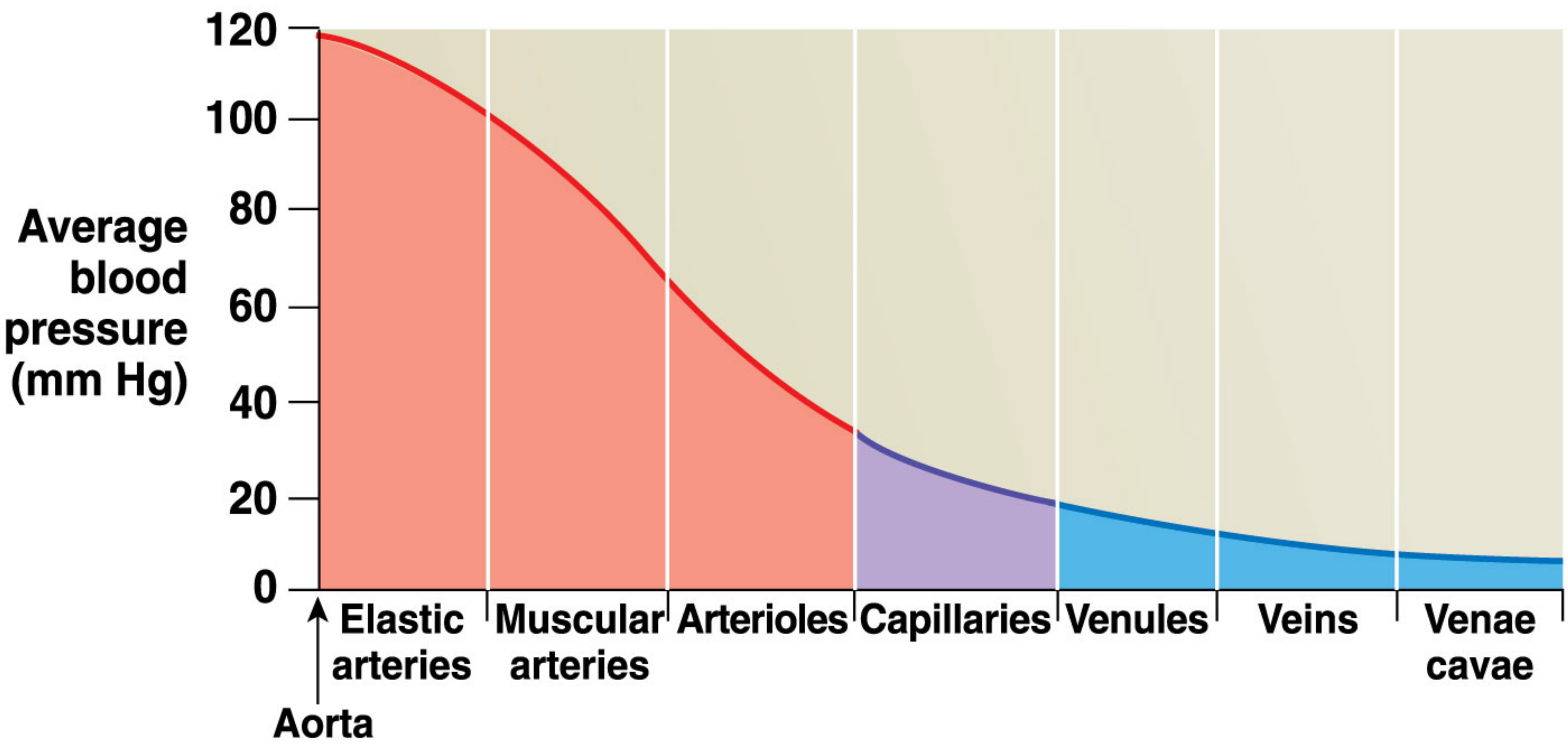


Module 19.7: Factors affecting blood flow

Blood flow (continued)

- Changes in blood pressure
  - Highest pressure at the aorta
    - Heart generates pressure of about 120 mm Hg
    - Aorta cross-sectional area 4.5 cm^2
  - Pressure drops at each branching in arterial system
    - Smaller, more numerous vessels produce more resistance, reducing pressure
    - At start of peripheral capillaries, pressure is 35 mm Hg
    - At the venules, pressure is 18 mm Hg

Blood pressure in the blood vessels

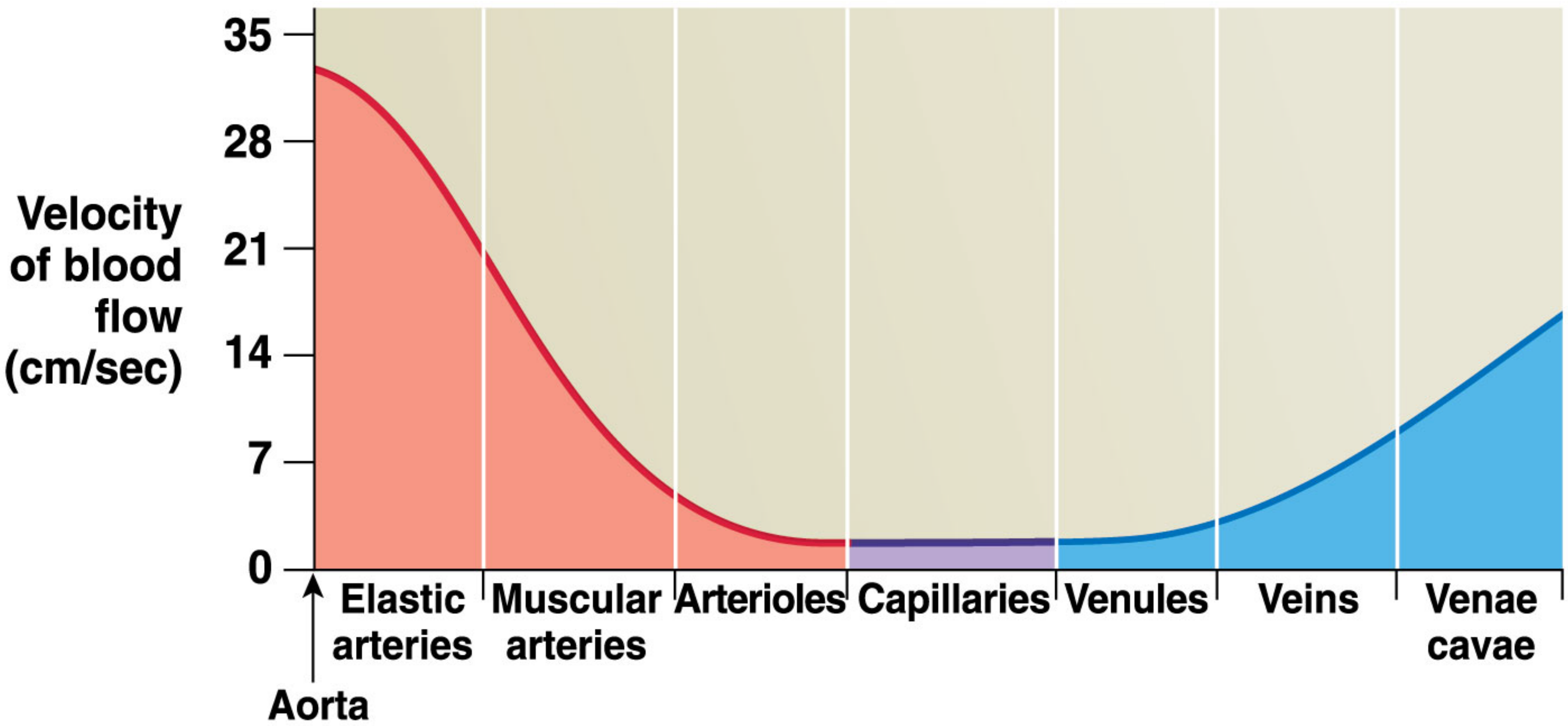


Module 19.7: Factors affecting blood flow

Blood flow (continued)

- Changes in blood flow
  - Highest flow in the aorta
    - Highest blood pressure, largest diameter
  - Slowest in the capillaries
    - Smallest diameter
    - Slow flow important to allow exchange between blood and interstitial fluid
  - Flow accelerates in venous system
    - Due to larger diameter vessels = lower resistance

Blood flow in the blood vessels



Module 19.7: Factors affecting blood flow

Changes in arterial pressure

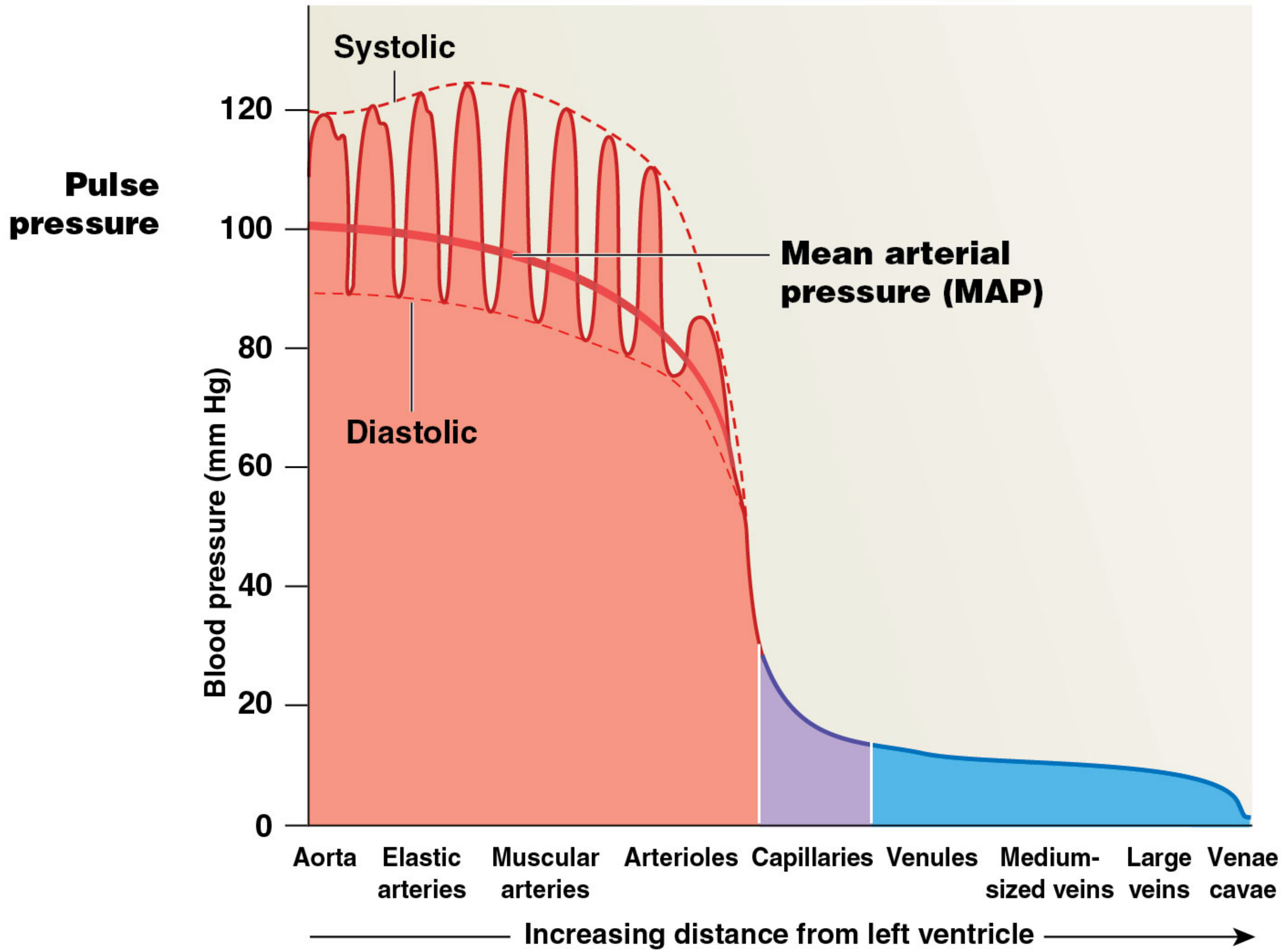
- Rises during ventricular systole
  - Peak pressure measured during systole is the **systolic pressure**
- Declines during ventricular diastole
  - Minimum pressure measured during diastole is the **diastolic pressure**
- Commonly written with a “/” between pressures
  - *Example*: 120/90

Module 19.7: Factors affecting blood flow

Changes in arterial pressure (continued)

- **Pulse pressure**
  - Difference between systolic and diastolic pressure
  - *Example:* 120 – 90 = 30 mm Hg
- **Mean arterial pressure** (**MAP**)
  - Adding one-third of pulse pressure to diastolic pressure
  - *Example:* 90 + (120 – 90)/3 = 100 mm Hg

Pulse pressure

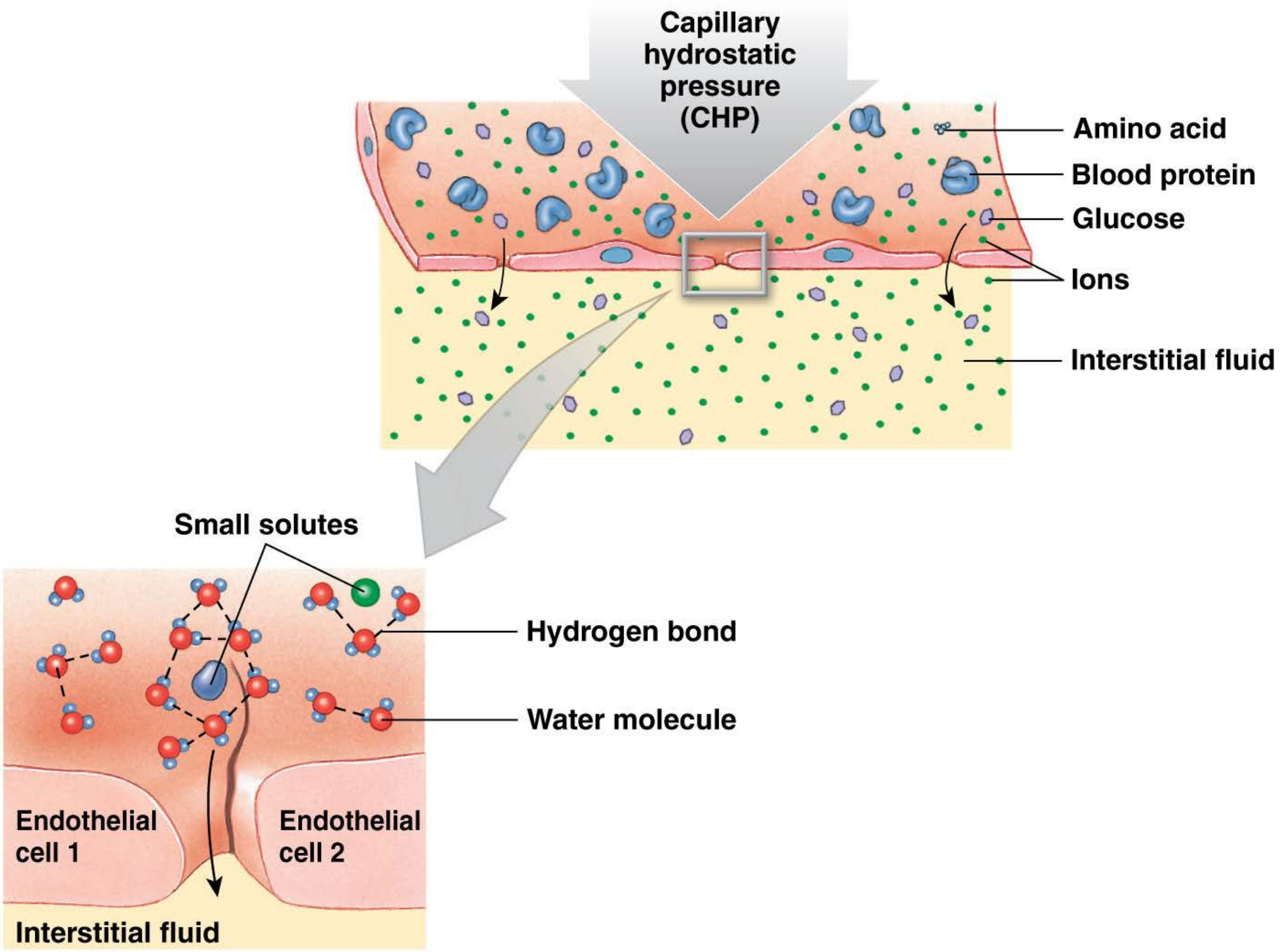


Module 19.7: Factors affecting blood flow

Capillary exchange

- Involves a combination of diffusion, osmosis, and **filtration**
- *Capillary hydrostatic pressure* (*CHP*)
  - Blood pressure within capillary beds
  - Provides driving force for filtration
  - Pushes water and small molecules out of the bloodstream into interstitial fluid
  - Larger molecules (such as plasma proteins) remain in blood

Capillary exchange



Module 19.7: Review

A. Define *blood flow*, and describe its relationship to blood pressure and peripheral resistance.
B. In a healthy person, where is blood pressure greater: in the aorta or in the inferior vena cava? Explain.
C. Calculate the mean arterial pressure for a person whose blood pressure is 125/70.

Learning Outcome: Describe the factors that determine blood flow.

Module 19.8: Capillary exchange is a dynamic process that includes diffusion, filtration, and reabsorption

Capillary exchange

- Diffusion
  - Net movement of substances from an area of higher concentration to lower concentration
  - Occurs most rapidly when:
    1. Distances are short
    2. Concentration gradient is large
    3. Ions or molecules involved are small
  - Occurs continuously across capillary walls, but transport mechanism varies for different substances

Routes of Diffusion Across Capillary Walls

- Water, ions, and small organic molecules, such as glucose, amino acids, and urea, can usually enter or leave the bloodstream by diffusion either between adjacent endothelial cells or through the pores of fenestrated capillaries.
- Many ions, including sodium, potassium, calcium, and chloride, can diffuse across endothelial cells by passing through channels in plasma membranes.
- Large water-soluble compounds are unable to enter or leave the bloodstream except at fenestrated capillaries, such as those in the hypothalamus, the kidneys, many endocrine organs, and the intestinal tract.
- Lipids, such as fatty acids and steroids, and lipid-soluble materials, including soluble gases such as oxygen and carbon dioxide, can cross capillary walls by diffusion through the endothelial plasma membranes.
- Plasma proteins are normally unable to cross the endothelial lining anywhere except in sinusoids, such as those of the liver, where plasma proteins enter the bloodstream.

Module 19.8: Capillary exchange

At the arterial end of the capillary

- **Filtration predominates**
  - **Capillary hydrostatic pressure** (**CHP**) is highest near arteriole
    - Causes water and small solutes to enter interstitial fluid
  - As filtration occurs, **blood colloid osmotic pressure** (**BCOP**) increases
    - Water leaves capillary, and plasma proteins remain
    - CHP decreases along capillary length
  - CHP > BCOP = fluid forced out of capillary

Module 19.8: Capillary exchange

At the arterial end of the capillary (continued)

- **Net filtration pressure (NFP)**
  - Difference between capillary hydrostatic and blood colloid osmotic pressure
  - **NFP = CHP – BCOP**
    - Is positive at beginning of capillary
      - Filtration
    - Becomes negative by end of capillary
      - Reabsorption

Module 19.8: Capillary exchange

At roughly two-thirds of the way along the capillary

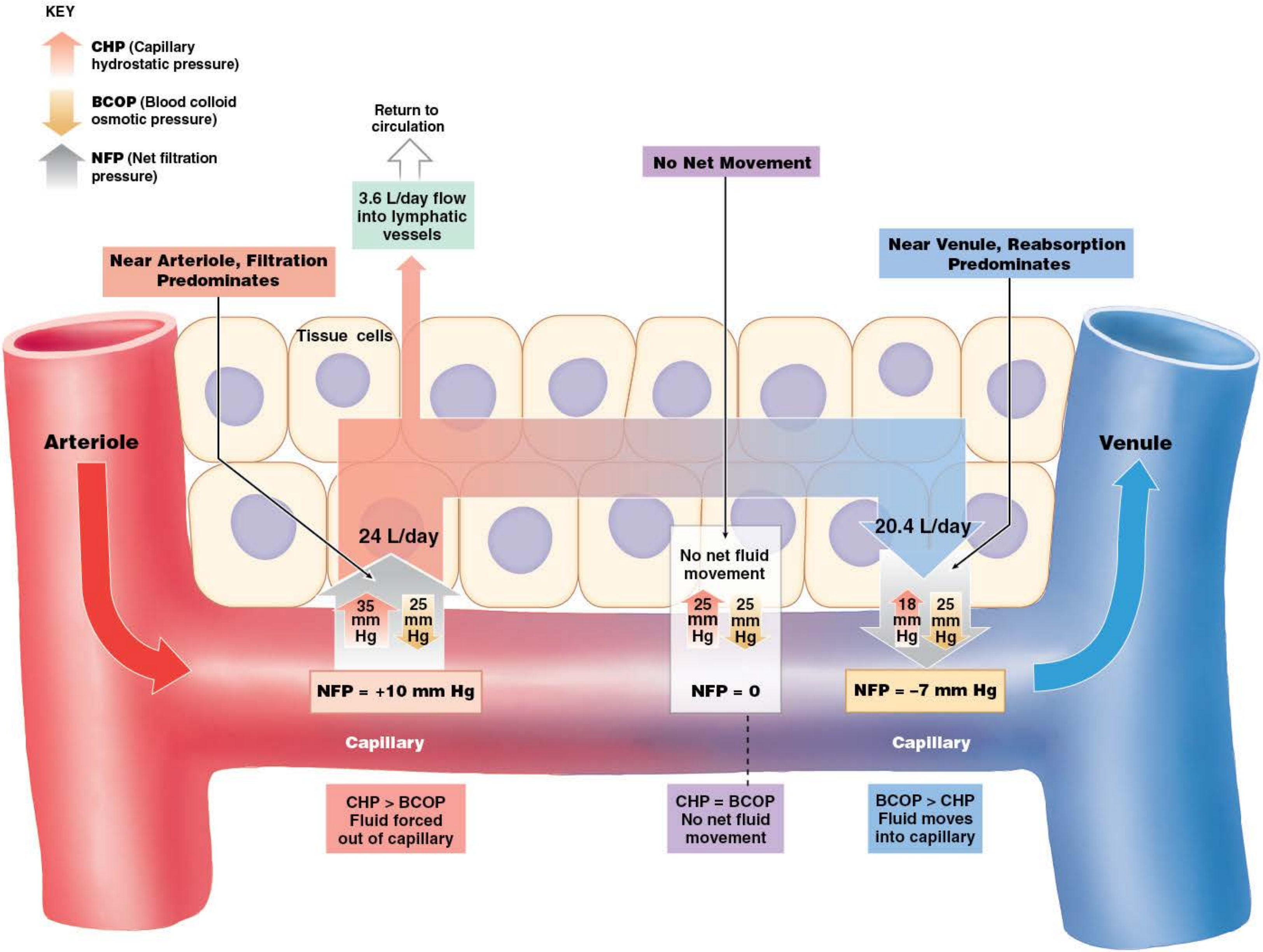
- **No net movement**
  - Capillary hydrostatic pressure equals blood colloid osmotic pressure
  - NFP = CHP – BCOP = 0

Module 19.8: Capillary exchange

At the venule end of the capillary

- **Reabsorption predominates**
  - Capillary hydrostatic pressure falls below blood colloid osmotic pressure
    - CHP < BCOP
    - Water moves into capillary
  - More water leaves bloodstream than is reabsorbed
    - Difference (about 3.6 L/day) enters the lymphatic vessels and is eventually returned to the venous system

Filtration and absorption at capillaries



Module 19.8: Capillary exchange

Possible variations in capillary exchange

- Any condition that affects blood pressure or osmotic pressure of blood or interstitial fluid shifts balance of hydrostatic and osmotic forces

Representative Variations in Capillary Exchange

- If hemorrhaging occurs, both blood volume and blood pressure decline. This decrease in CHP lowers the NFP and increases the amount of capillary reabsorption. The result is a reduction in the volume of interstitial fluid and an increase in the circulating plasma volume. This process is known as a **recall of fluids**.
- If dehydration occurs, the plasma volume decreases because of water loss, and the concentration of plasma proteins increases. The increase in BCOP accelerates reabsorption and a recall of fluids that delays the onset and severity of clinical problems caused by low blood volume and blood pressure.
- If the CHP rises or the BCOP decreases, fluid moves out of the blood in capillaries and builds up in peripheral tissues, an abnormal condition called **edema**.

Module 19.8: Review

A. Under what general conditions would fluid move into a capillary?
B. Define *edema*.
C. Identify the conditions that would shift the balance between hydrostatic and osmotic forces.

Learning Outcome: Describe the movement of fluids between capillaries and interstitial spaces.

Module 19.9: Cardiovascular regulatory mechanisms respond to changes in blood pressure or blood chemistry

Homeostatic mechanisms

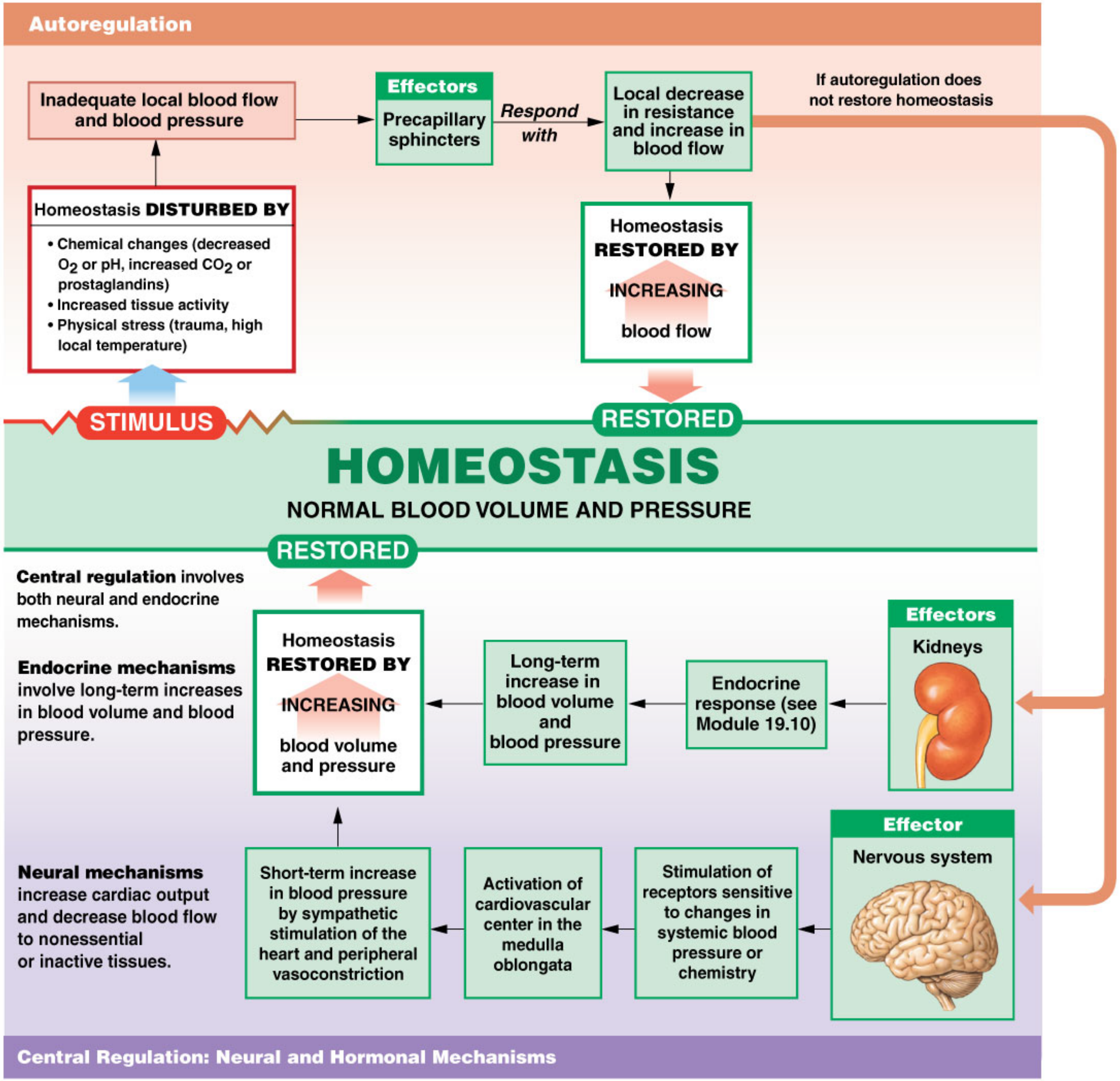
- Ensure adequate **tissue perfusion** (blood flow through tissues)
  - Blood flow must match changes in demand for oxygen and nutrients
- Two regulatory pathways
  1. **Autoregulation**
     – Occurs at local level
  2. **Central regulation**
     – Neural and endocrine control
     – Activated if autoregulation is ineffective

Module 19.9: Cardiovascular regulatory mechanisms

Two regulatory pathways

1. **Autoregulation**
   - Involves local changes in blood flow within capillary beds
   - Regulated by precapillary sphincters in response to chemical changes in interstitial fluid
     - **Vasodilators**
       - Local chemicals that increase blood flow

Autoregulation



Module 19.9: Cardiovascular regulatory mechanisms

Two regulatory pathways (continued)

2. **Central regulation**
   - Involves both neural and endocrine mechanisms
     - Neural
       - Activation of **cardioacceleratory center**
       - Activation of vasomotor center (controls peripheral vasoconstriction)
       - Can increase cardiac output and reduce blood flow to nonessential or inactive tissues
     - Endocrine
       - Release of **vasoconstrictor** (primarily NE), producing long-term increases in blood pressure

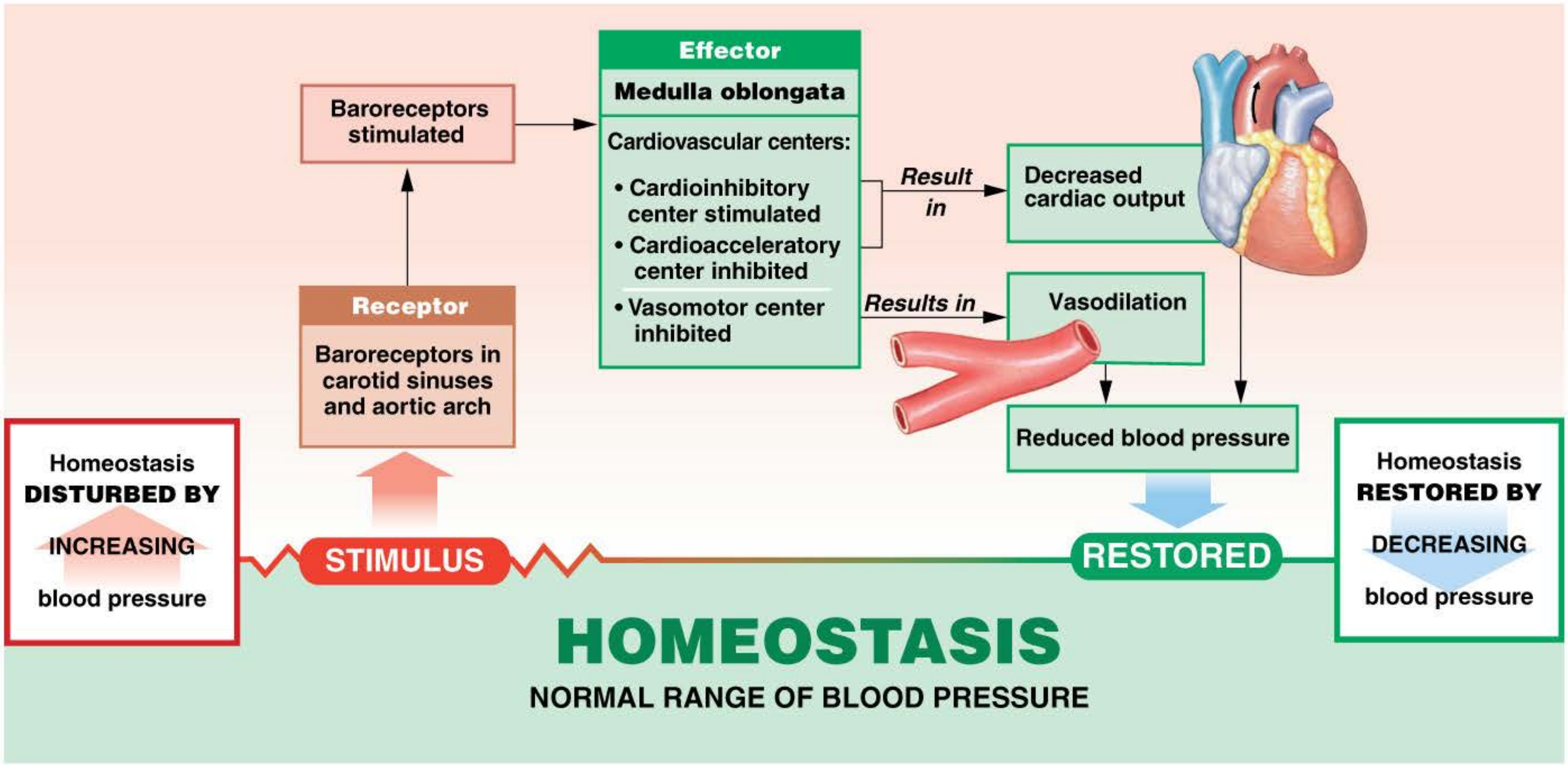
Module 19.9: Cardiovascular regulatory mechanisms

Baroreceptor reflexes (*baro-*, pressure)

- Respond to changes in blood pressure
- Receptors are located in walls of:
  1. Carotid sinuses
  2. Aortic sinuses
  3. Right atrium

Responses to Increased Baroreceptor Stimulation
• Cardiac centers decrease cardiac output through parasympathetic stimulation and sympathetic inhibition.
• Widespread peripheral vasodilation due to the inhibition of the *vasomotor center* of the medulla oblongata.

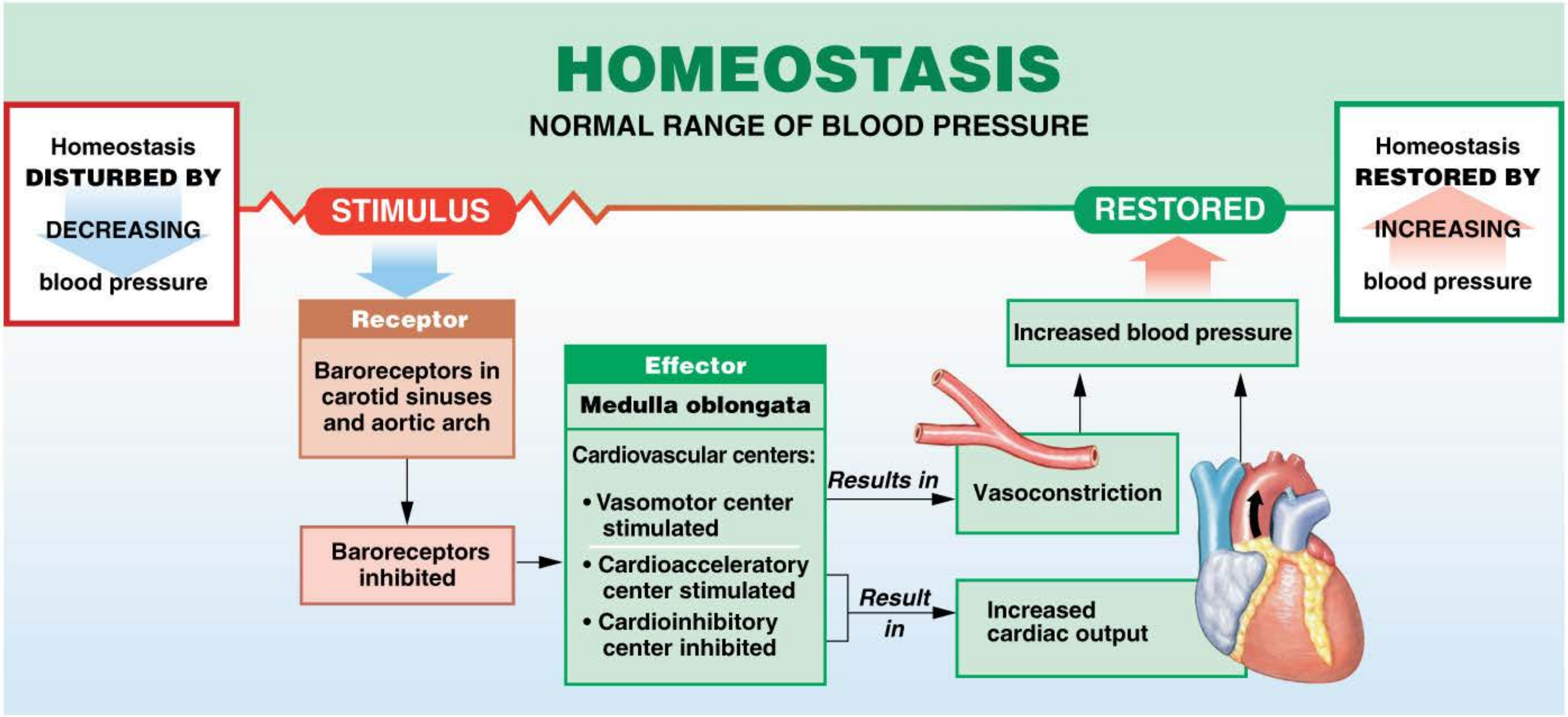
Baroreceptor reflex response to increased blood pressure



Responses to Decreased Baroreceptor Stimulation

- Cardiac centers increase cardiac output through the stimulation of sympathetic innervation to the heart. This results from the stimulation of the cardioacceleratory center and is accompanied by an inhibition of the cardioinhibitory center (see Module 18.14).
- Widespread peripheral vasoconstriction caused by the stimulation of the vasomotor center.
- In a crisis, such as a major blood loss sympathetic activation occurs; both norepinephrine and epinephrine enter the bloodstream. The net effect is an immediate increase in cardiac output and generalized vascular constriction, a combination that rapidly elevates blood pressure.

Baroreceptor reflex response to decreased blood pressure



Module 19.9: Review

A. Define *tissue perfusion*.

B. Describe autoregulation as it relates to cardiovascular function.

C. Explain the function of baroreceptor reflexes.

Learning Outcome: Explain central regulation, autoregulation, and baroreceptor reflexes in response to changes in blood pressure and blood composition.

Module 19.10: Endocrine responses to low blood pressure and low blood volume…

Endocrine responses

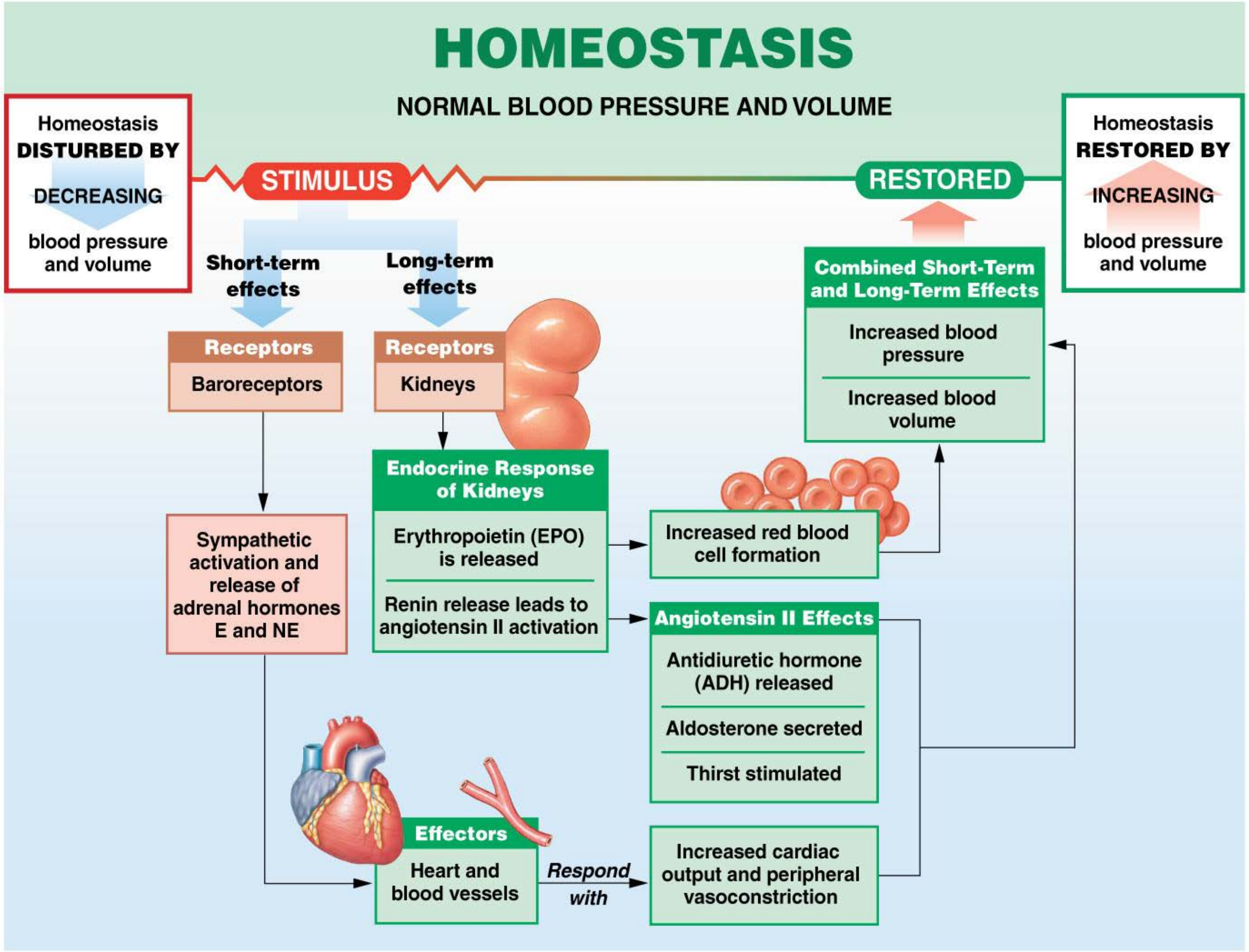
- Provide short-term and long-term regulation of cardiovascular function
- Utilize endocrine functions of:
  - The heart
  - The kidneys
  - The pituitary gland (antidiuretic hormone, or ADH)

Module 19.10: Endocrine responses to changes in blood pressure and volume

Hormonal response to low blood pressure and volume

- Immediate response
  - Release of epinephrine (E) and norepinephrine (NE)
    - Released from the adrenal medullae
- Other hormones important in the long-term response
  1. Antidiuretic hormone (ADH)
  2. Angiotensin II
  3. Erythropoietin (EPO)
  4. Aldosterone

Endocrine response to decreased low blood pressure and volume

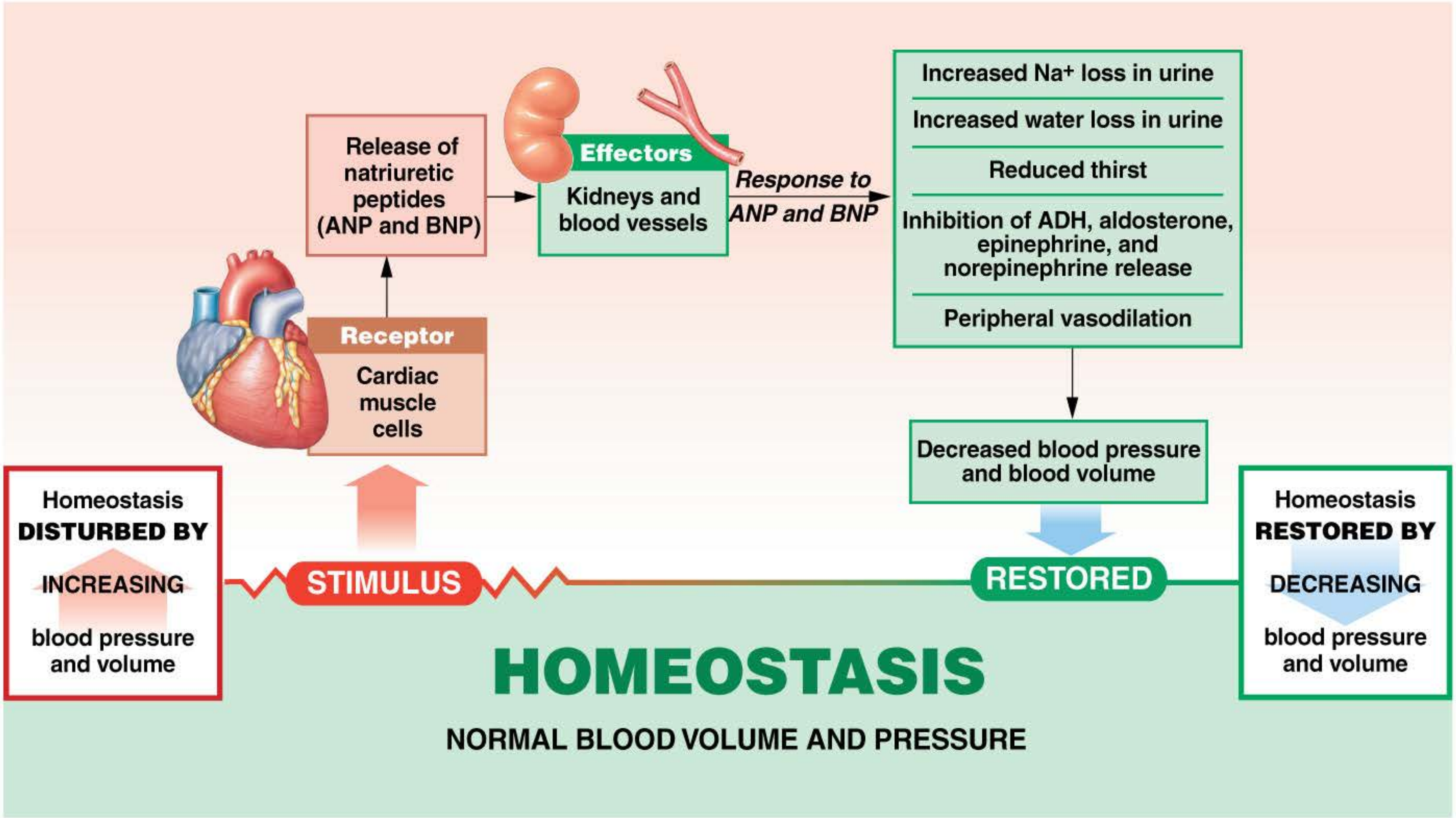


Module 19.10: ...are very different from those to high blood pressure and high blood volume

Hormonal response to high blood pressure and blood volume

- High blood volume stretches the heart wall during diastole
  - Triggers release of **natriuretic peptides**
    - **Atrial natriuretic peptide** (*natrium*, sodium + *ouresis*, urination), or **ANP**
      - Released from right atrial walls
    - **Brain natriuretic peptide,** or **BNP**
      - Released from ventricular muscle cells
- Decrease in blood volume and pressure = decreased stress on heart walls = decreased production of natriuretic peptides

Endocrine response to increased low blood pressure and volume



Module 19.10: Review

A. Identify the hormones responsible for short-term regulation of decreasing blood pressure and blood volume.

B. How does the kidney respond to vasoconstriction of the renal artery?

C. Describe the roles of the natriuretic peptides.

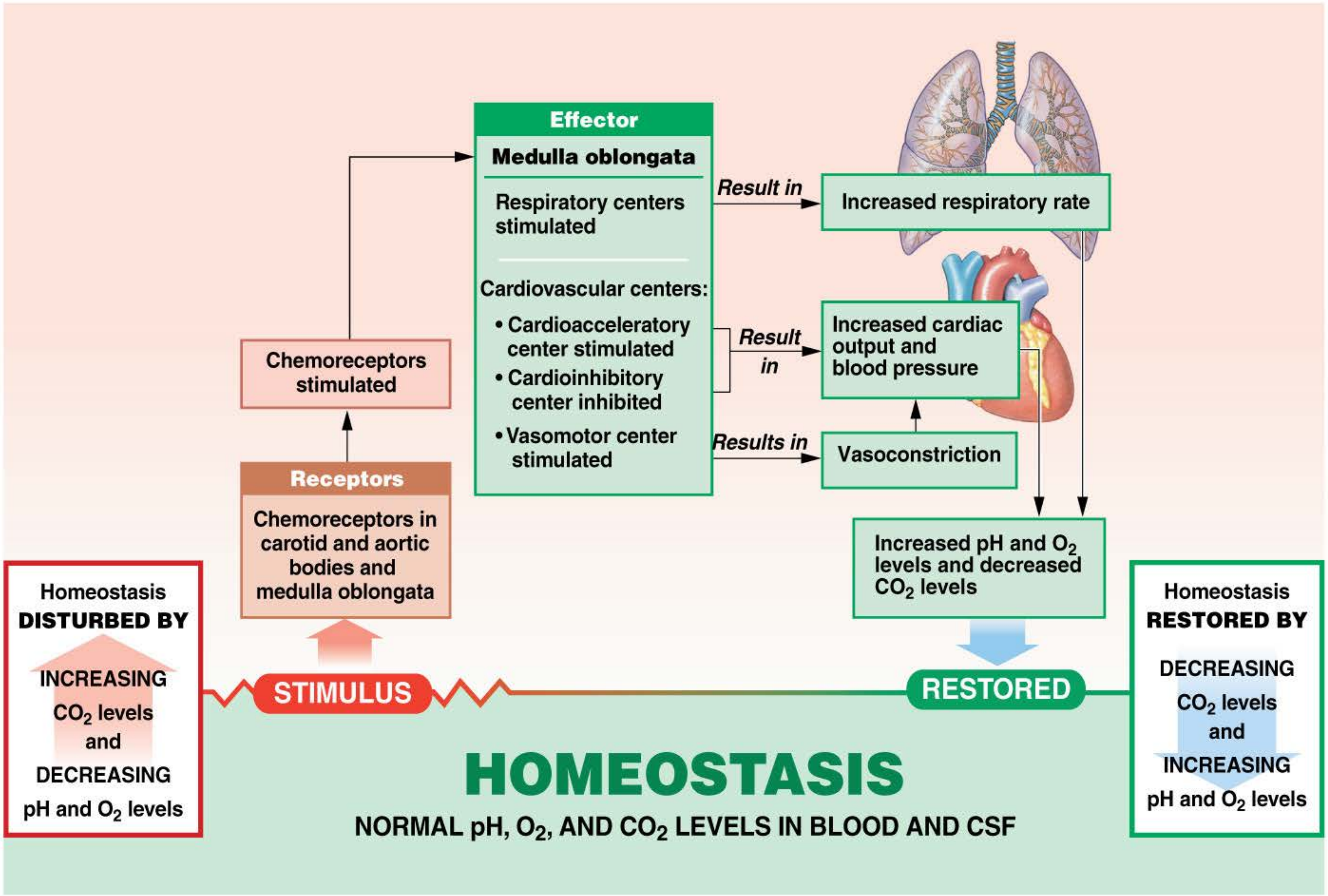
Learning Outcome: Explain the hormonal regulation of blood pressure and blood volume.

Module 19.11: Chemoreceptors monitor the chemical composition of the blood and cerebrospinal fluid

Chemoreceptor reflexes

- Respond to blood and CSF changes in:
  - Carbon dioxide
  - Oxygen
  - pH
- Receptors located in:
  - **Carotid bodies**
  - **Aortic bodies**
  - Ventrolateral surface of medulla oblongata
- Stimulation of receptors triggers coordinated adjustment in cardiovascular and respiratory activity

Effects of increasing CO_2 and decreasing pH and O_2 levels on cardiovascular system



Module 19.11: Review

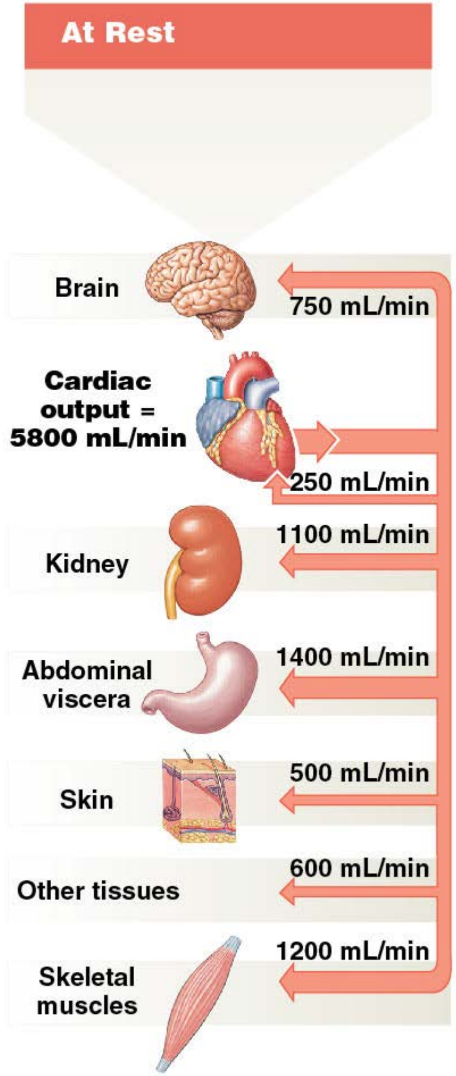
A. Where are chemoreceptors located?
B. What is the function of chemoreceptor reflexes?
C. What effect does an increase in the respiratory rate have on CO_2 levels?

Learning Outcome: Describe the role of chemoreceptor reflexes in adjusting cardiovascular activity.

Module 19.12: The cardiovascular center makes extensive adjustments to cardiac output and blood distribution during exercise

Cardiovascular adjustments

- **At rest**
  - Cardiac output = 5800 mL/min

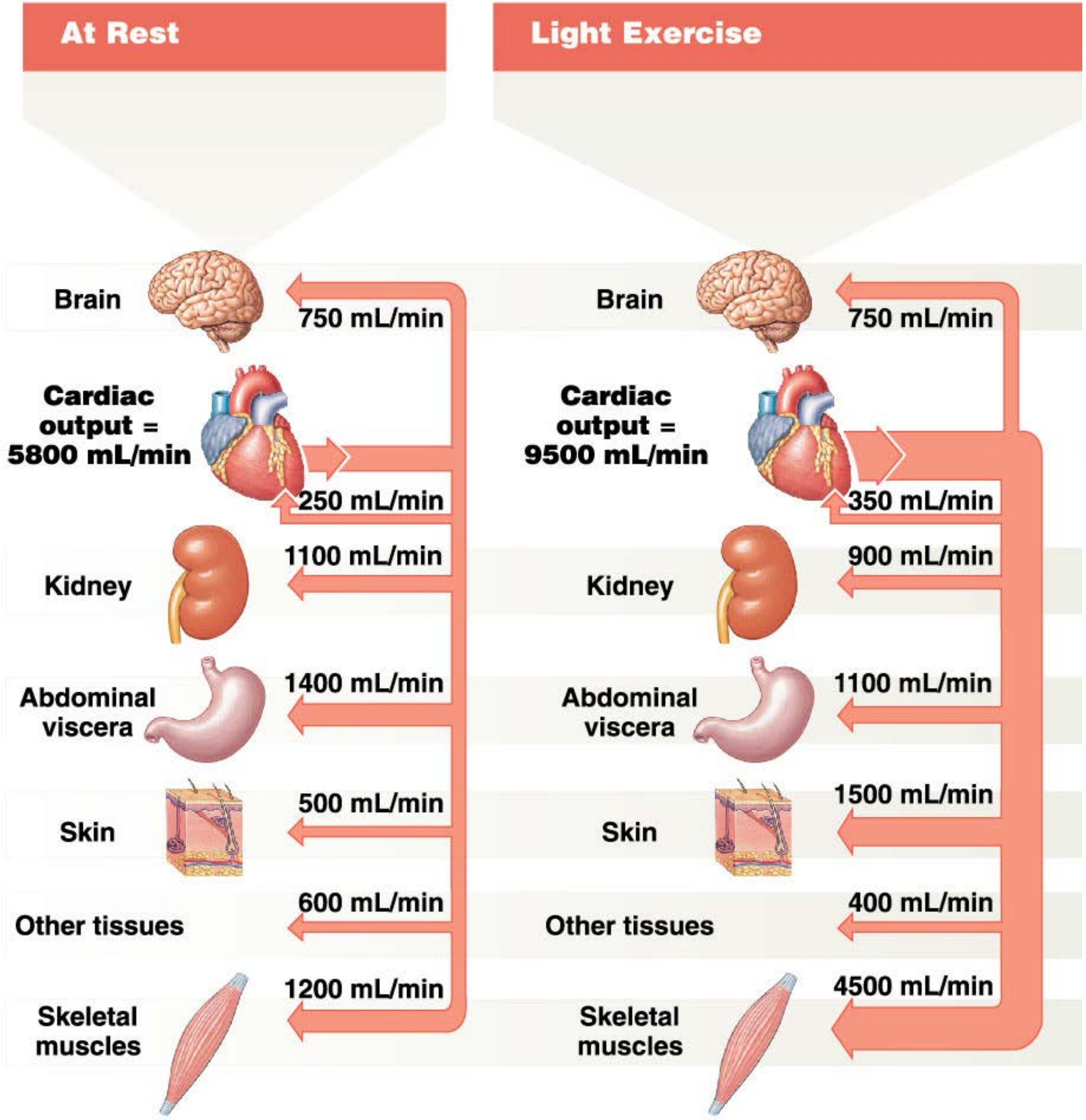


Module 19.12: Cardiovascular adjustments during exercise

Cardiovascular adjustments (continued)

- **During light exercise**
  - Three changes take place
    1. Vasodilation occurs, peripheral resistance drops, and capillary blood flow increases
    2. Venous return increases with skeletal muscle contraction; increased respiration creates negative pressure in thoracic cavity, drawing blood back (**respiratory pump**)
    3. Cardiac output increases to 9500 mL/min
       - Primarily due to venous return

Light exercise

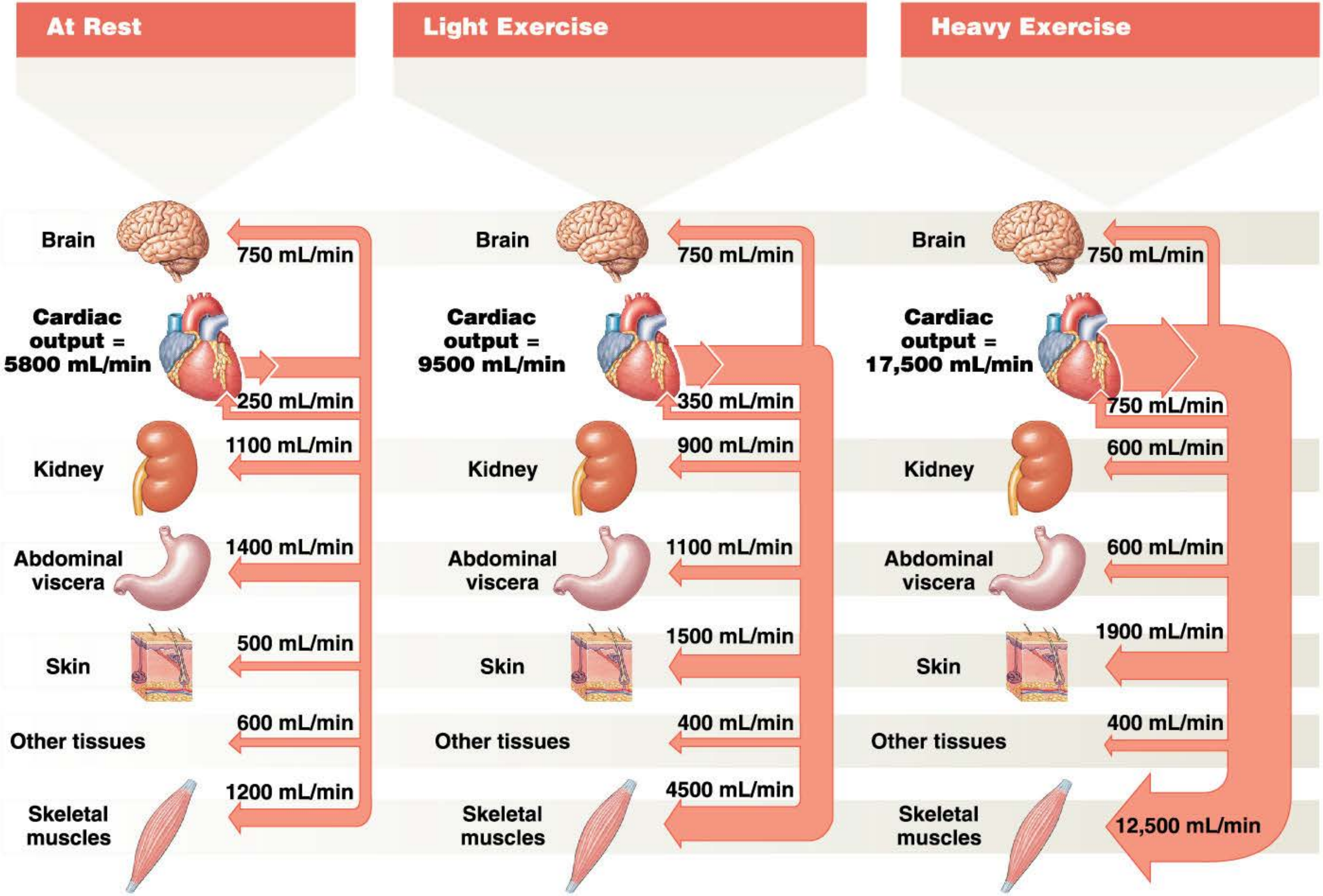


Module 19.12: Cardiovascular adjustments during exercise

Cardiovascular adjustments (continued)

- **During heavy exercise**
  - Cardiac output approaches maximal levels (~17,500 mL/min)
  - Major changes in peripheral blood distribution allow large increase in flow to skeletal muscles without overall decrease in systemic blood pressure
    - Increased flow to skeletal muscles
    - Increased flow to skin (promotes heat loss)
    - Reduced flow to digestive viscera and kidneys
    - Brain blood flow remains unchanged

Heavy exercise



Module 19.12: Cardiovascular adjustments during exercise

Cardiovascular adjustments (continued)

- Cardiovascular performance improves with training
  - Trained athletes have bigger hearts and stroke volumes
    - Can maintain normal blood flow with lower heart rate (as low as 32 bpm)
    - Maximal cardiac output can be 50 percent higher than in nonathletes

Module 19.12: Review

A. Describe the respiratory pump.

B. Describe the changes in cardiac output and blood flow during exercise.

Learning Outcome: Explain how the cardiovascular system responds to the demands of exercise.

Module 19.13: Clinical Module: Short-term and long-term mechanisms compensate for a reduction in blood volume

Compensation mechanisms

- When hemostasis fails to prevent significant blood loss, entire cardiovascular system adjusts to compensate
- Immediate problem is maintenance of blood pressure and peripheral blood flow
- Long-term problem is restoration of blood volume
- Mechanisms can cope with blood losses equal to ~30 percent of total blood volume

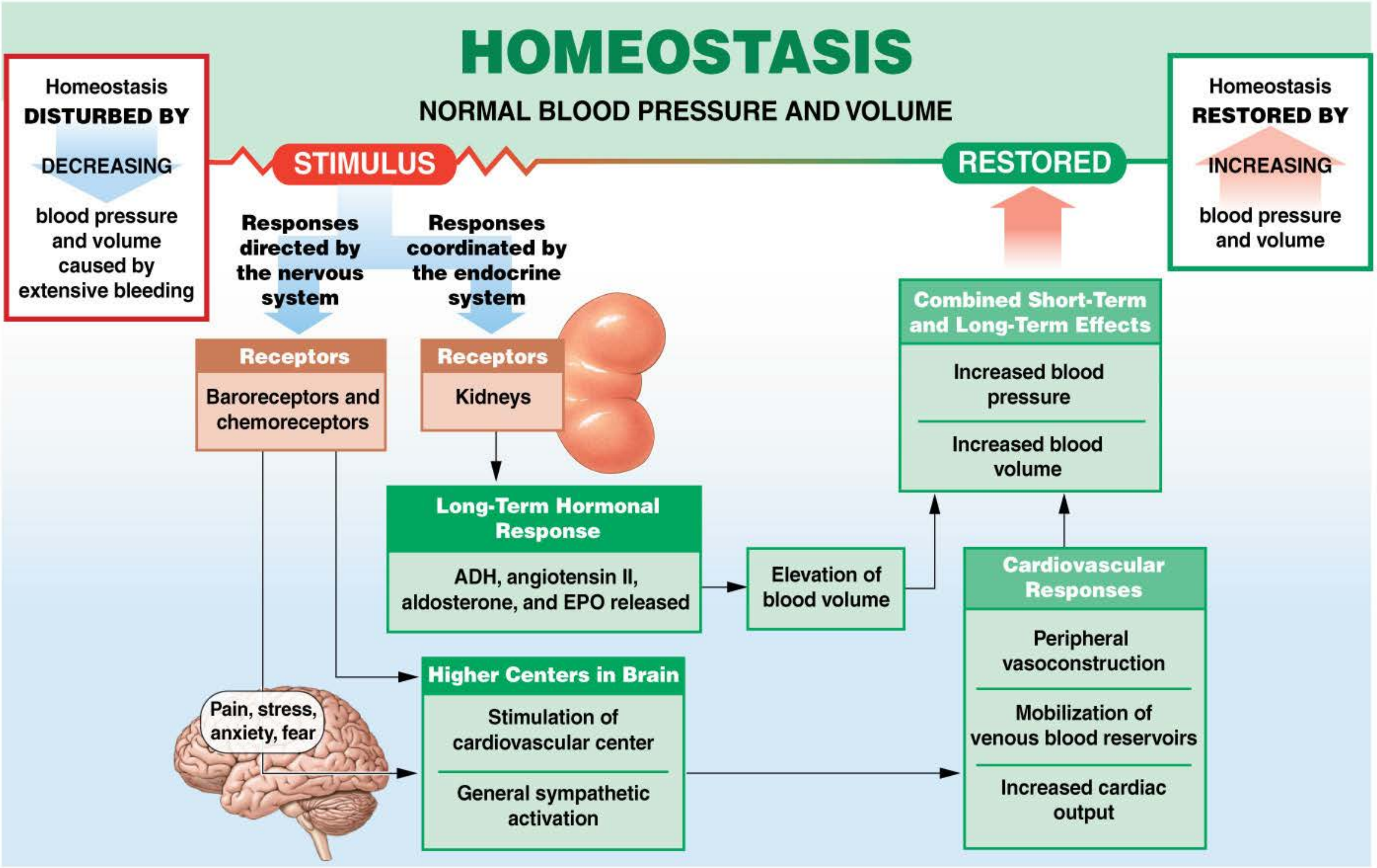
Short-Term Responses to Blood Loss

- Carotid and aortic reflexes increase cardiac output and cause peripheral vasoconstriction. Cardiac output is maintained by increasing the heart rate, typically to 180–200 bpm.
- The combination of stress and anxiety stimulates the sympathetic nervous system, which causes a further increase in vasomotor tone, constricting the arterioles and increasing blood pressure. At the same time, venoconstriction, the constriction of large and medium-sized veins, improves venous return and shifts blood into the arterial system.
- Sympathetic activation causes the secretion of E and NE by the adrenal medullae, increasing cardiac output and extending peripheral vasoconstriction. The release of ADH by the neurohypophysis and the production of angiotensin II enhance vasoconstriction; ADH also participates in the long-term response.

Long-Term Responses to Blood Loss

- The decrease in capillary blood pressure triggers a recall of fluids from the interstitial spaces.
- Aldosterone and ADH promote fluid retention and reabsorption by the kidneys.
- Thirst increases, and additional water is obtained by absorption across the digestive tract.
- Erythropoietin (EPO) stimulates the maturation of red blood cells in the red bone marrow, resulting in increased blood volume and improved oxygen delivery to peripheral tissues.

Homeostatic response to decreased blood pressure and volume due to extensive bleeding



Module 19.13: Responses to blood loss

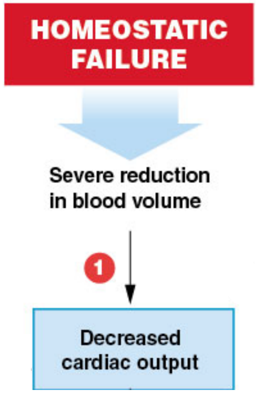
Shock

- Acute cardiovascular crisis marked by:
  - Low blood pressure (**hypotension**)
  - Inadequate peripheral blood flow
- Most common causes are hemorrhaging and heart damage (as in heart attack)
  - Normal homeostatic mechanisms cannot compensate
- **Circulatory shock**
  - Positive feedback loops beginning when blood loss >35 percent

Module 19.13: Responses to blood loss

Shock (continued)

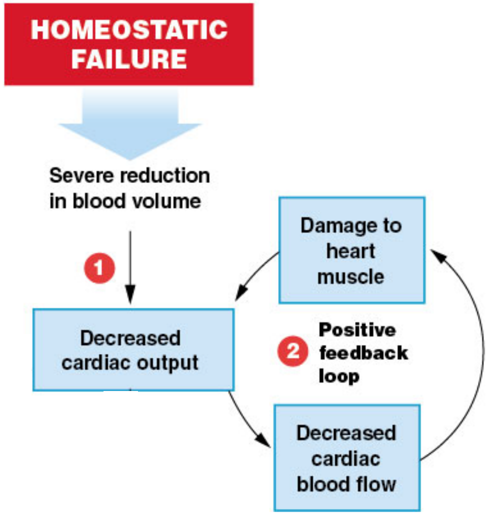
- **Progressive shock**
  1. Blood volume drops by more than 35 percent
     - Despite sustained vasoconstriction and mobilized venous reserves:
       - Blood pressure remains low
       - Venous return reduced
       - Cardiac output inadequate



Module 19.13: Responses to blood loss

Shock (continued)

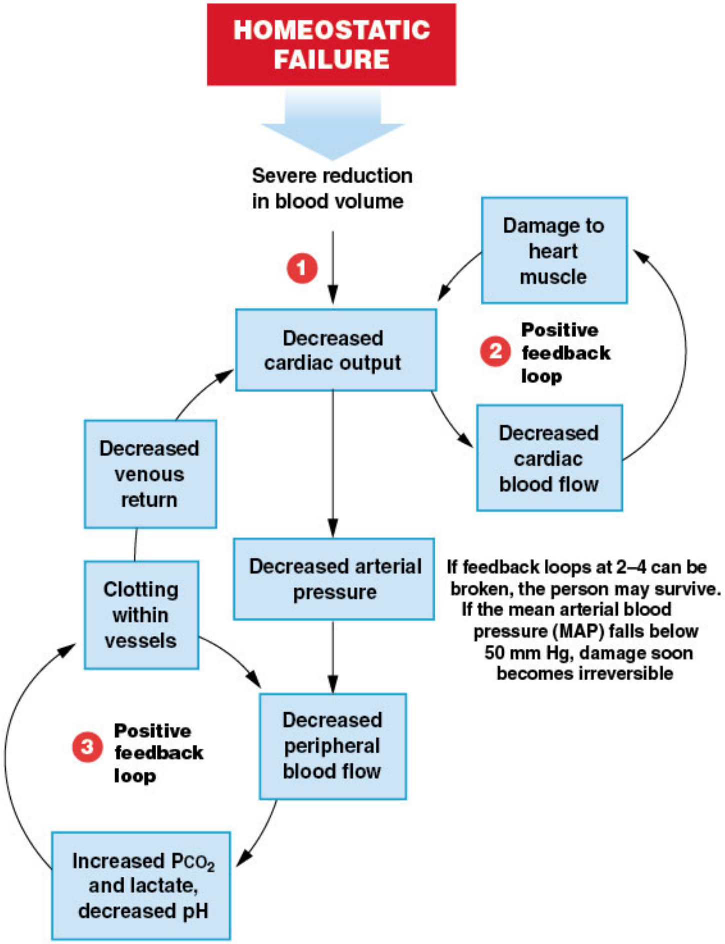
- **Progressive shock** (continued)
  2. Low cardiac output reduces blood flow to heart
     – Damages myocardium
     – Leads to further reduction to cardiac output



Module 19.13: Responses to blood loss

Shock (continued)

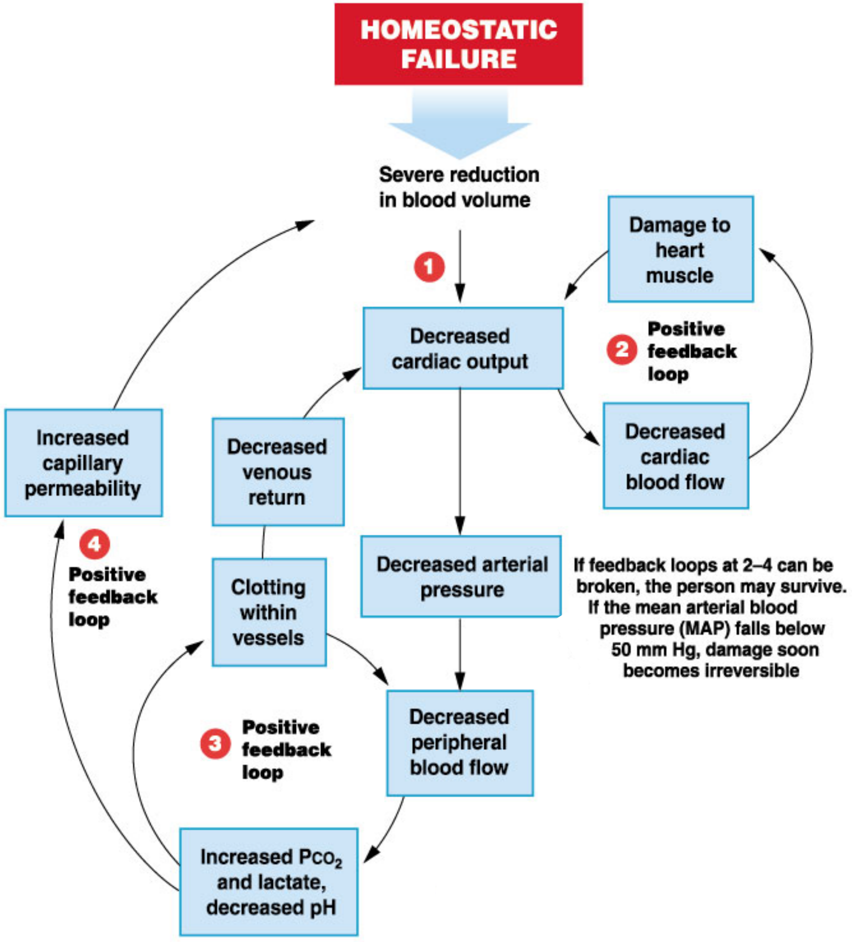
- **Progressive shock** (continued)
  3. Reduced cardiac output accelerates oxygen starvation in tissues
     – Local chemical changes promote intravascular clotting
     – Further restricts peripheral blood flow



Module 19.13: Responses to blood loss

Shock (continued)

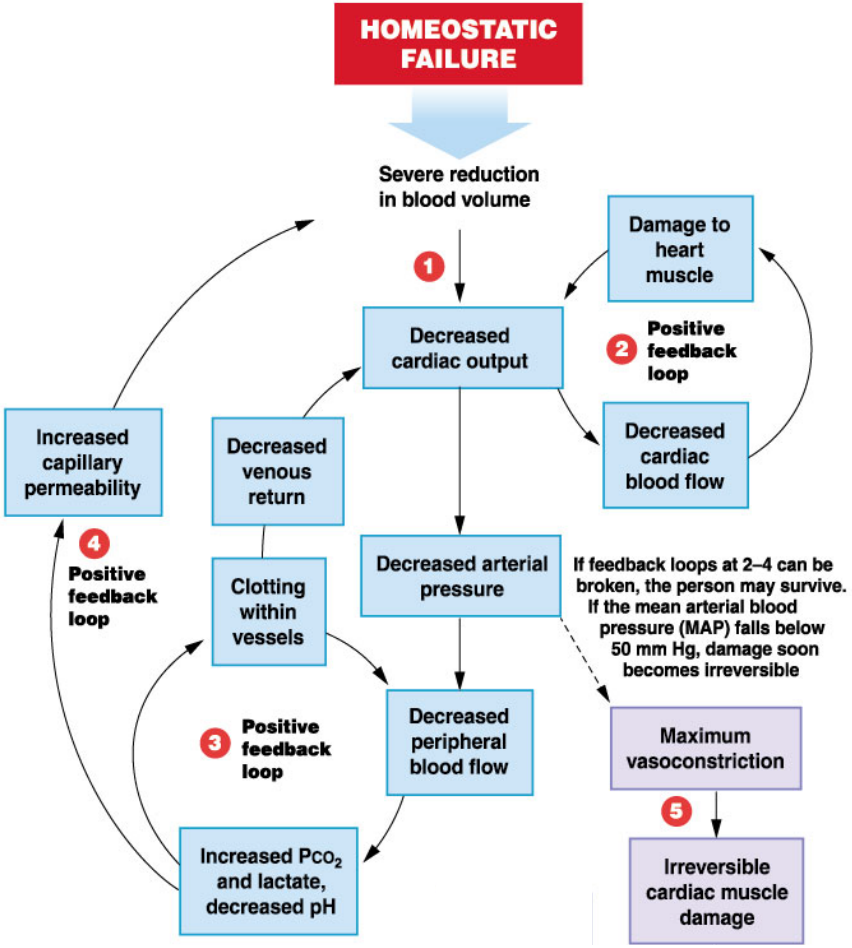
- **Progressive shock** (continued)
  4. Local pH changes increase capillary permeability
     – Further reducing blood volume



Module 19.13: Responses to blood loss

Shock (continued)

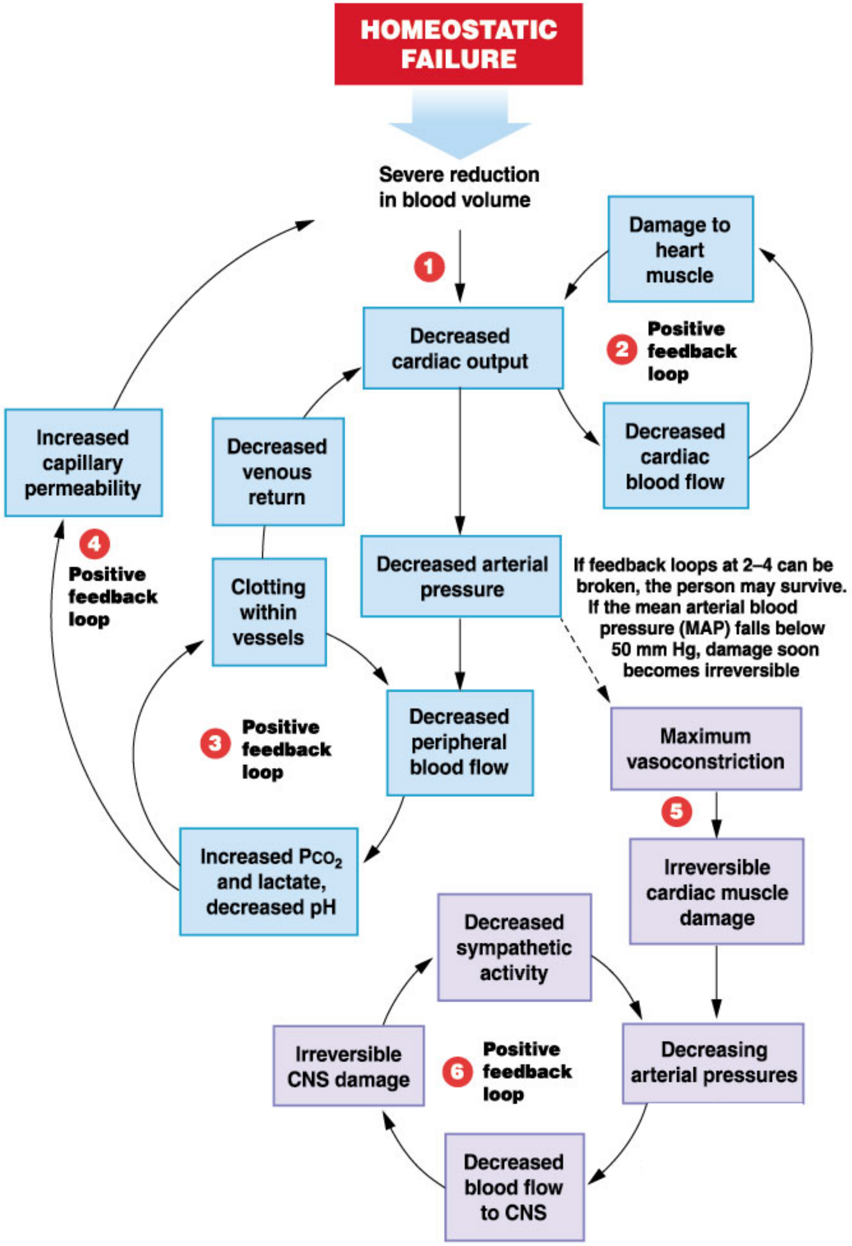
- **Irreversible shock**
  5. Carotid baroreceptors trigger vasomotor centers
     - Sympathetic output causes widespread vasoconstriction
       - Reduces peripheral circulation but increases brain blood flow temporarily



Module 19.13: Responses to blood loss

Shock (continued)

- **Irreversible shock** (continued)
  6. Without treatment, blood pressure will again decline
     – Heart is now seriously damaged, and cardiac output declines

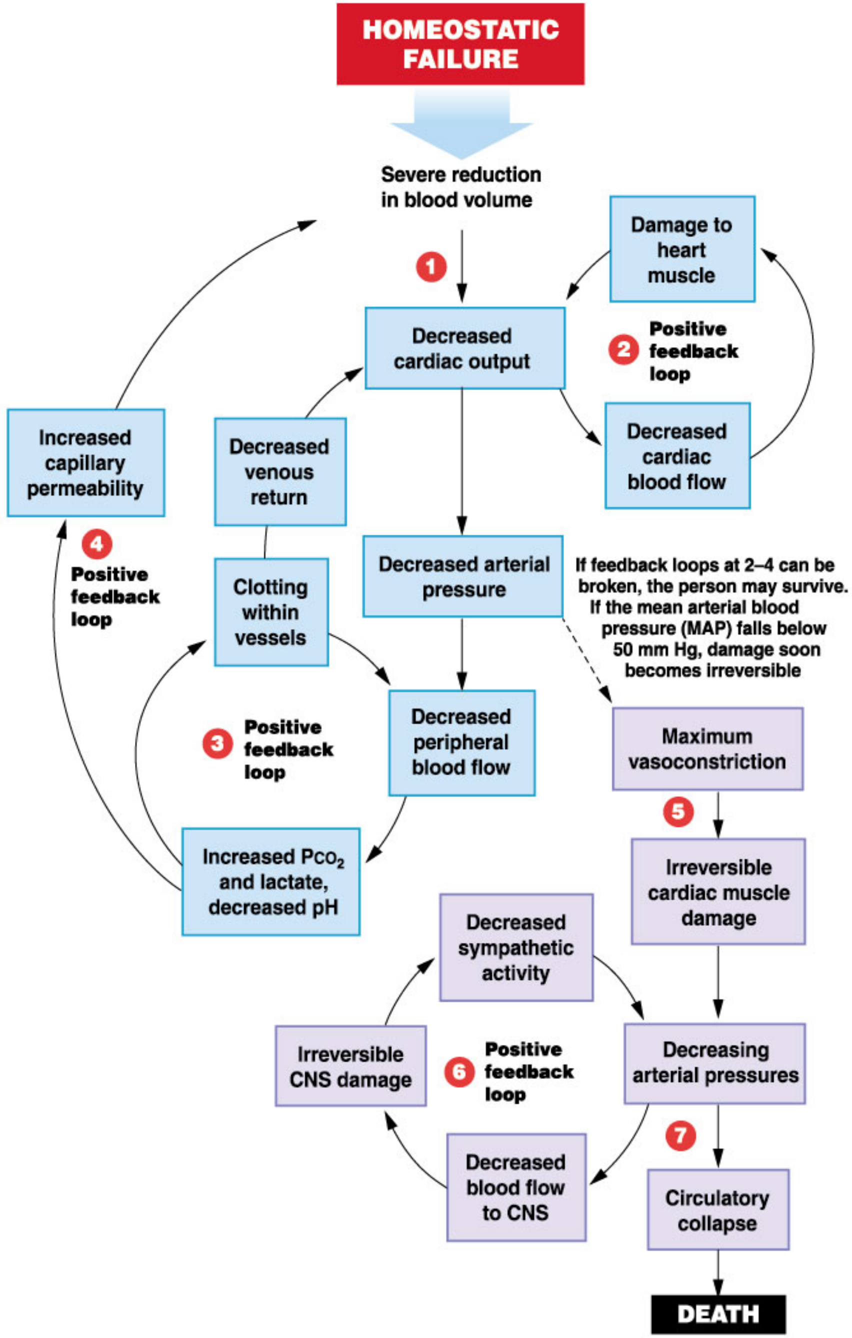


Module 19.13: Responses to blood loss

Shock (continued)

- **Irreversible shock** (continued)
  7. **Circulatory collapse**
     - Occurs when arteriolar smooth muscles and precapillary sphincters cannot contract
     - Leads to:
       - Widespread vasodilation
       - Immediate and fatal decrease in blood pressure
       - Cessation of blood flow

Shock



HOMEOSTATIC FAILURE
Severe reduction in blood volume
1
Decreased cardiac output
Damage to heart muscle
2 Positive feedback loop
Decreased cardiac blood flow
Increased capillary permeability
Decreased venous return
Decreased arterial pressure
If feedback loops at 2–4 can be broken, the person may survive. If the mean arterial blood pressure (MAP) falls below 50 mm Hg, damage soon becomes irreversible
4 Positive feedback loop
Clotting within vessels
3 Positive feedback loop
Decreased peripheral blood flow
Maximum vasoconstriction
5
Increased P_{CO_2} and lactate, decreased pH
Irreversible cardiac muscle damage
Decreased sympathetic activity
Irreversible CNS damage
6 Positive feedback loop
Decreasing arterial pressures
7
Decreased blood flow to CNS
Circulatory collapse
DEATH

Module 19.13: Review

A. Identify the compensatory mechanisms that respond to blood loss.
B. Name the immediate and long-term problems related to hemorrhage.
C. Describe circulatory shock, progressive shock, and irreversible shock.

Learning Outcome: Explain the body's response to blood loss.

Section 3: Patterns of Blood Flow

Learning Outcomes

19.14 Distinguish between vasculogenesis and angiogenesis.

19.15 Identify the major arteries and veins of the pulmonary circuit, and name the areas each serves.

19.16 Identify the major arteries and veins of the systemic circuit, and name the areas each serves.

19.17 Identify the branches of the aortic arch and the branches of the superior vena cava, and name the areas each serves.

Section 3: Patterns of Blood Flow

Learning Outcomes (continued)

19.18 Identify the branches of the carotid arteries and the branches of the external jugular veins, and name the areas each serves.

19.19 Identify the branches of the internal carotid and vertebral arteries and the branches of the internal jugular veins, and name the areas each serves.

19.20 Identify the branches of the descending aorta and the branches of the venae cavae, and name the areas each serves.

Section 3: Patterns of Blood Flow

Learning Outcomes (continued)

19.21 Identify the branches of the visceral arterial vessels and the venous branches of the hepatic portal system, and name the areas each serves.

19.22 Identify the branches of the common iliac arteries and the branches of the common iliac veins, and name the areas each serves.

19.23 Describe the pathways taken by oxygenated blood and deoxygenated blood in the systemic circuit.

Section 3: Patterns of Blood Flow

Learning Outcomes (continued)

19.24 **Clinical Module:** Identify the differences between fetal and adult circulation patterns, identify changes in blood flow patterns at birth, and list common congenital heart problems.

Module 19.14: New blood vessels form through vasculogenesis and angiogenesis

Blood vessel formation involves two processes

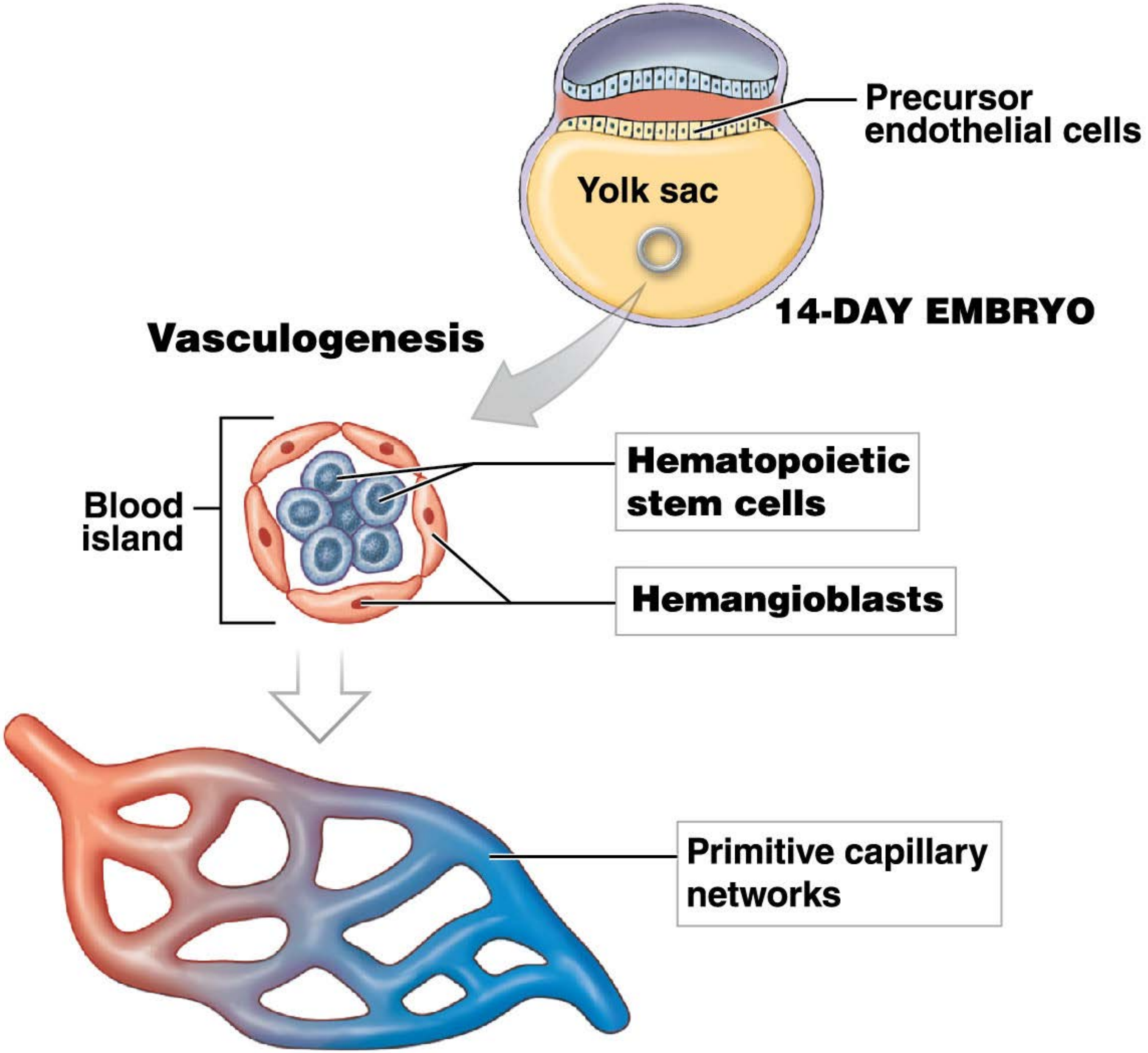
1. **Vasculogenesis**
   - Formation of the first blood vessels by precursor endothelial cells called **hemangioblasts**
   - Around day 7 of embryonic development, begin by forming blood islands in the yolk sac
   - Hemangioblasts in the center of blood island differentiate into **hematopoietic stem cells**
     - Give rise to all other blood cells

Module 19.14: New blood vessels form through vasculogenesis and angiogenesis

Blood vessel formation involves two processes

1. **Vasculogenesis** (continued)
   - Hemangioblasts in periphery become **angioblasts**
     - Combine to form first blood vessels
   - Angioblasts remodel blood islands into primitive capillary networks, then into larger vessel networks

Vasculogenesis



Module 19.14: Vasculogenesis and angiogenesis

Blood vessel formation involves two processes (continued)

1. **Vasculogenesis** (continued)
   - **Cardinal veins**
     - Series of venous channels that will form the superior and inferior venae cavae
   - **Aortic arches**
     - Series of arterial channels that will form the carotid arteries, aortic arch, and part of pulmonary arteries
   - **Dorsal aorta**
     - Becomes the descending aorta

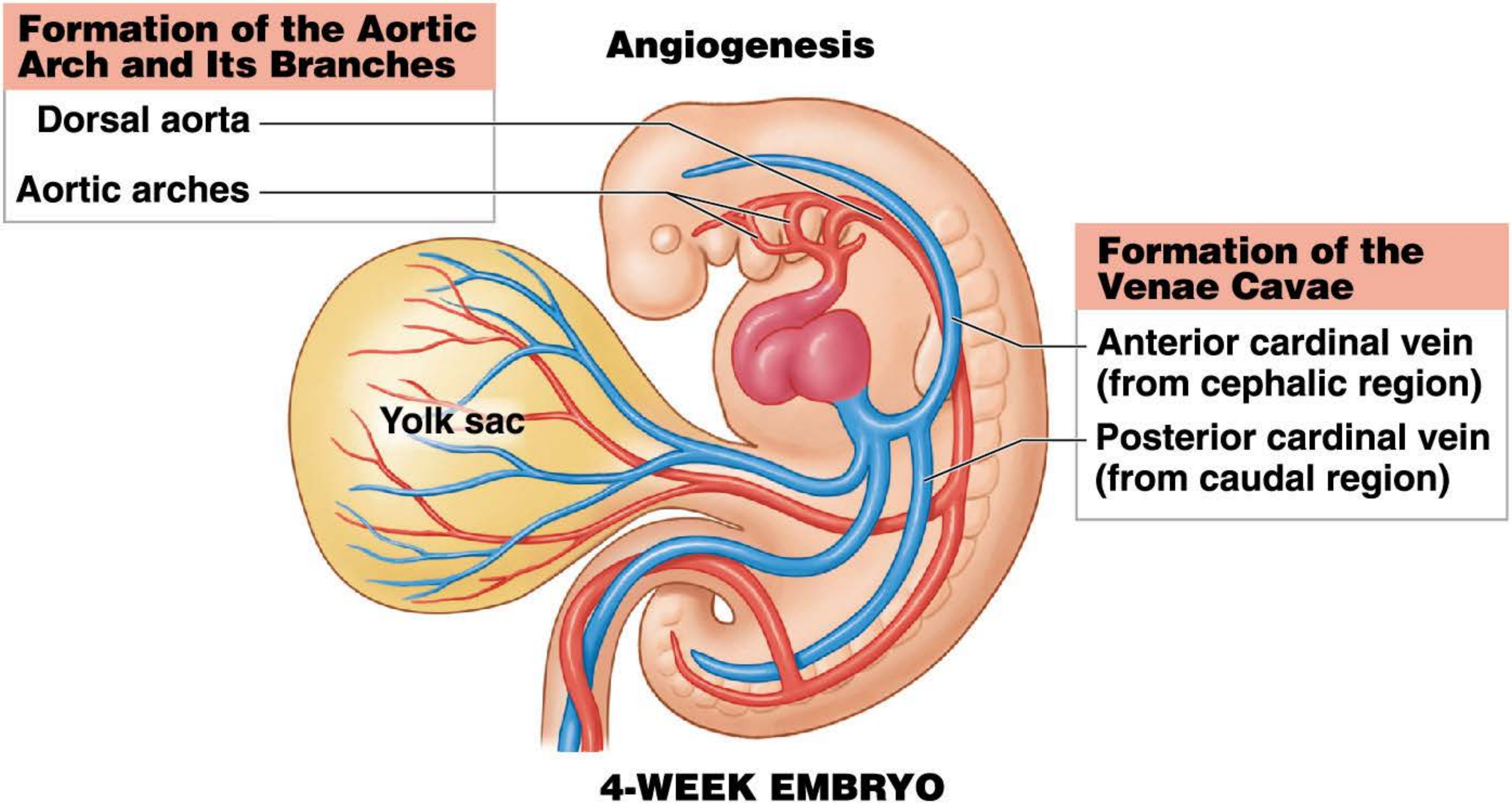
Module 19.14: Vasculogenesis and angiogenesis

Blood vessel formation involves two processes (continued)

2. **Angiogenesis**
    - Growth of new blood vessels from preexisting vessels

- Dorsal aorta and cardinal veins formed by vasculogenesis
- Further growth of blood vessels occurs through angiogenesis

Formation of the aortic arch and its branches



Module 19.14: Review

A. What are blood islands, and from which cells do they form?
B. What is the function of hemangioblasts?

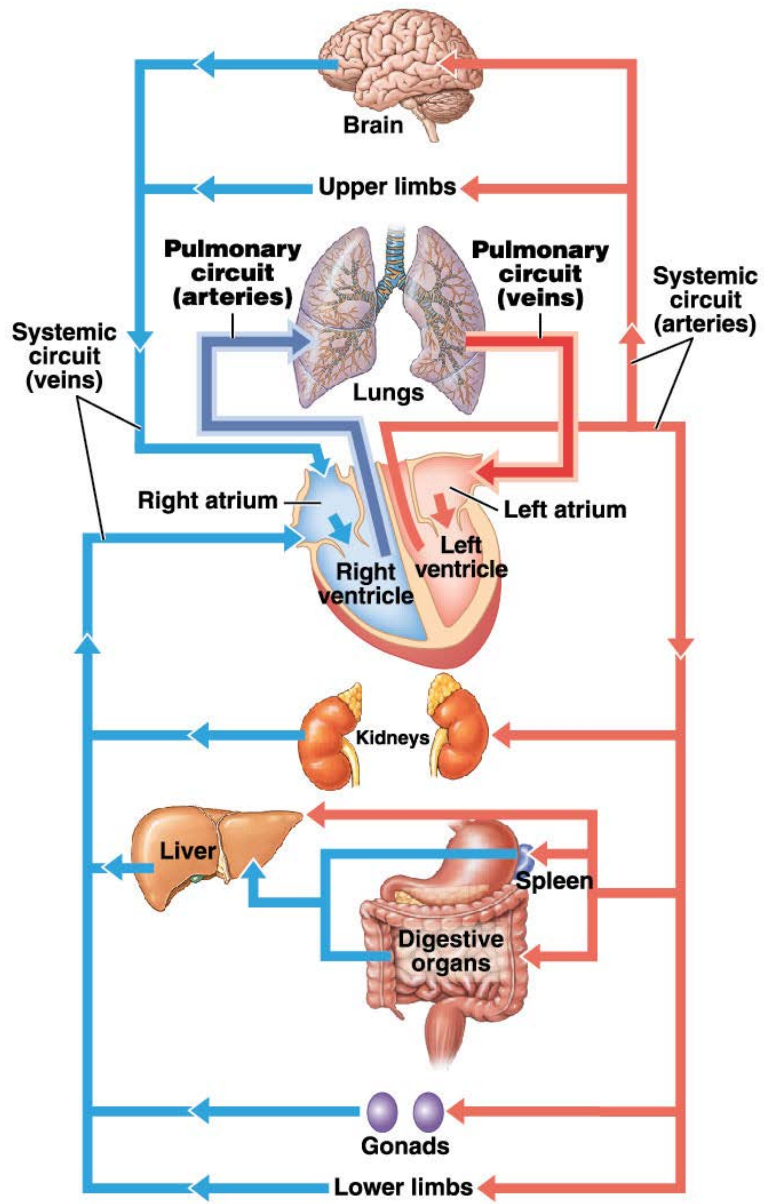
Learning Outcome: Distinguish between vasculogenesis and angiogenesis.

Module 19.15: The pulmonary circuit carries deoxygenated blood from the right ventricle to the lungs and returns oxygenated blood to the left atrium

Circuit review

- **Pulmonary circuit**
  - Composed of arteries and veins that transport blood between the heart and lungs
  - Begins at the right ventricle; ends at the left atrium
- **Systemic circuit**
  - Transports oxygenated blood to all organs and tissues
  - Begins at the left ventricle; ends at the right atrium

Pulmonary and systemic circuits



General Patterns of Blood Vessel Organization

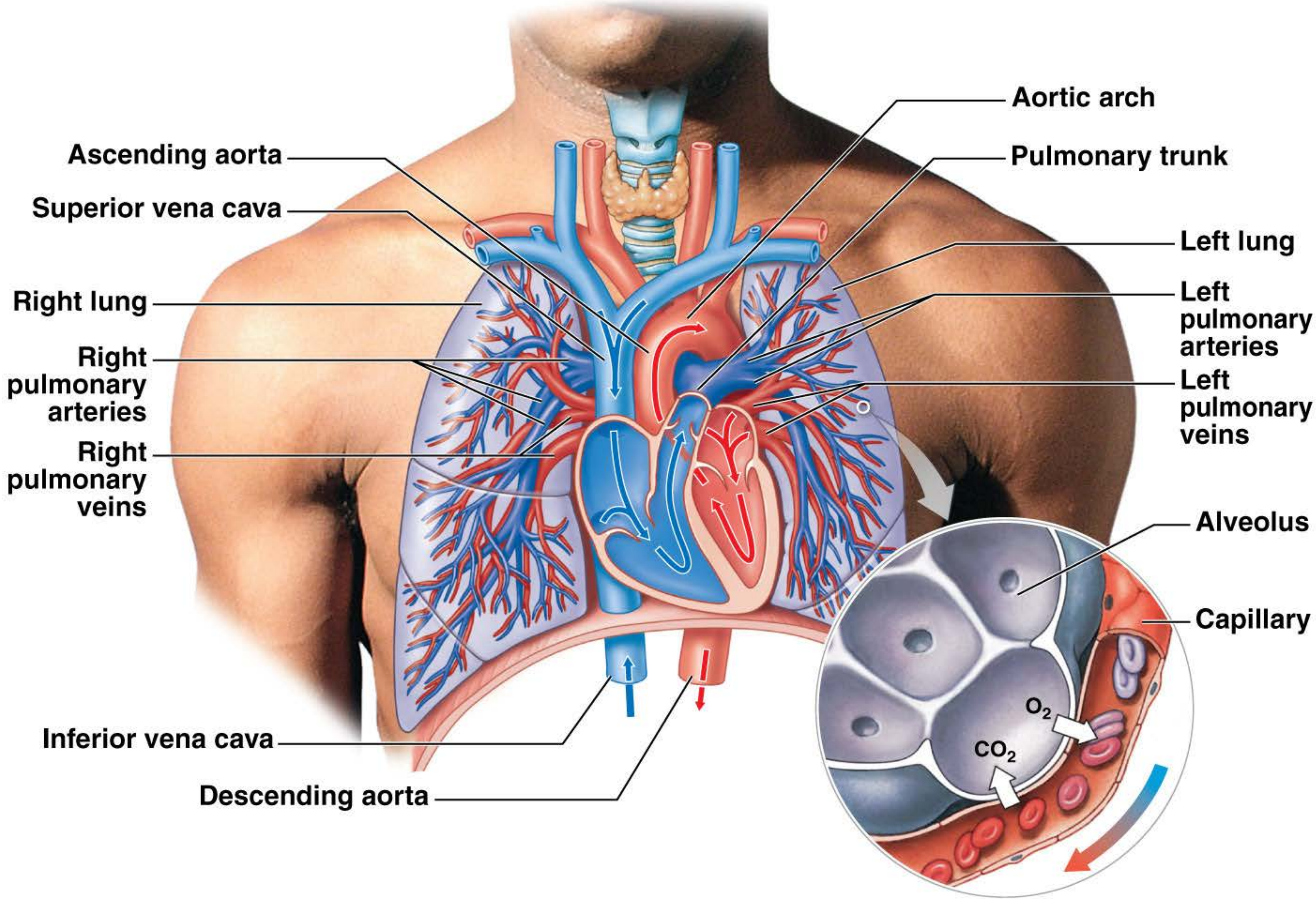
- The peripheral distributions of arteries and veins on the body's left and right sides are generally identical, except near the heart, where the largest vessels connect to the atria or ventricles.
- A single vessel may have several names as it crosses specific anatomical boundaries, making accurate anatomical descriptions possible when the vessel extends far into the periphery. For example, the external iliac artery becomes the femoral artery as it leaves the trunk and enters the lower limb.
- Tissues and organs are usually serviced by several arteries and veins. Often, anastomoses between adjacent arteries or veins reduce the impact of a temporary or even permanent **occlusion** (blockage) of a single blood vessel.

Module 19.15: The pulmonary circuit

Pulmonary circuit

- Arteries of pulmonary circuit differ from those in systemic circuit
- **Pulmonary trunk** (large artery coming out of the right ventricle) branches into:
  - Right and left **pulmonary arteries**, which branch into:
    - Smaller arteries and **pulmonary arterioles** supplying:
    - **Alveolar capillaries** around **alveoli** (air pockets), where gas exchange occurs
    - Oxygenated blood returns along small venules that join to form:
  - **Pulmonary veins** (two right and two left) which drain into the left atrium

Pulmonary circuit



Module 19.15: Review

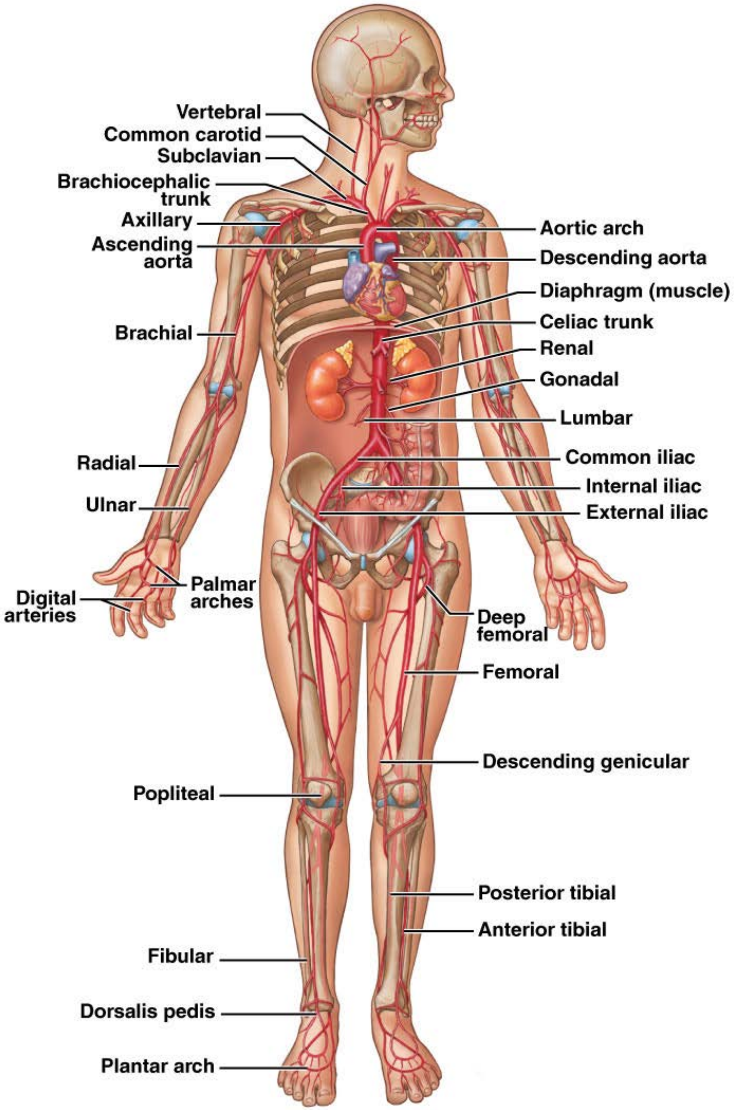
A. Compare the oxygen content in the two circulatory circuits.
B. Briefly describe the general patterns of blood vessel organization.
C. Trace a drop of blood through the lungs, beginning at the right ventricle and ending at the left atrium.

Learning Outcome: Identify the major arteries and veins of the pulmonary circuit, and name the areas each serves.

Module 19.16: The arteries and veins of the systemic circuit operate in parallel, and the major vessels often have similar names

Systemic vessels

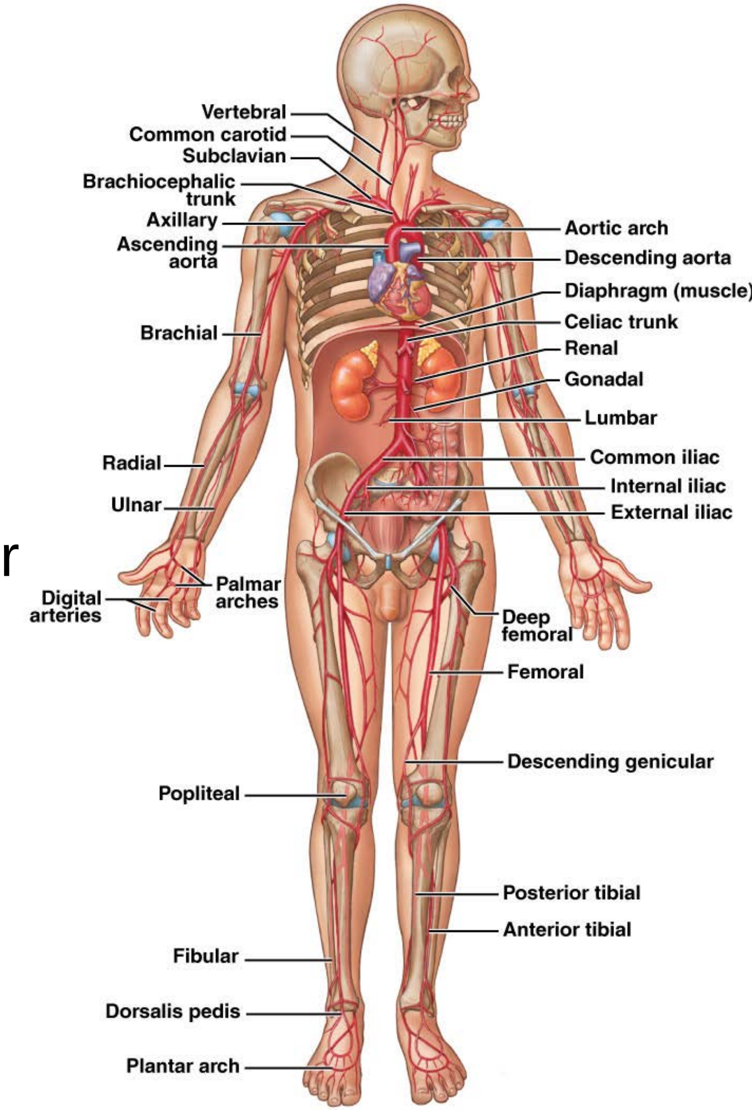
- **Arterial system**
  - All vessels originate from the **aorta** (the largest elastic artery) extending from the left ventricle
  - Most arteries are paired (left and right)



Module 19.16: Systemic vessels

Systemic vessels (continued)

- **Venous system**
  - All vessels drain into:
    - **Superior vena cava**
      - From head, neck, chest, and upper limbs
    - **Inferior vena cava**
      - From all structures inferior to the diaphragm (trunk and lower limbs)



Module 19.16: Systemic vessels

Systemic vessels (continued)

- Arteries and veins usually similar on both sides of body
- One significant difference between arteries and veins is distribution in the neck and limbs
  - Arteries: deep in skin, protected by bones and soft tissues

Module 19.16: Systemic vessels

Systemic vessels (continued)

- One significant difference between arteries and veins is distribution in the neck and limbs (continued)
  - Veins: generally two sets, one deep and one superficial
    - Important in controlling body temperature
      - Venous blood flows superficially in hot weather to radiate heat
      - Venous blood flows deep in cold weather to conserve heat

Module 19.16: Review

A. Identify the largest artery in the body.
B. Name the two large veins that collect blood from the systemic circuit.
C. Besides containing valves, cite another major difference between the arterial and venous systems.

Learning Outcome: Identify the major arteries and veins of the systemic circuit, and name the areas each serves.

Module 19.17: Arteries and veins of the upper limb

Arteries

- Branches of the aortic arch
  - Three elastic arteries
    1. **Brachiocephalic trunk**
       - Branches into:
         - **Right subclavian artery** (to right arm and chest)
         - **Right common carotid artery** (to right side of head and neck)
    2. **Left common carotid artery** (to left side of head and neck)
    3. **Left subclavian artery** (to left arm and chest)

Module 19.17: Arteries and veins of the upper limb

Arteries (continued)

- Branches of the right subclavian artery
  - In the thoracic cavity
    - **Internal thoracic artery** (internal mammary artery)
      - Supplies pericardium and anterior chest wall
    - **Vertebral artery**
      - Supplies brain and spinal cord

Module 19.17: Arteries and veins of the upper limb

Arteries (continued)

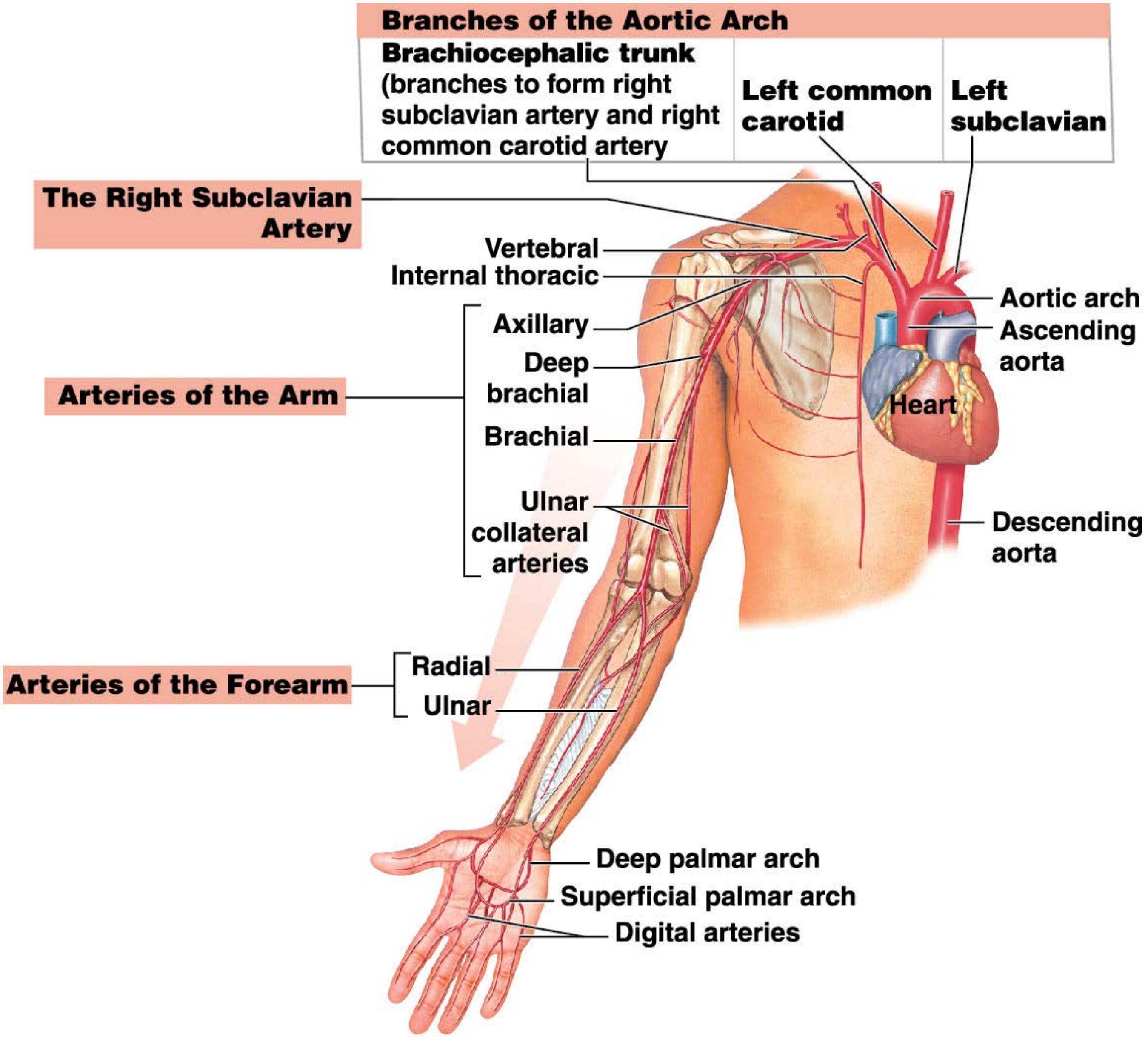
- Branches of the right subclavian artery (continued)
  - Arteries of the arm
    - Continuation of the subclavian artery
    - **Axillary artery** (crosses axilla to enter arm)
    - **Brachial artery** (supplies upper limb)
      - In the upper arm, gives rise to:
        - Deep brachial artery (supplies deep arm structures)
        - Ulnar collateral arteries (supply elbow area)

Module 19.17: Arteries and veins of the upper limb

Arteries (continued)

- Branches of the right subclavian artery (continued)
  - Arteries of the forearm (branches of the brachial artery)
    - **Radial artery** (follows the radius)
    - **Ulnar artery** (follows the ulna)
    - Radial and ulnar arteries fuse to form superficial and deep **palmar arches** (supply blood to the hand)
    - Palmar arches branch into **digital arteries** supplying thumb and fingers

Arteries of the upper limb



Module 19.17: Arteries and veins of the upper limb

Veins

- Draining into the right subclavian vein
  - From the **digital veins** in the fingers and thumb, blood drains into veins of the hand and forearm
    - **Deep palmar arch**, which drains into the:
      - **Ulnar vein**
      - **Radial vein**
    - **Superficial palmar arch**, which drains into the:
      - **Cephalic vein**
      - **Median antebrachial vein**
      - **Basilic vein**

Module 19.17: Arteries and veins of the upper limb

Veins (continued)

- Draining into the right subclavian vein (continued)
  - The cephalic and basilic veins are interconnected by the **medial cubital vein** (typical location for collecting venous blood sample)
  - In the arm
    - **Cephalic vein** extends along the lateral side of the arm
    - **Brachial vein** merges with the **basilic vein**
      - Becomes the **axillary vein** as it enters axilla
  - Cephalic vein joins the axillary vein to form the **right subclavian vein**

Module 19.17: Arteries and veins of the upper limb

Veins (continued)

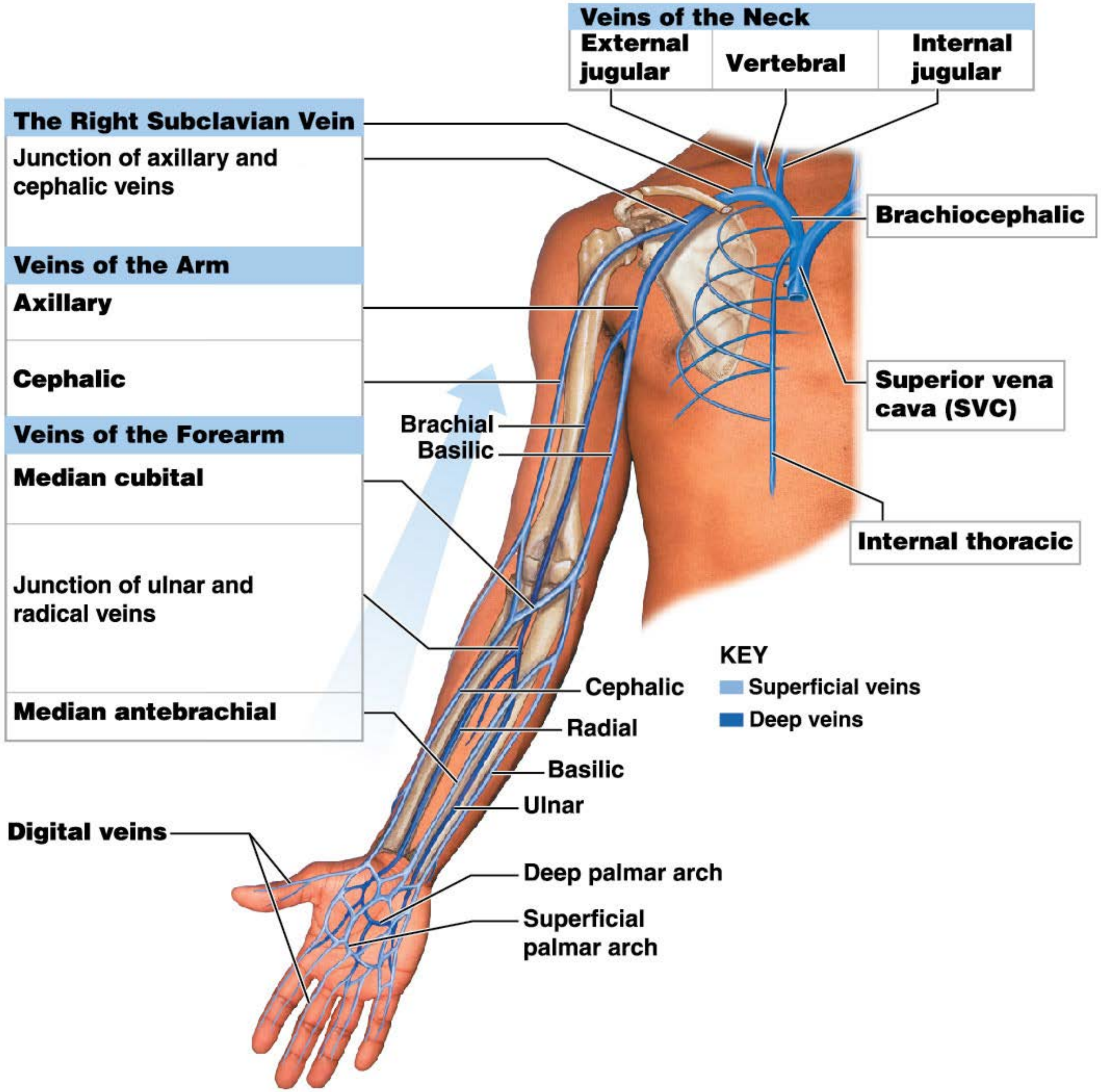
- Veins of the neck
  - **External jugular vein**
    - Drains superficial structures of the head and neck
  - **Internal jugular vein**
    - Drains deep structures of the head and neck
  - **Vertebral vein**
    - Drains the cervical spinal cord and posterior surface of the skull

Module 19.17: Arteries and veins of the upper limb

Veins (continued)

- Veins draining into **superior vena cava** (**SVC**)
  - **Internal thoracic vein**
    - Collects blood from intercostal veins
    - Drains into the brachiocephalic vein
  - **Brachiocephalic vein**
    - Forms at junction of the jugular and subclavian veins
    - Also receives blood from the vertebral and internal thoracic veins
  - Right and left brachiocephalic veins join to form the superior vena cava
    - Drains blood into the right atrium of the heart

Veins of the upper limb



Module 19.17: Review

A. Name the two arteries formed by the division of the brachiocephalic trunk.
B. A blockage of which branch of the aortic arch would interfere with blood flow to the left arm?
C. Whenever Thor gets angry, a large vein bulges in the lateral region of his neck. Which vein is this?

Learning Outcome: Identify the branches of the aortic arch and the branches of the superior vena cava, and name the areas each serves.

Module 19.18: The external carotid arteries supply the neck, lower jaw, and face, and the internal carotid and vertebral arteries supply the brain . . .

Arteries

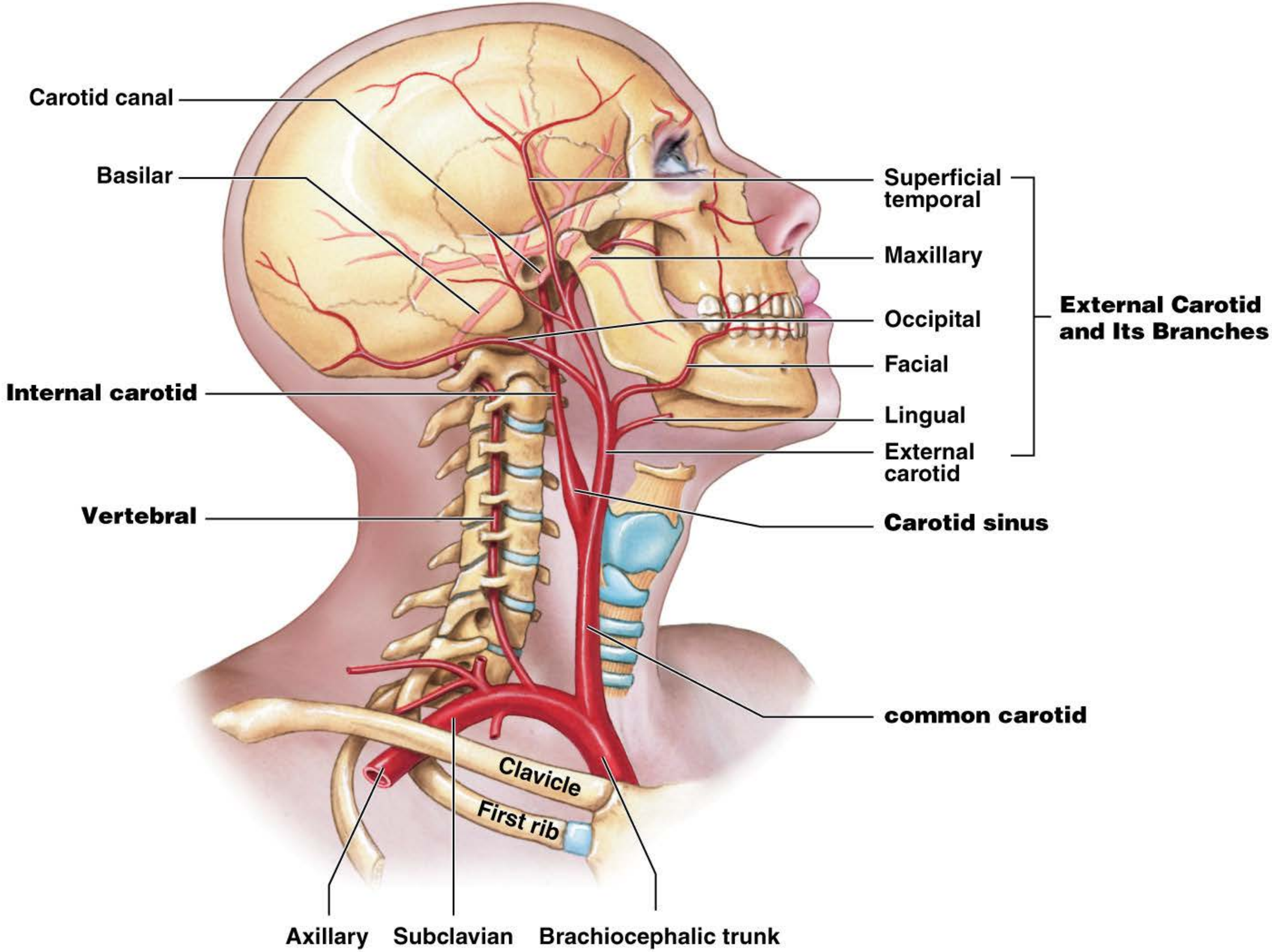
- **Common carotid artery**
  - Supplies blood to face, neck, and brain
  - Branches
    - **External carotid artery**
      - Supplies neck, esophagus, pharynx, larynx, lower jaw, cranium, and face on that side
    - **Internal carotid artery**
      - Supplies brain and eyes
      - **Carotid sinus** at base of the internal carotid artery contains baroreceptors monitoring blood pressure

Module 19.18: Arteries of the head and neck

Arteries (continued)

- **Vertebral artery**
  - From the subclavian artery, ascends within the transverse foramina of the cervical vertebrae
  - Left and right vertebral arteries
    - Enter the cranium at the foramen magnum
    - Fuse to form the **basilar artery** along the ventral surface of the medulla oblongata

Arteries of the head and neck



Module 19.18: . . . while the external jugular veins drain the regions supplied by the external carotid arteries, and the internal jugular veins drain the brain

Veins

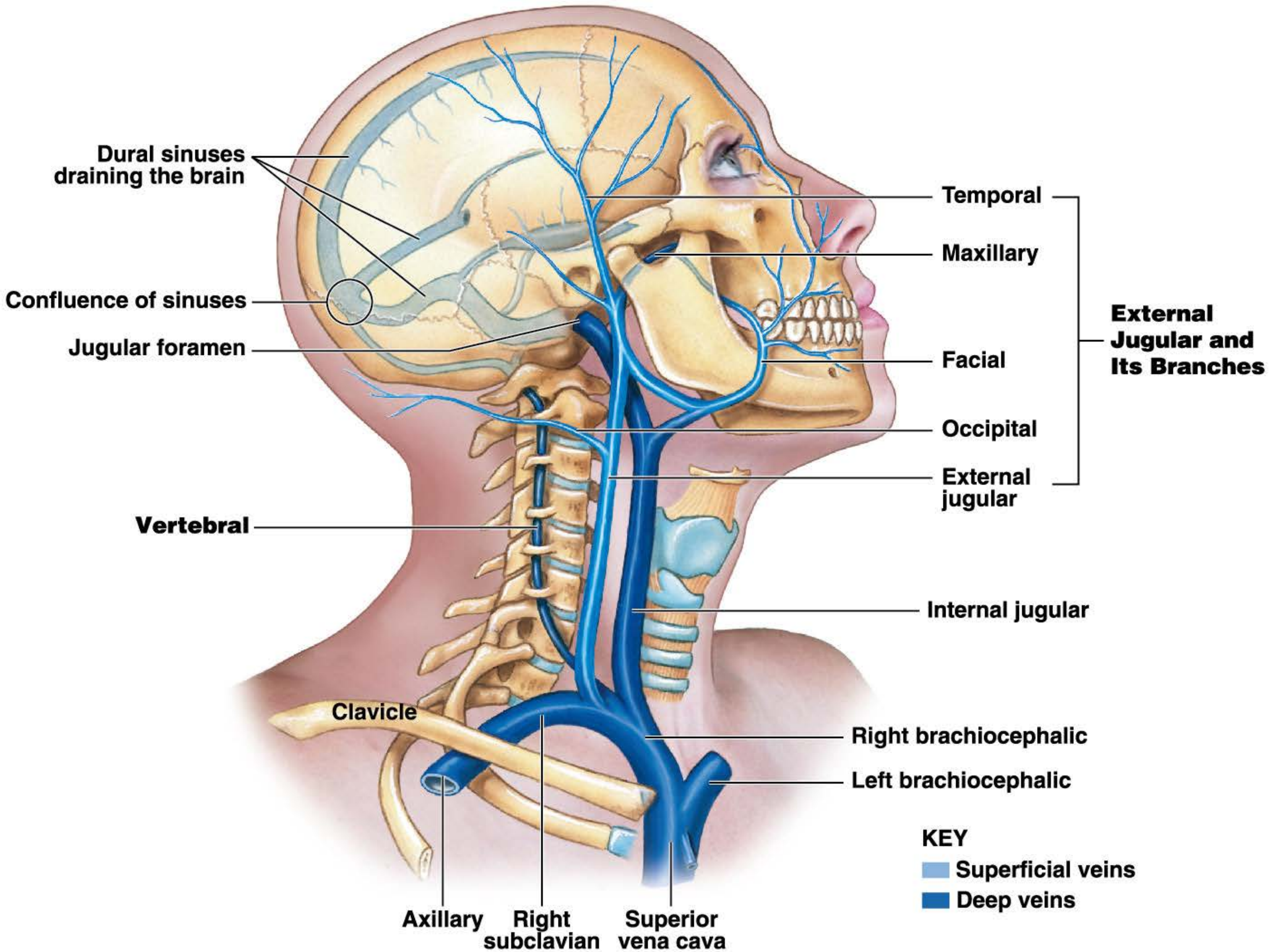
- **External jugular vein**
  - Formed by the maxillary and temporal veins
  - Drains the cranium, face, lower jaw, and neck on that side
- **Internal jugular vein**
  - Drains various cranial venous sinuses
  - Exits skull through the jugular foramen

Module 19.18: Veins of the head and neck

Veins (continued)

- **Vertebral vein**
  - Drains the cervical spinal cord and posterior skull surface
  - Passes through the transverse foramina of the cervical vertebrae
- The external jugular, internal jugular, and vertebral veins merge with the subclavian vein to form the **brachiocephalic vein**

Veins of the Head and Neck



Module 19.18: Review

A. Identify the branches of the external carotid artery.
B. Name the arterial structure in the neck region that contains baroreceptors.
C. Identify the veins that combine to form the brachiocephalic vein.

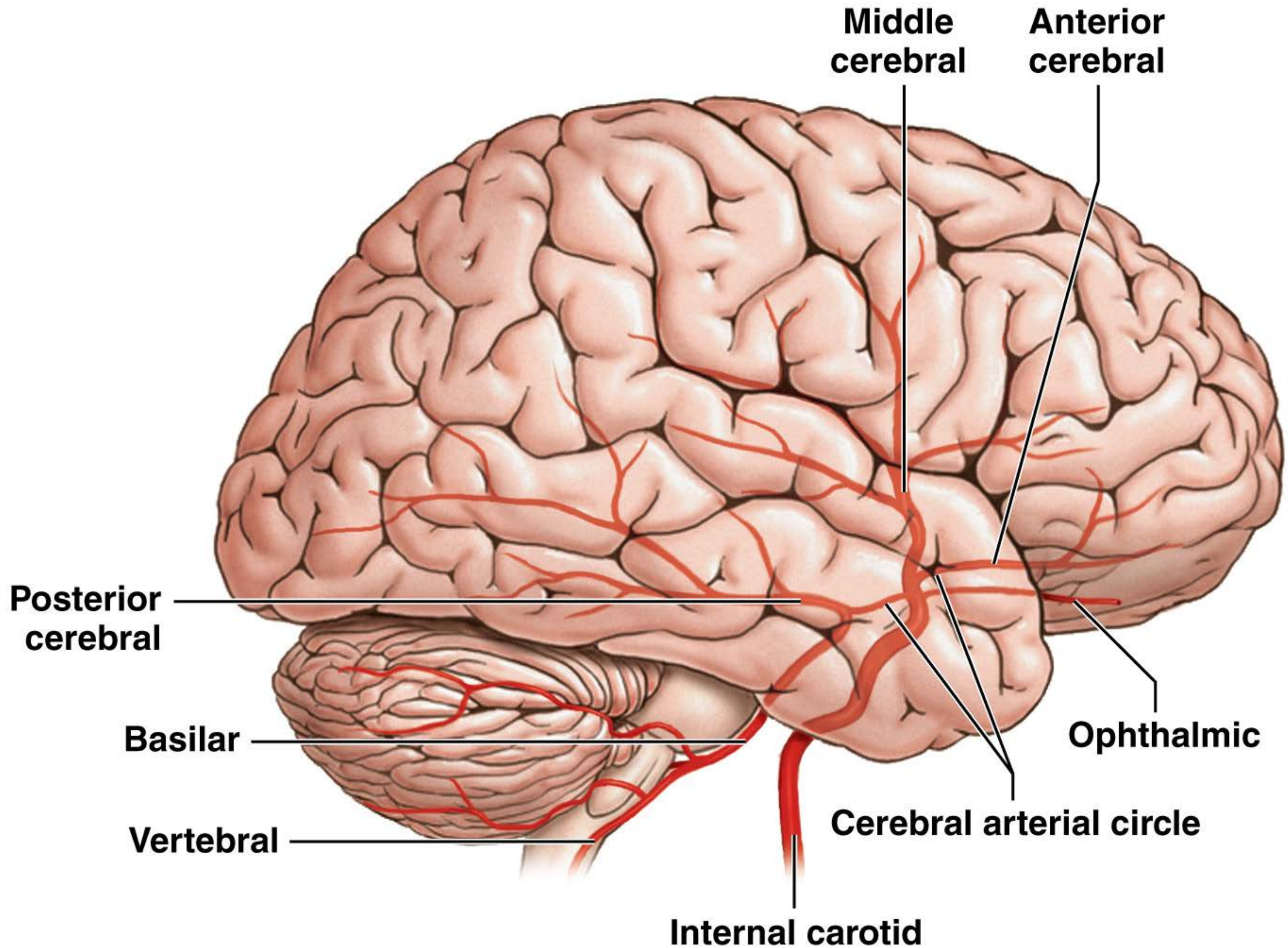
Learning Outcome: Identify the branches of the carotid arteries and the branches of the external jugular veins, and name the areas each serves.

Module 19.19: The internal carotid arteries and the vertebral arteries supply the brain . . .

Arteries

- Internal carotid arteries supply anterior half of the cerebrum
  - Branches of internal carotid artery
    1. **Ophthalmic artery** to the eyes
    2. **Anterior cerebral artery** to the frontal and parietal lobes of brain
    3. **Middle cerebral artery** to the midbrain and lateral surfaces of cerebral hemispheres
- **Vertebral** and **basilar arteries** supply rest of the brain

Arterial branches of the internal jugular and vertebral arteries

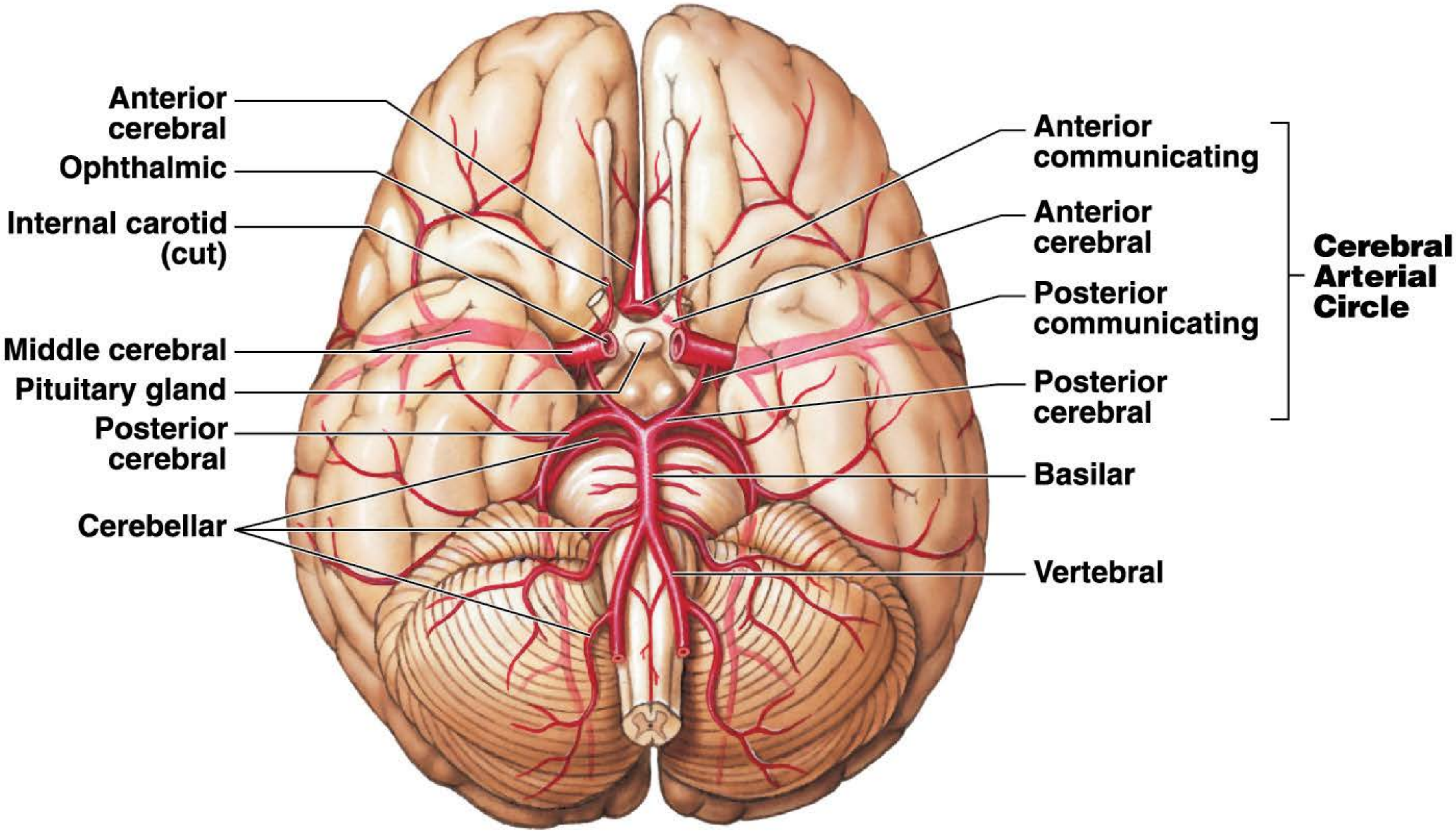


Module 19.19: Arteries of the brain

Arteries (continued)

- **Cerebral arterial circle** (**circle of Willis**)
  - Ring-shaped anastomosis
  - Formed by internal carotid arteries and basilar artery
  - Encircles infundibulum of pituitary gland
    - Arrangement reduces likelihood of serious interruption of cerebral blood flow
  - Basilar artery divides into the posterior cerebral arteries
    - Branch into posterior communicating arteries

Arteries of the brain



Module 19.19: . . . which is drained by the dural sinuses and the internal jugular vein

Veins

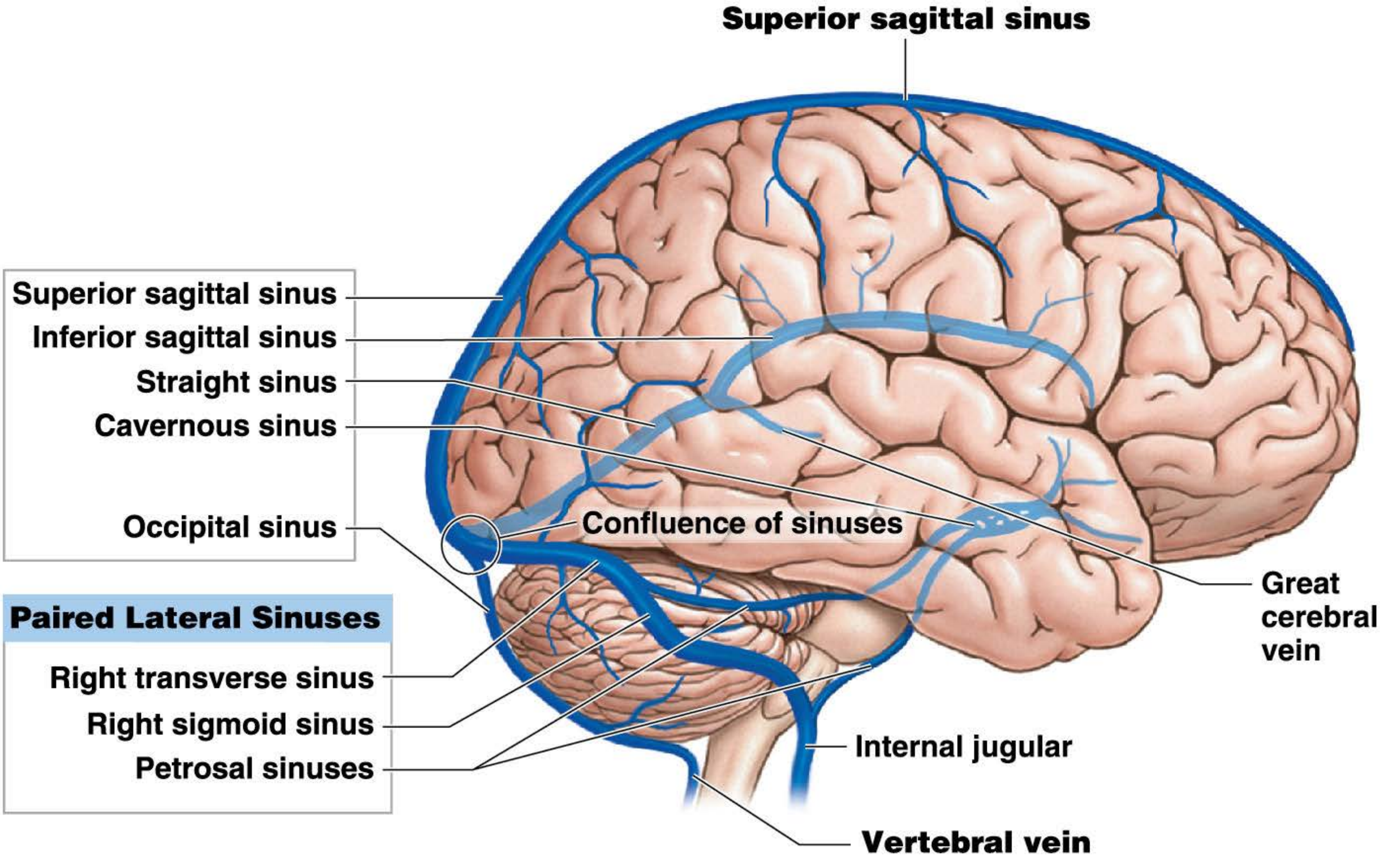
- Superficial cerebral veins and small veins of the brain stem drain into network of dural sinuses
  - **Superior sagittal sinus** is the largest dural sinus
- Deep cerebral veins drain into the **great cerebral vein**
  - Great cerebral vein drains into the **straight sinus**
- Other small cerebral veins and veins from the orbit drain into the **cavernous sinus**

Module 19.19: Veins of the brain

Veins (continued)

- **Vertebral vein**
  - Receives blood from transverse sinus, occipital sinus, superficial veins of the skull, and veins draining the cervical vertebrae

Veins of the brain

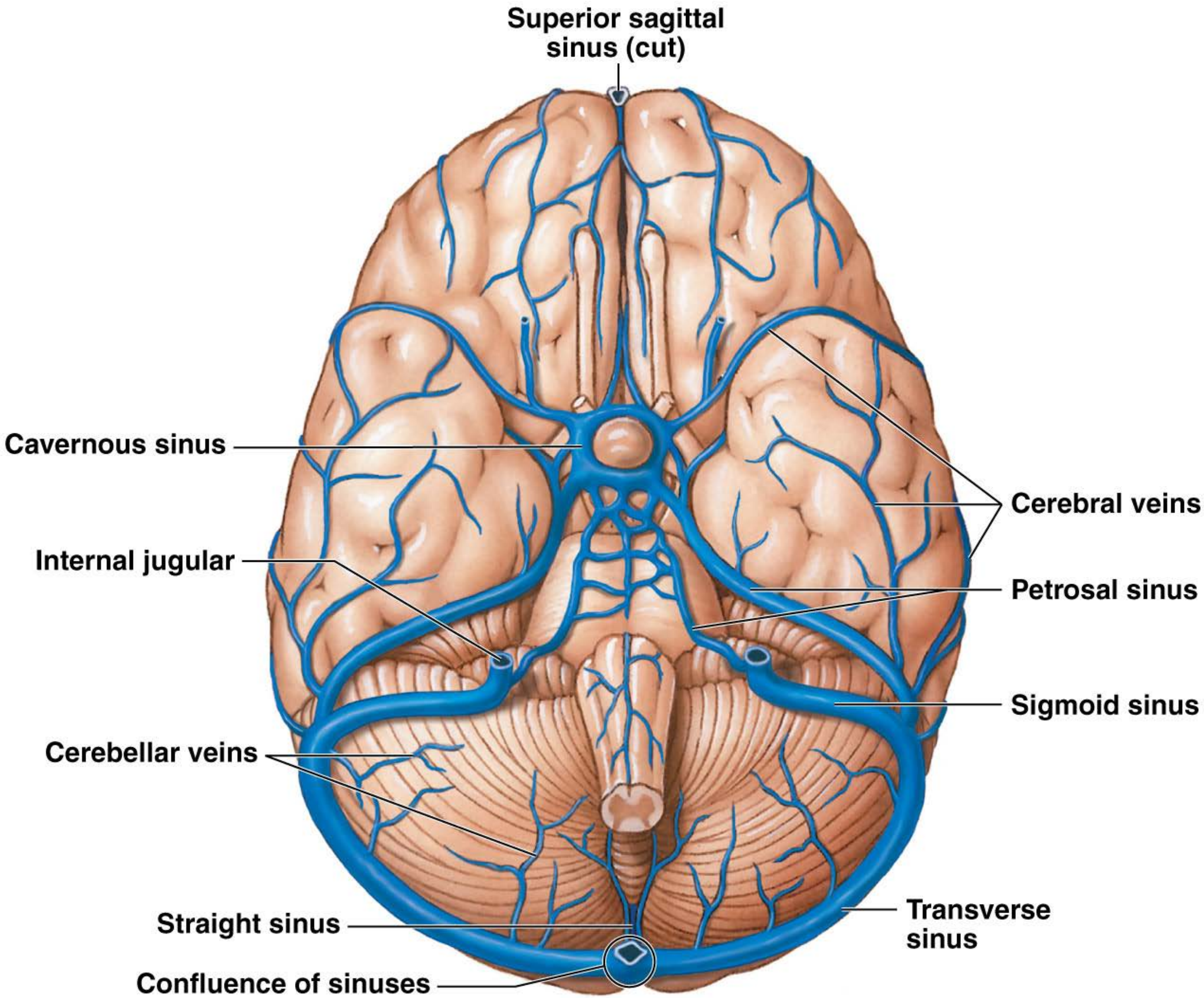


Module 19.19: Veins of the brain

Veins (continued)

- Cavernous sinus empties into two **petrosal sinuses**
  - They drain into the **transverse sinus**
- **Sigmoid sinuses**
  - Formed at convergence of the transverse sinus, straight sinus, and superior sagittal sinus
  - Penetrate skull at the jugular foramina as the internal jugular vein

Veins of the brain



Module 19.19: Review

A. Name the three branches of the internal carotid artery.

B. Describe the structure and function of the cerebral arterial circle.

C. Name the veins that drain the dural sinuses of the brain.

Learning Outcome: Identify the branches of the internal carotid and vertebral arteries and the branches of the internal jugular veins, and name the areas each serves.

Module 19.20: The regions supplied by the descending aorta . . .

Arteries

- Descending aorta continues from the aortic arch
- Diaphragm divides the descending aorta into:
  - **Thoracic aorta**
  - **Abdominal aorta**

Module 19.20: Arteries of the trunk

Arteries (continued)

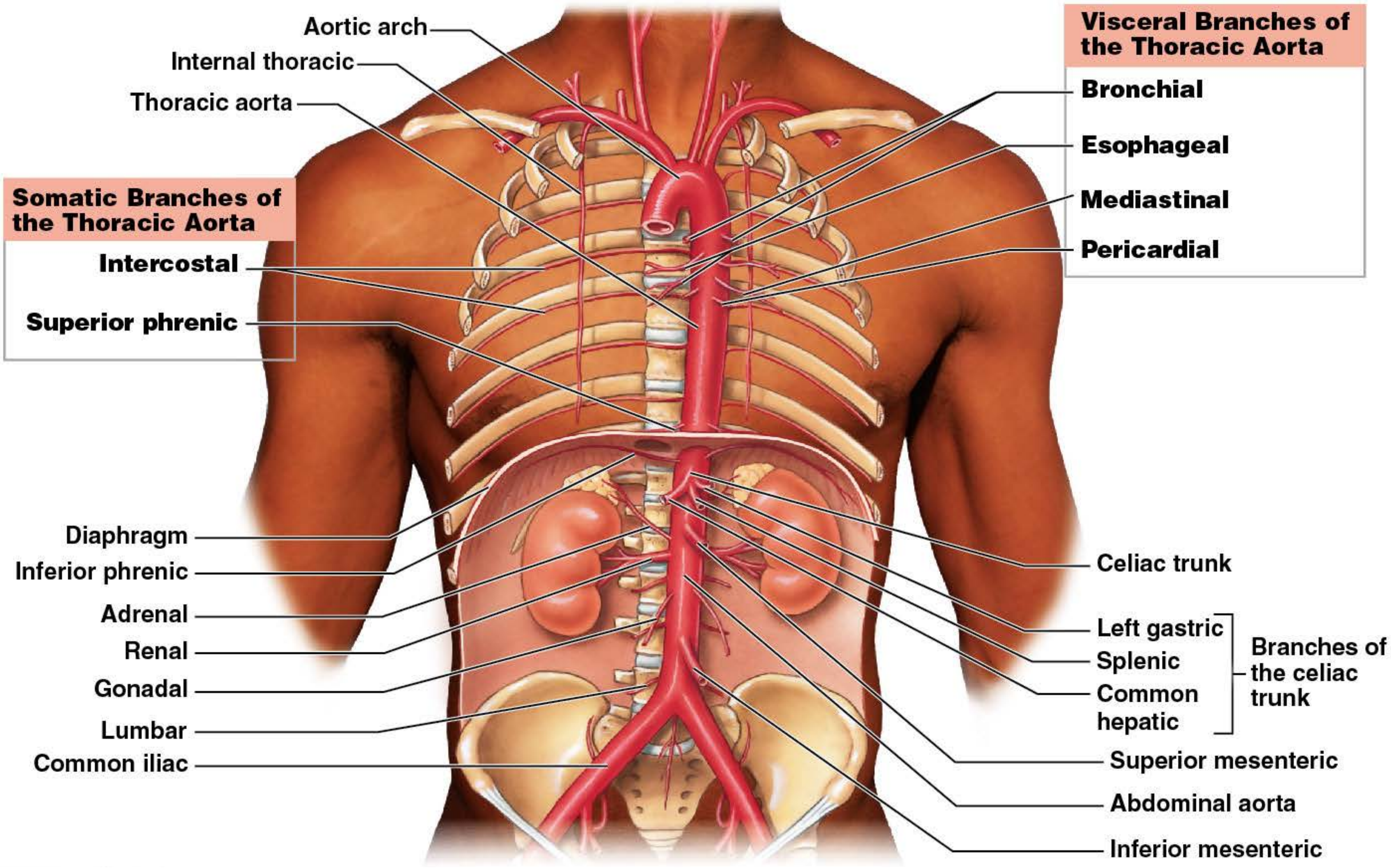
- Somatic branches of thoracic aorta
  - **Intercostal arteries**
    - Supply chest muscles and vertebral column
  - **Superior phrenic arteries**
    - Supply the superior surface of the diaphragm

Module 19.20: Arteries of the trunk

Arteries (continued)

- Visceral branches of thoracic aorta (supply the organs of the chest)
  - **Bronchial arteries**
    - Supply lung tissues not involved in gas exchange
  - **Esophageal arteries**
    - Supply the esophagus
  - **Mediastinal arteries**
    - Supply tissues of the mediastinum
  - **Pericardial arteries**
    - Supply the pericardium

Arteries of the trunk



Module 19.20: Arteries of the trunk

Arteries (continued)

- Major paired branches of the abdominal aorta
  - **Inferior phrenic arteries** (supply the inferior diaphragm and esophagus)
  - **Adrenal arteries** (supply the adrenal glands)
  - **Renal arteries** (supply the kidneys)
  - **Gonadal arteries** (supply the gonads)
    - Called testicular arteries in males
    - Called ovarian arteries in females
  - **Lumbar arteries** (supply the vertebrae, spinal cord, abdominal wall)

Module 19.20: Arteries of the trunk

Arteries (continued)

- Major unpaired branches of the abdominal aorta
  - **Celiac trunk** (three branches)
    1. Left gastric artery (stomach and inferior esophagus)
    2. Splenic artery (spleen and stomach arteries)
    3. Common hepatic artery (arteries to liver, stomach, gallbladder, and proximal small intestine)
  - **Superior mesenteric artery** (pancreas, duodenum, most of large intestine)
  - **Inferior mesenteric artery** (colon and rectum)

Module 19.20: . . .are drained by the superior and inferior venae cavae

Veins

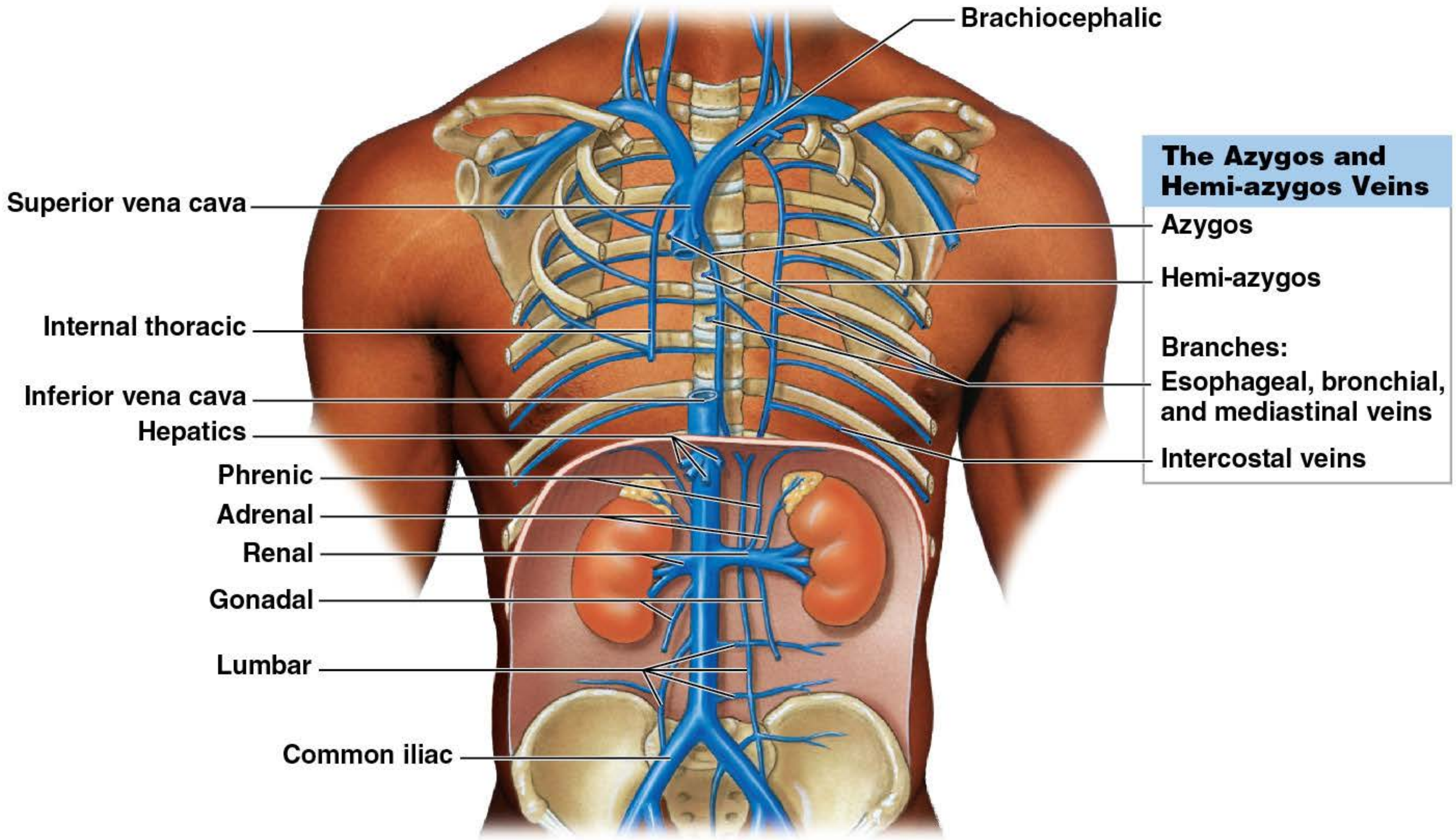
- Superior vena cava drains blood from the head, neck, shoulders, chest, and upper limbs
  - Major collecting vessels of the trunk
  - **Azygos vein** (major branch of superior vena cava)
  - **Hemiazygos vein** (drains into the azygos vein; may drain into left brachiocephalic vein)

Module 19.20: Veins of the trunk

Veins (continued)

- Drainage into the azygos vein and hemiazgos vein from the:
  1. **Intercostal veins** (chest muscles)
  2. **Esophageal veins** (inferior esophagus)
  3. **Bronchial veins** (passageways of lungs)
  4. **Mediastinal veins** (mediastinal structures)

Veins of the trunk



Module 19.20: Veins of the trunk

Veins (continued)

- The inferior vena cava collects most of the blood inferior to the diaphragm
- Major tributaries of inferior vena cava
  - **Lumbar veins** (lumbar portion of abdomen)
  - **Gonadal** (ovarian or testicular) veins (gonads)
  - **Hepatic veins** (liver)
  - **Renal veins** (kidneys)
    - Largest branches of the inferior vena cava

Module 19.20: Veins of the trunk

Veins (continued)

- Major tributaries of inferior vena cava (continued)
  - **Adrenal veins** (adrenal glands)
  - **Phrenic veins** (diaphragm)
    - Only the right phrenic vein drains into the inferior vena cava
    - The left phrenic vein drains into the left renal vein

Module 19.20: Review

A. Which vessel collects most of the venous blood inferior to the diaphragm?
B. Identify the major branches of the inferior vena cava.
C. Grace is in an automobile accident, and her celiac trunk is ruptured. Which organs will be affected most directly by this injury?

Learning Outcome: Identify the branches of the descending aorta and the branches of the venae cavae, and name the areas each serves.

Module 19.21: The viscera supplied by the celiac trunk and mesenteric arteries . . .

Arteries

- The **celiac trunk**
  - Divides into the common hepatic artery, left gastric artery, and splenic artery
- Branches of the **common hepatic artery**
  - Hepatic artery proper (liver)
  - Cystic (gallbladder)
  - Gastroduodenal (stomach and duodenum)
  - Right gastric (stomach)
  - Right gastro-epiploic (stomach and duodenum)
  - Superior pancreaticoduodenal (duodenum)

Module 19.21: Arteries of the viscera

Arteries (continued)

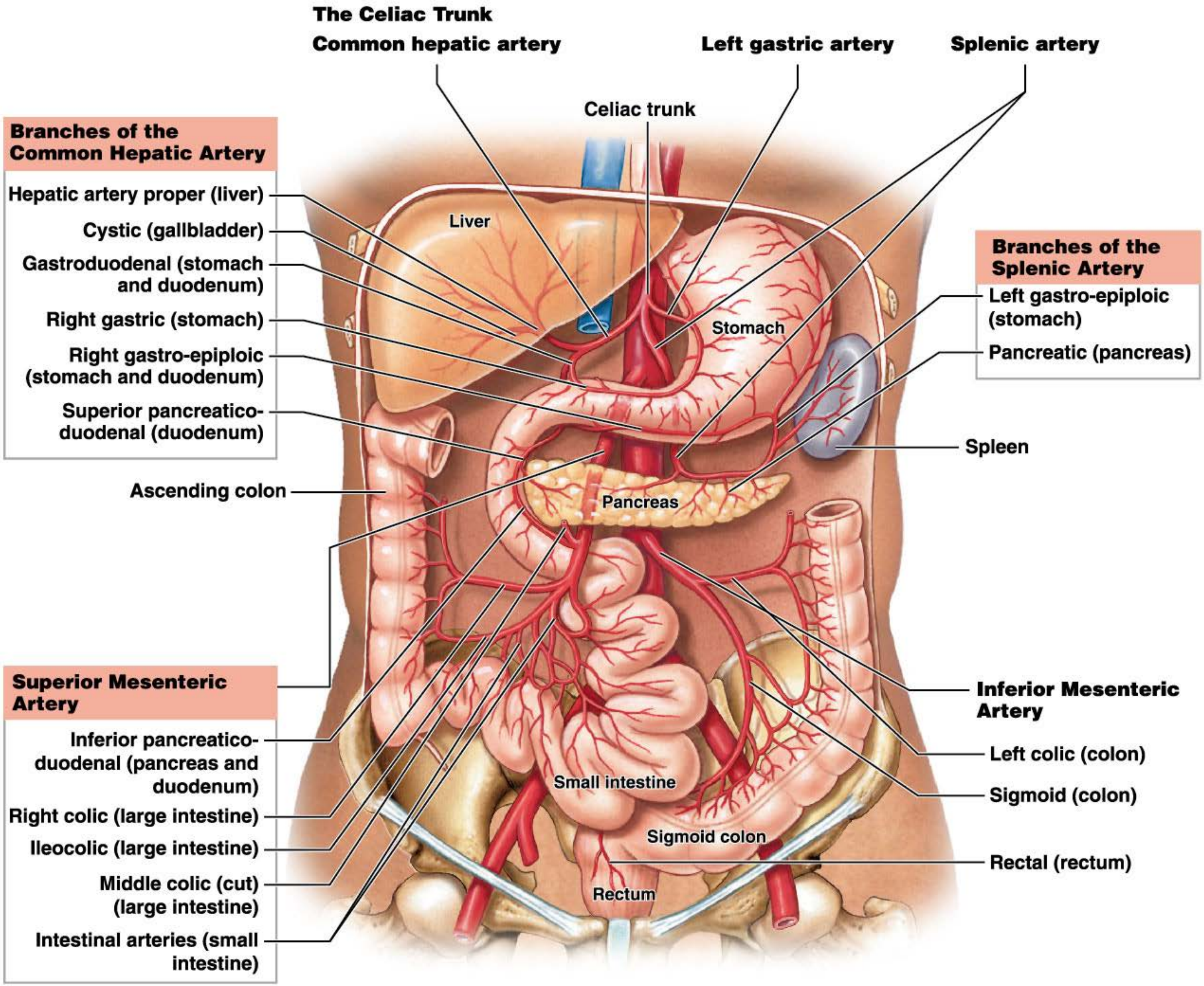
- **Superior mesenteric artery**
  - Supplies the pancreas, duodenum, small intestine, and most of large intestine with these branches:
    - Inferior pancreaticoduodenal (pancreas and duodenum)
    - Right colic (large intestine)
    - Ileocolic (large intestine)
    - Middle colic (large intestine)
    - Intestinal arteries (small intestine)

Module 19.21: Arteries of the viscera

Arteries (continued)

- **Inferior mesenteric artery**
  - Supplies the terminal portions of the colon and rectum with these branches:
    - Left colic (colon)
    - Sigmoid (colon)
    - Rectal (rectum)
- Branches of the **splenic artery**
  - Left gastro-epiploic (stomach)
  - Pancreatic (pancreas)

Arteries of the viscera



Module 19.21: . . . are drained by the branches of the hepatic portal vein

Veins

- **Hepatic portal vein** formed by fusion of:
  1. **Superior mesenteric vein** (carries the largest volume of blood and the most nutrients)
  2. **Inferior mesenteric vein**
  3. **Splenic vein**
  - Also receives blood from:
    - Left and right **gastric veins**
    - **Cystic vein**

Module 19.21: Veins of the viscera

Veins (continued)

- Circulatory pattern called the **hepatic portal system**
  - Directs blood with absorbed nutrients from the digestive system to liver for processing

Branches of the Hepatic Portal Vein

- The inferior mesenteric vein
- The splenic vein
- The superior mesenteric vein

Module 19.21: Veins of the viscera

Veins (continued)

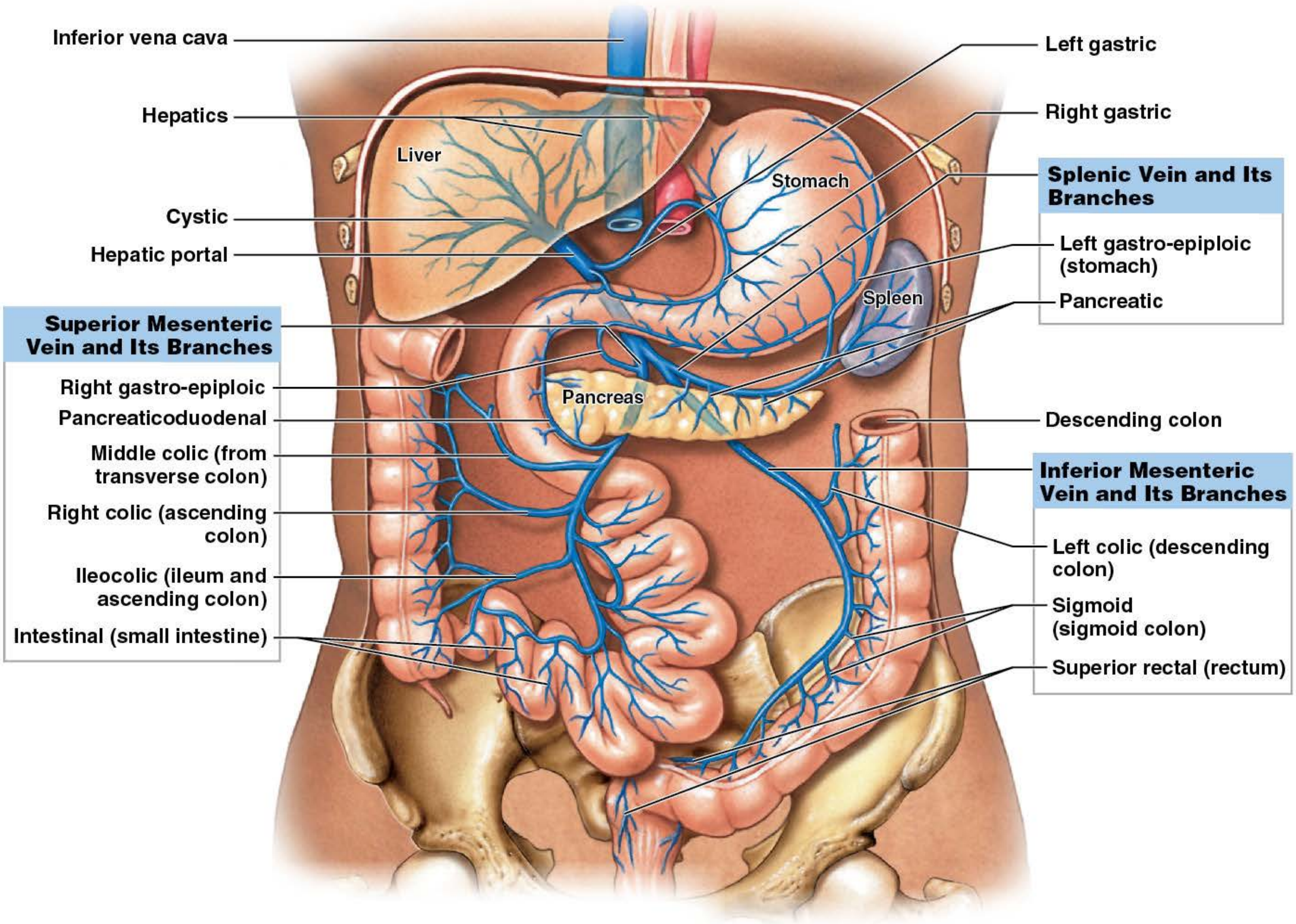
- Branches of the **superior mesenteric vein**
  - Pancreaticoduodenal
  - Middle colic (transverse colon)
  - Right colic (ascending colon)
  - Ileocolic (Ileum and ascending colon)
  - Intestinal (small intestine)

Module 19.21: Veins of the viscera

Veins (continued)

- Branches of the **splenic vein**
  - Left gastro-epiploic (stomach)
  - Right gastro-epiploic (stomach)
  - Pancreatic
- Branches of the **inferior mesenteric vein**
  - Left colic (descending colon)
  - Sigmoid (sigmoid colon)
  - Superior rectal (rectum)

Veins of the viscera



Module 19.21: Review

A. List the unpaired branches of the abdominal aorta that supply blood to the visceral organs.
B. Identify the three veins that merge to form the hepatic portal vein.
C. Identify two veins that carry blood away from the stomach.
D. Describe the function of the hepatic portal system, and name its primary vessel.

Learning Outcome: Identify the branches of the visceral arterial vessels and the venous branches of the hepatic portal system, and name the areas each serves.

Module 19.22: The pelvis and lower limbs are supplied by branches of the common iliac arteries . . .

Arteries

- Abdominal aorta divides to form **right** and **left common iliac arteries**
- Each common iliac artery branches into an **internal** and **external iliac artery**
  - **Internal iliac artery**
    - Supplies the urinary bladder, internal and external walls of the pelvis, external genitalia, medial side of the thigh
    - In females, also supplies the uterus and vagina

Module 19.22: Arteries of the lower limb

Arteries (continued)

- Branches of the common iliac artery (continued)
  - **External iliac artery**
    - As it enter the lower limb, becomes the **femoral artery**
    - Femoral artery branches off to form the **deep femoral artery**
    - Deep femoral artery forms the **femoral circumflex arteries** (supply ventral and lateral skin and deep muscles of the thigh)

Module 19.22: Arteries of the lower limb

Arteries (continued)

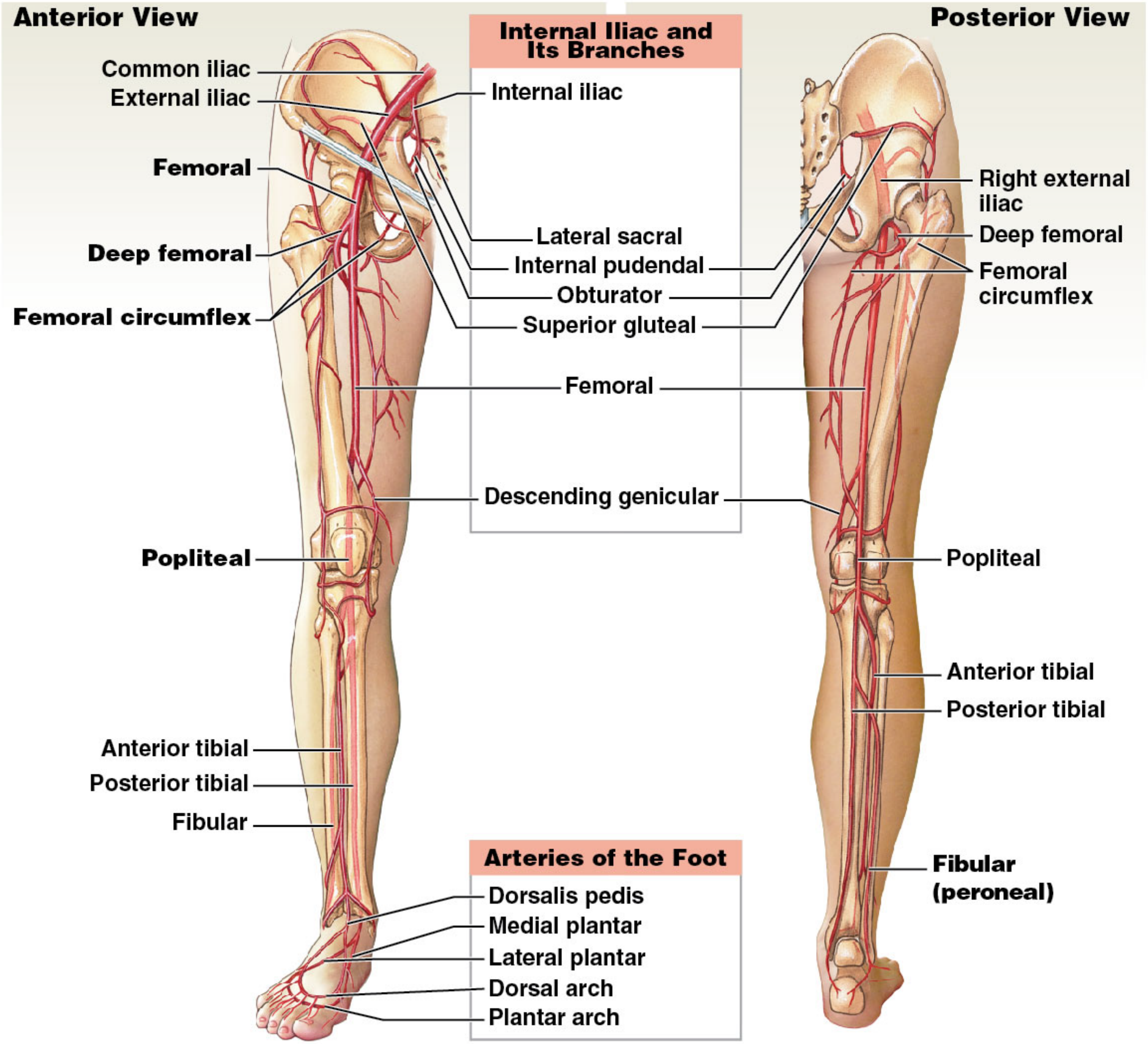
- Branches of the common iliac artery (continued)
  - **External iliac artery** (continued)
    - Femoral artery changes name to **popliteal artery** posterior to the knee joint
    - Popliteal artery branches to form:
      - **Posterior tibial artery**
        - Gives rise to the **fibular artery**
          - Also called the **peroneal** (*perone*, fibula) **artery**
      - **Anterior tibial artery**
    - Descending genicular artery is another branch off the femoral artery

Module 19.22: Arteries of the lower limb

Arteries (continued)

- Arteries of the foot
  - Supply distal portions of the foot and digital arteries of the toes
  - Tibial and fibular arteries interconnect by the anastomoses of the:
    - **Dorsal pedis**
    - **Dorsal arch**
    - **Plantar arch**

Arteries of the lower limb



Module 19.22: . . . and drained by branches of the common iliac veins

Veins

- **Plantar venous arch** delivers blood to deep veins
  - **Anterior tibial**, **posterior tibial**, **fibular** (**peroneal**)
- **Dorsal venous arch** collects blood from capillaries on superior surface of foot and digital veins of toes
  - Drains into superficial veins
    - **Great saphenous vein** and s**mall saphenous vein**

Module 19.22: Veins of the lower limb

Veins (continued)

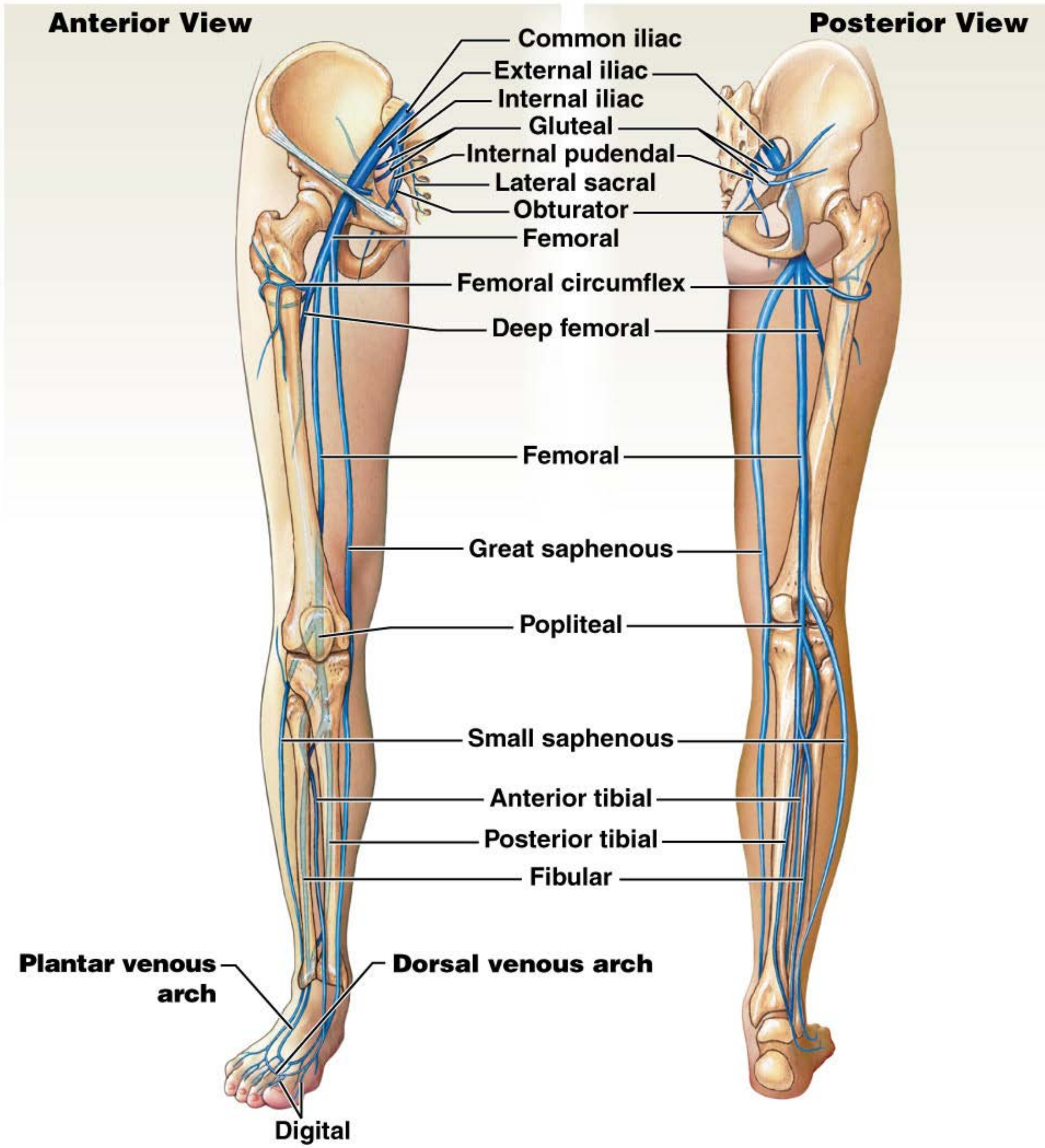
- Small saphenous vein merges with **popliteal vein** at the knee to form the **femoral vein**
- Femoral vein receives blood from:
  1. Great saphenous vein
  2. **Deep femoral vein** (drains from deeper structures in the thigh)
  3. **Femoral circumflex vein** (drains region around the neck and head of the femur)
- Femoral vein penetrates body wall and becomes the **external iliac vein** in the pelvic cavity

Module 19.22: Veins of the lower limb

Veins (continued)

- **External iliac veins**
  - Receive blood from lower limbs, pelvis, and lower abdomen
- **Internal iliac veins**
  - Drain the pelvic organs
  - Formed by fusion of gluteal, internal pudendal, obturator, and lateral sacral veins
- At inner surface of the ilium, external and internal iliac veins fuse to form **common iliac veins**

Veins of the lower limb



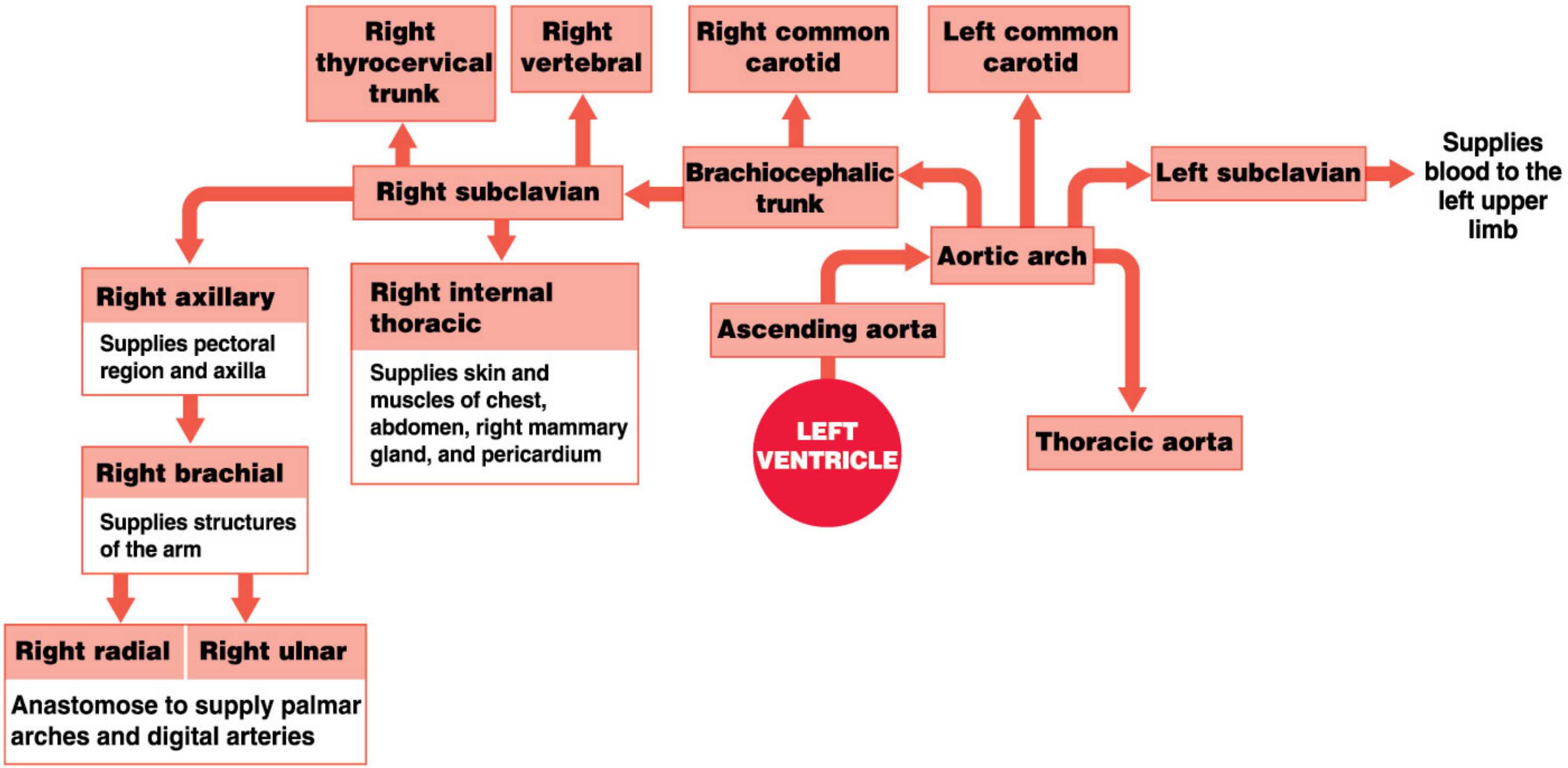
Module 19.22: Review

A. Name the first two branches of the common iliac artery.
B. The plantar venous arch carries blood to which three veins?
C. A blood clot that blocks the popliteal vein would interfere with blood flow in which other veins?

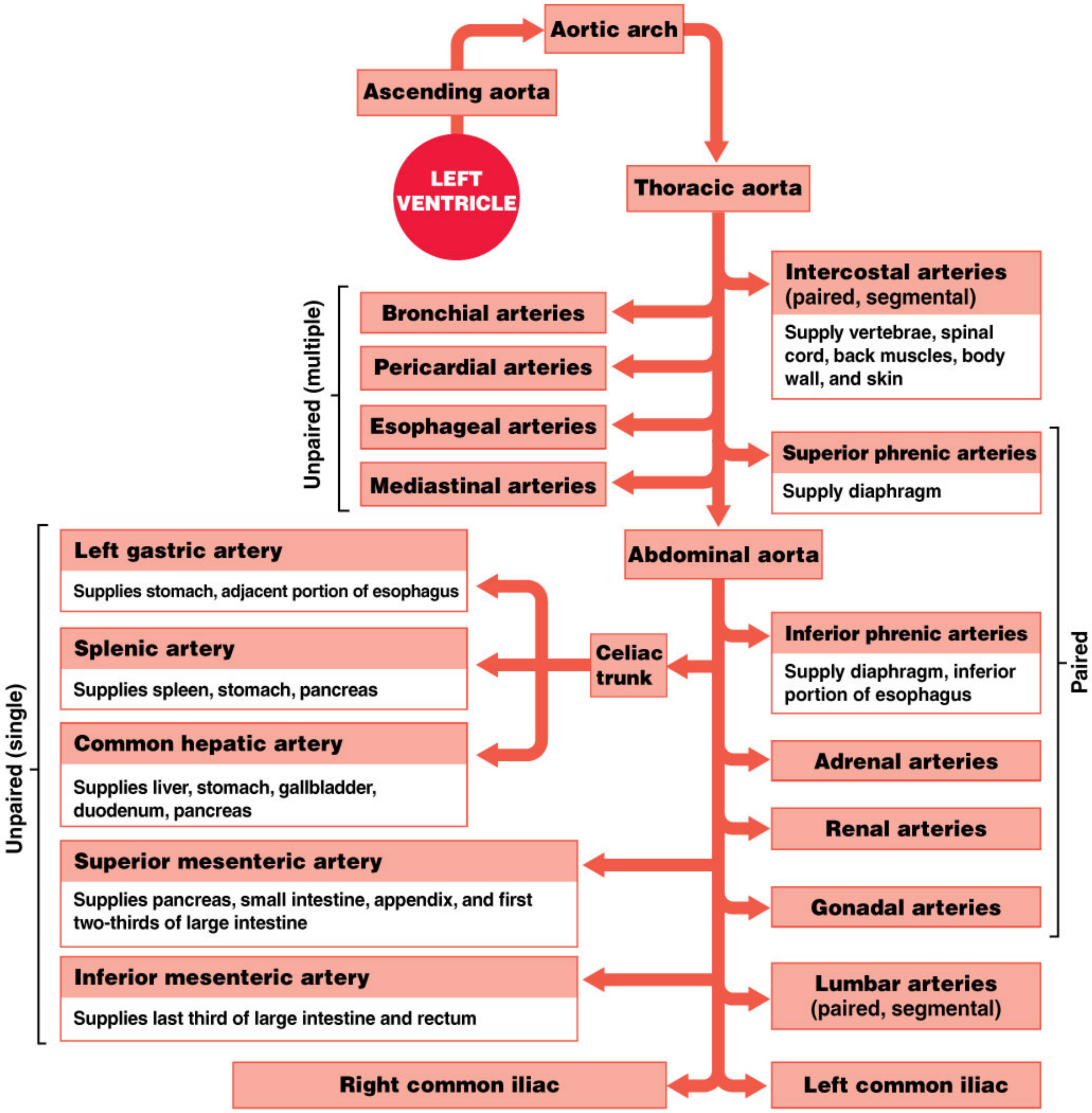
Learning Outcome: Identify the branches of the common iliac arteries and the branches of the common iliac veins, and name the areas each serves.

Module 19.23: The arteries of the systemic circuit deliver oxygenated blood throughout the body . . .

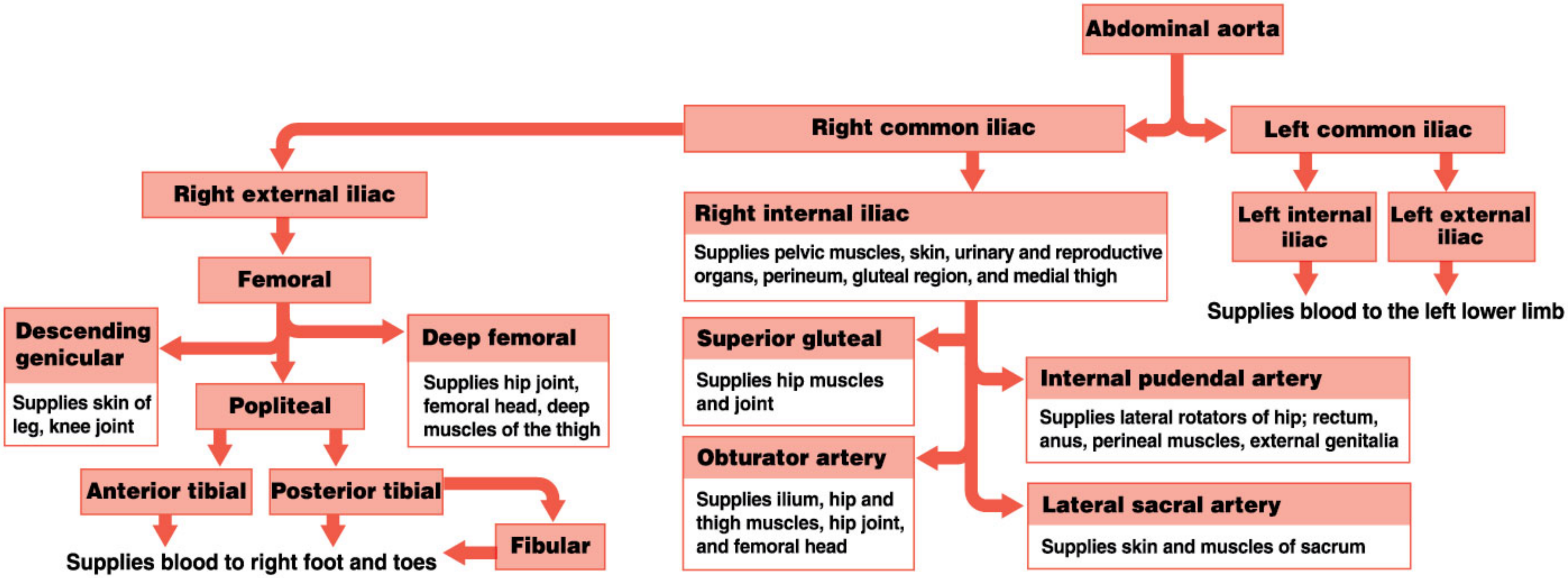
Blood supply to the upper limbs



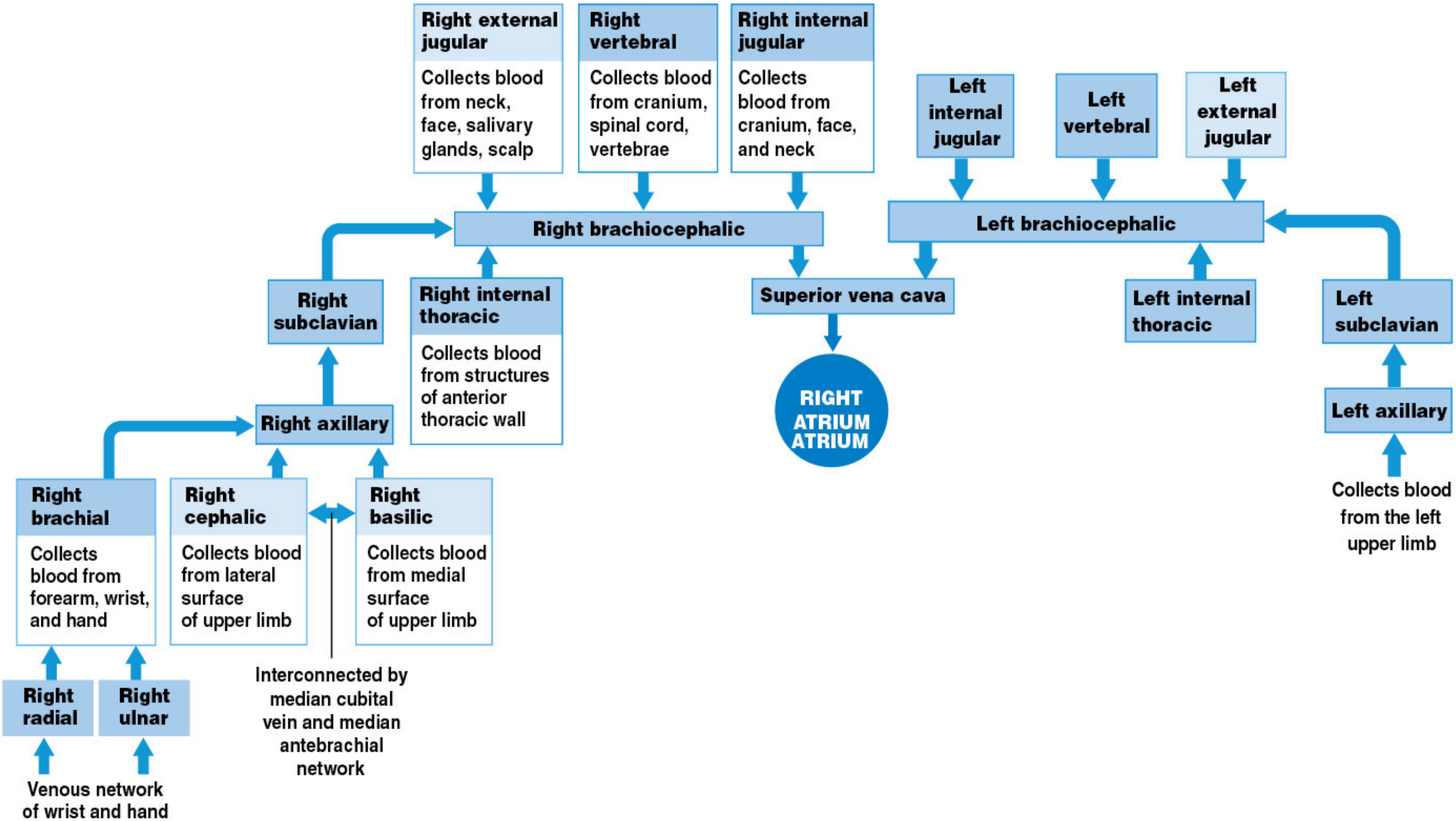
Blood supply to the systemic circuit



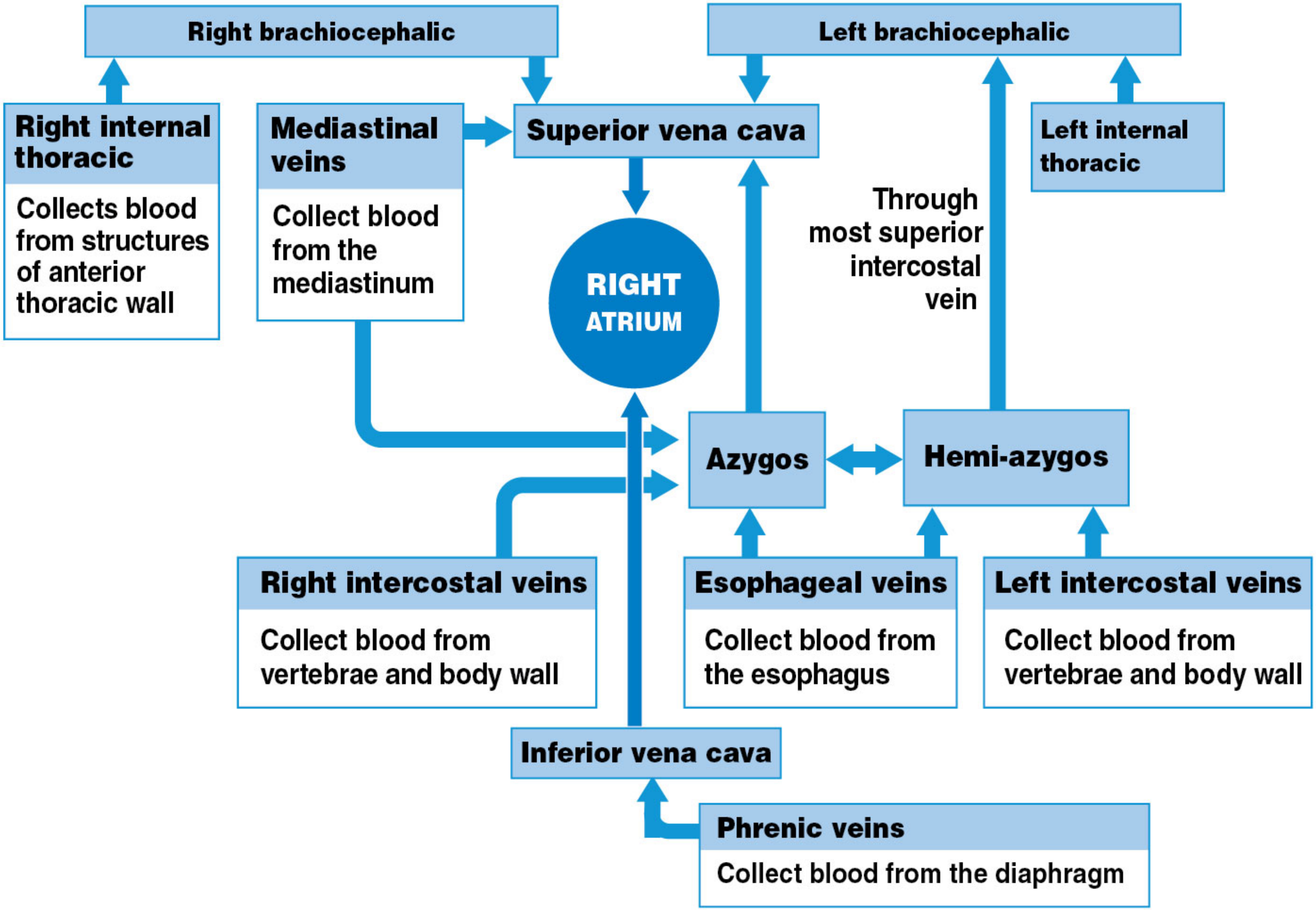
Blood supply from the common iliacs



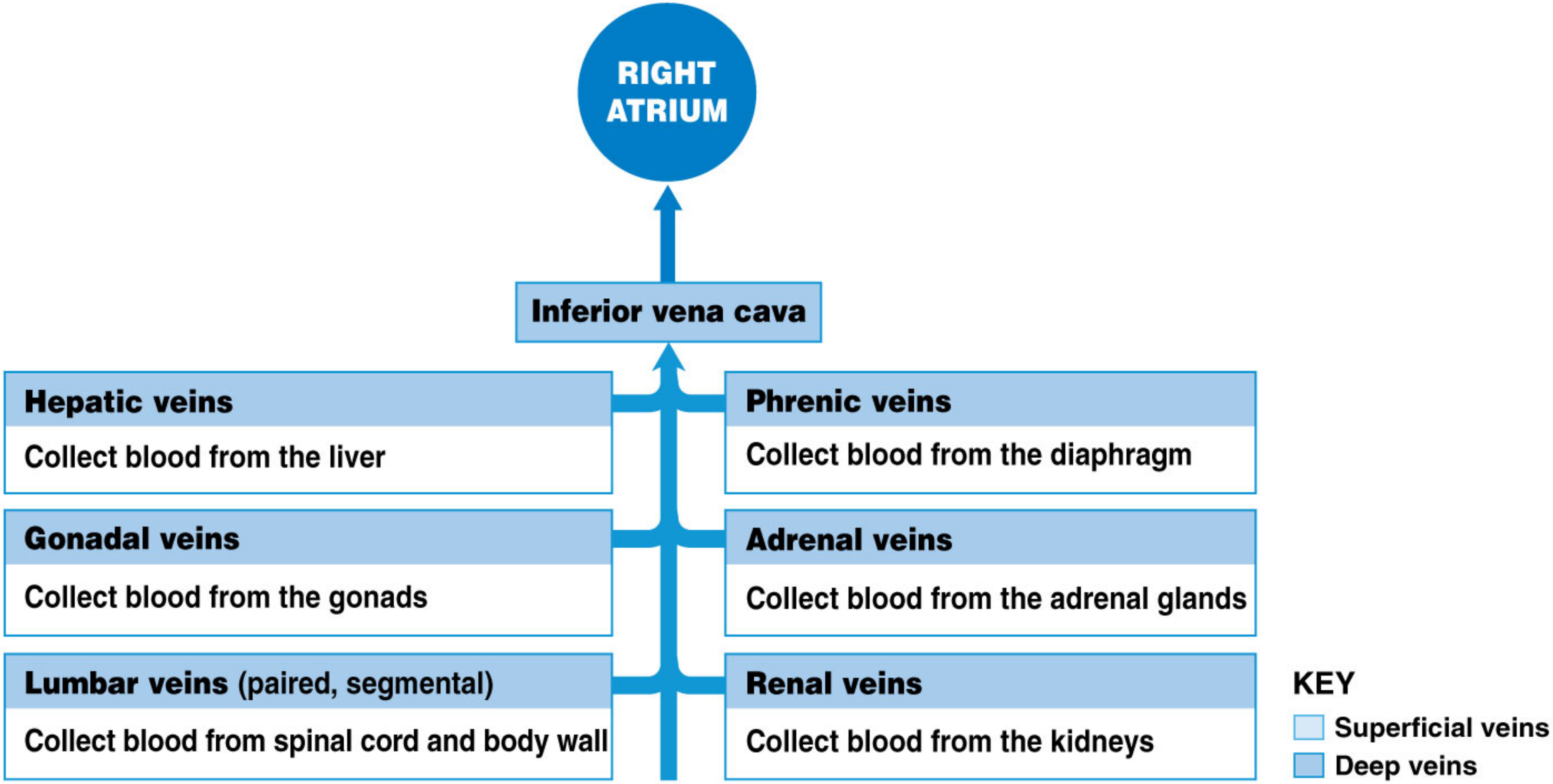
Blood return from the upper limbs



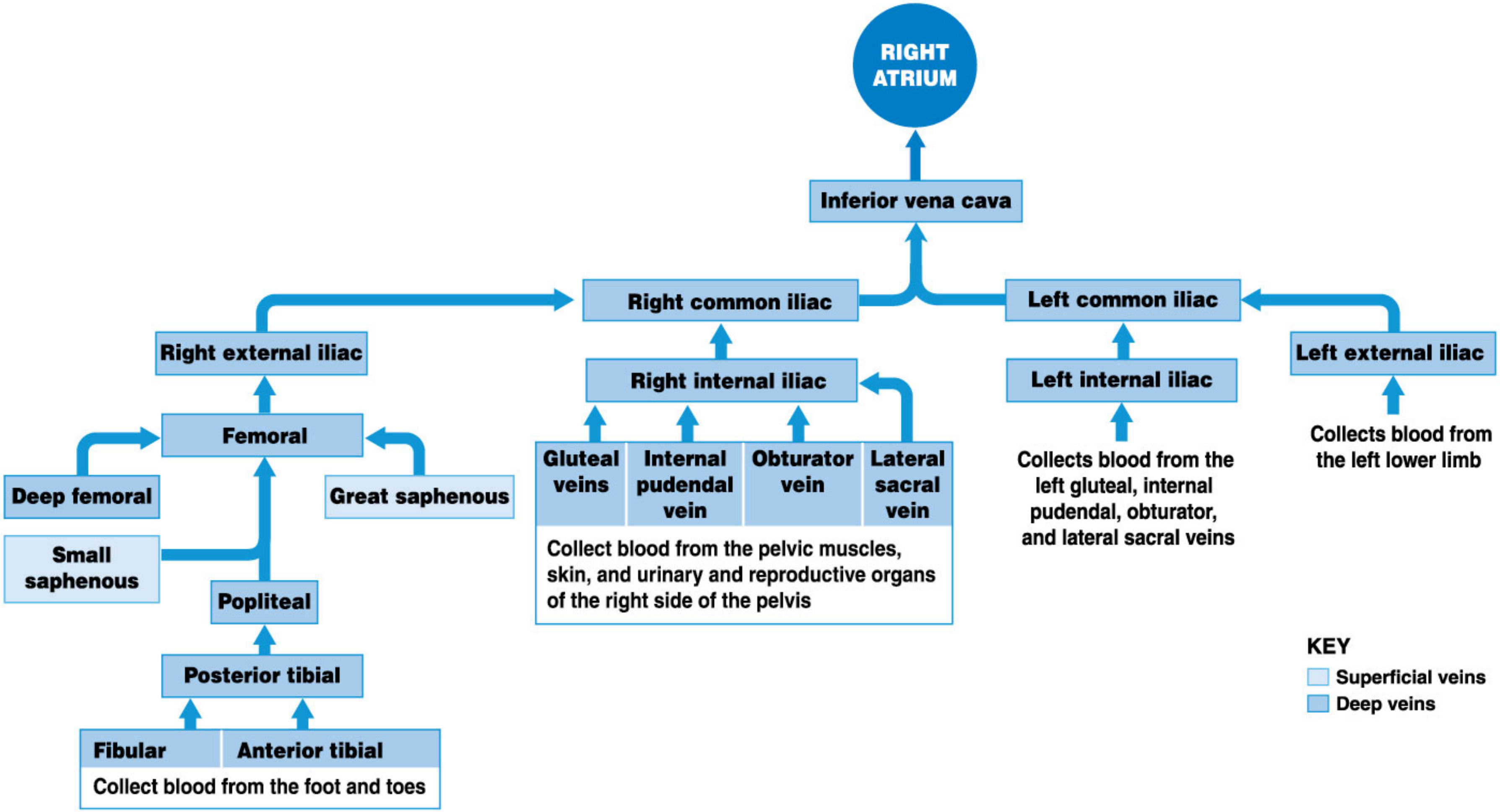
Thoracic blood return to the heart



Blood return from the abdomen and pelvis



Blood return from the lower limbs



Module 19.23: Review

A. Trace the path of a drop of blood from the left ventricle to the right hip joint.
B. Trace the path of a drop of blood from the right forearm to the right atrium.

Learning Outcome: Describe the pathways taken by oxygenated and deoxygenated blood in the systemic circuit.

Module 19.24: Clinical Module: The pattern of blood flow through the fetal heart and the systemic circuit must change at birth

Fetal circulation

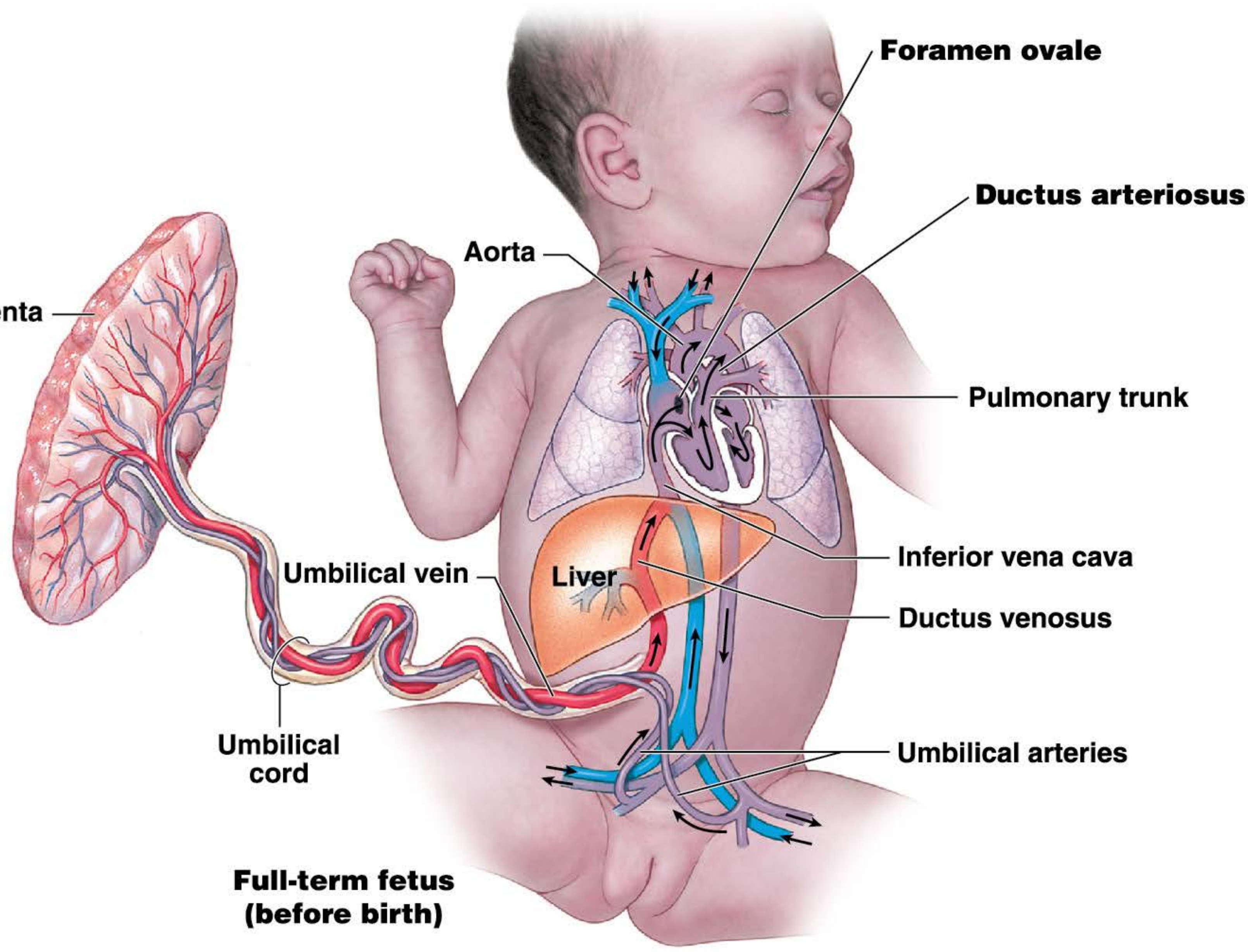
- **Umbilical arteries**
  - Pair of arteries that carry blood from the fetus to the placenta
  - Run from the internal iliac arteries into the umbilical cord
- **Umbilical vein**
  - Carries blood from the placenta
  - Brings oxygen and nutrients
  - Drains into the **ductus venosus**
- All umbilical vessels degenerate after birth
  - Remnants remain as fibrous cords

Module 19.24: Fetal circulation and congenital defects

Fetal circulation (continued)

- **Ductus venosus**
  - Vascular connection to veins within the liver
  - Collects blood from liver and from umbilical vein
  - Empties into inferior vena cava
- **Foramen ovale**, or interatrial opening
  - Allows blood to pass from right atrium to left atrium
    - Bypasses pulmonary circuit
  - Has one-way valve to prevent backflow
- **Ductus arteriosus**
  - Bypass between pulmonary trunk and aorta
  - Sends blood from right ventricle to systemic circuit

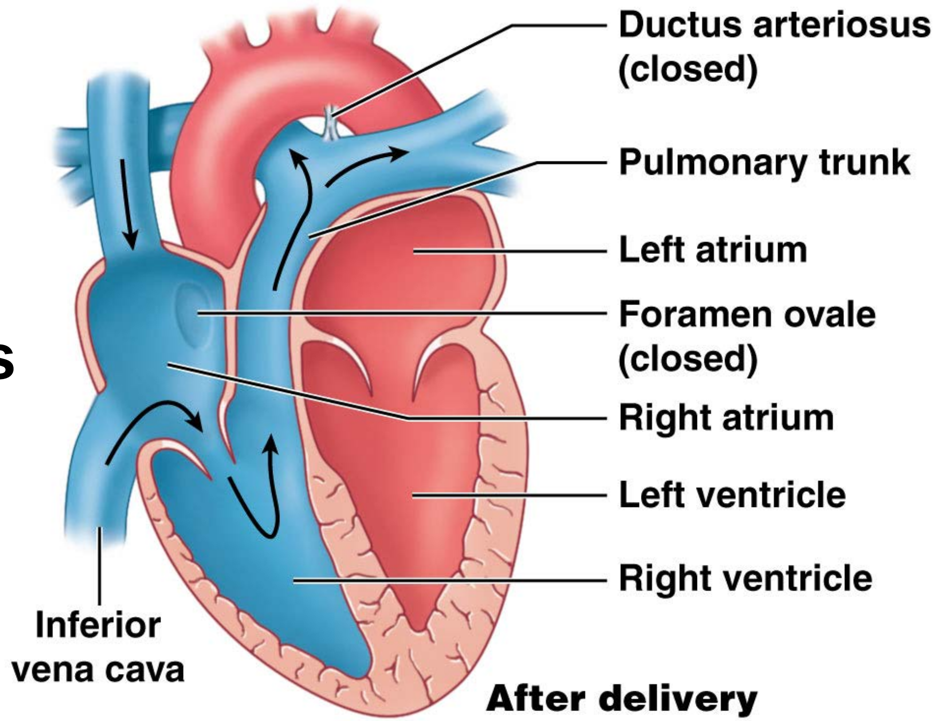
Fetal blood flow



Module 19.24: Fetal circulation and congenital defects

Changes in circulation at birth

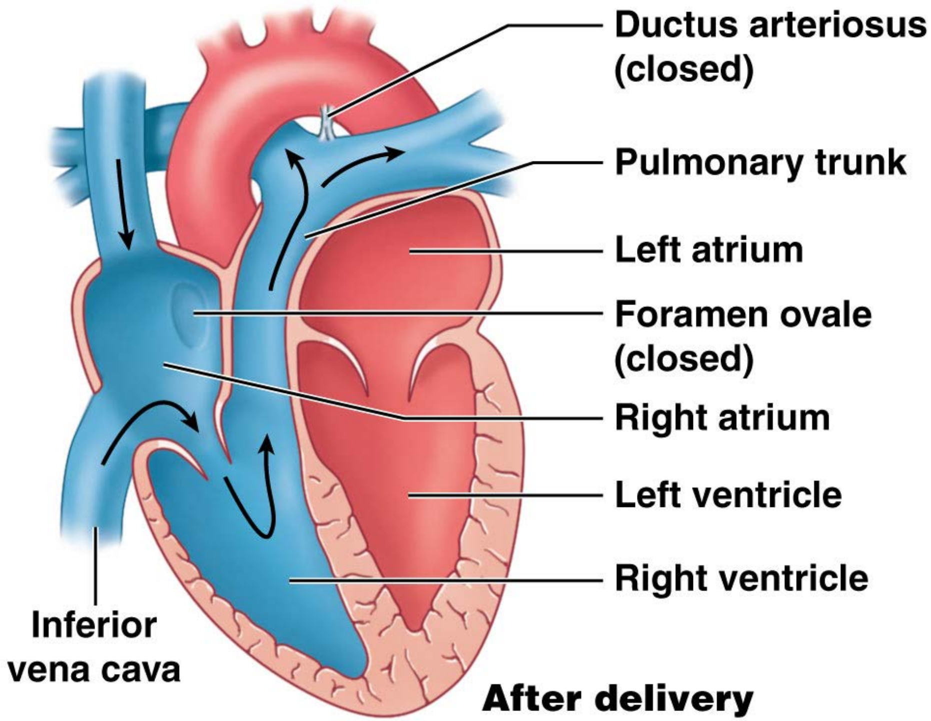
- Are due to expansion of the pulmonary blood vessels and resulting pressure changes
- Increasing pressure in the left atrium closes foramen ovale
  - Remnant of the foramen ovale is a shallow depression called the **fossa ovalis**



Module 19.24: Fetal circulation and congenital defects

Changes in circulation at birth (continued)

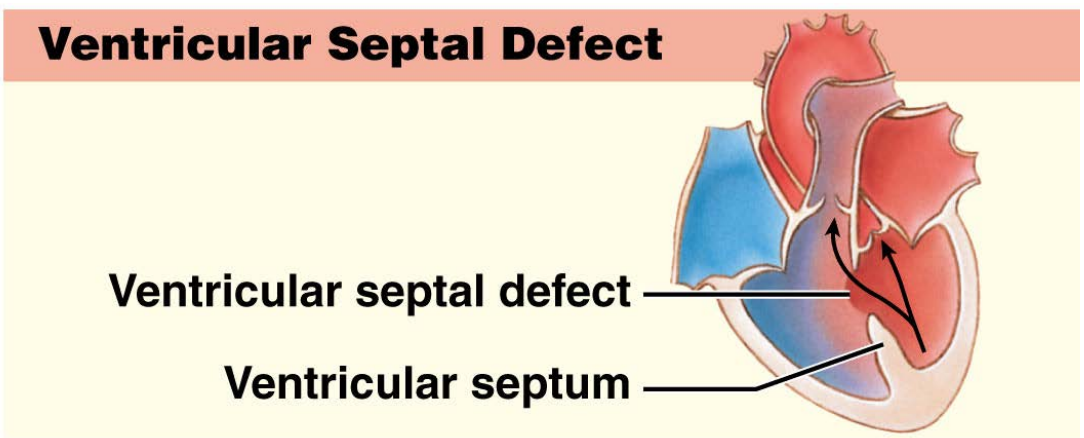
- Rising oxygen levels cause ductus arteriosus to constrict and close
  - Remnant of the ductus arteriosus is a fibrous cord called the **ligamentum arteriosum**



Module 19.24: Fetal circulation and congenital defects

Congenital defects

- **Ventricular septal defects**
  - Openings in interventricular septum
  - Most common congenital heart problem
  - Affect 0.12 percent of newborns
  - Causes mixing of oxygenated and deoxygenated blood

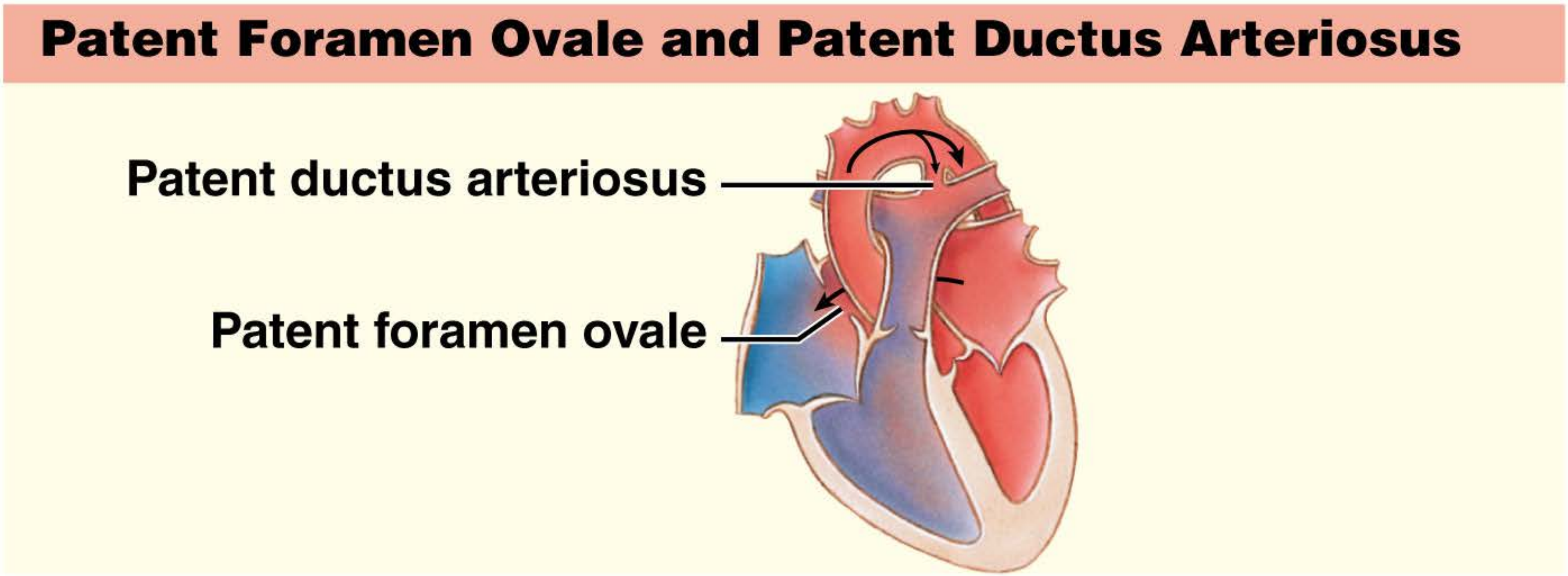


Module 19.24: Fetal circulation and congenital defects

Congenital defects (continued)

- **Patent foramen ovale**
  - Passageway remains open
  - Blood recirculates through pulmonary circuit
  - “Left-to-right shunt”
  - Normal oxygen content, but left ventricle must work harder to provide adequate systemic flow
- **Patent ductus arteriosus**
  - Passageway remains open
  - “Right-to-left shunt”
  - Blood is not adequately oxygenated, and skin is bluish

Patent foramen ovale and patent ductus arteriosus

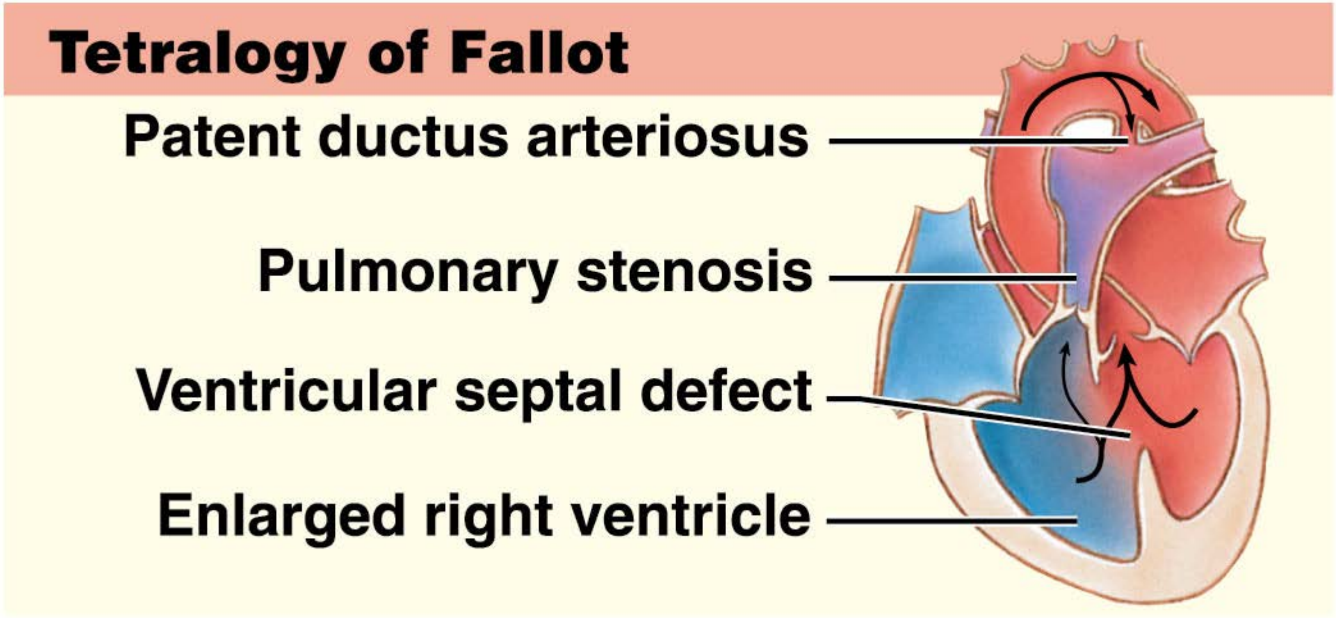


Module 19.24: Fetal circulation and congenital defects

Congenital defects (continued)

- **Tetralogy of Fallot**
  - Complex group of defects
  - Affects 0.10 percent of newborn infants
  - Four defects involved
    1. Pulmonary trunk is abnormally narrow (pulmonary stenosis)
    2. Interventricular septum is incomplete
    3. Aorta originates where interventricular septum normally ends
    4. Right ventricle is enlarged
       - Both ventricles thicken because of increased workload

Tetralogy of Fallot

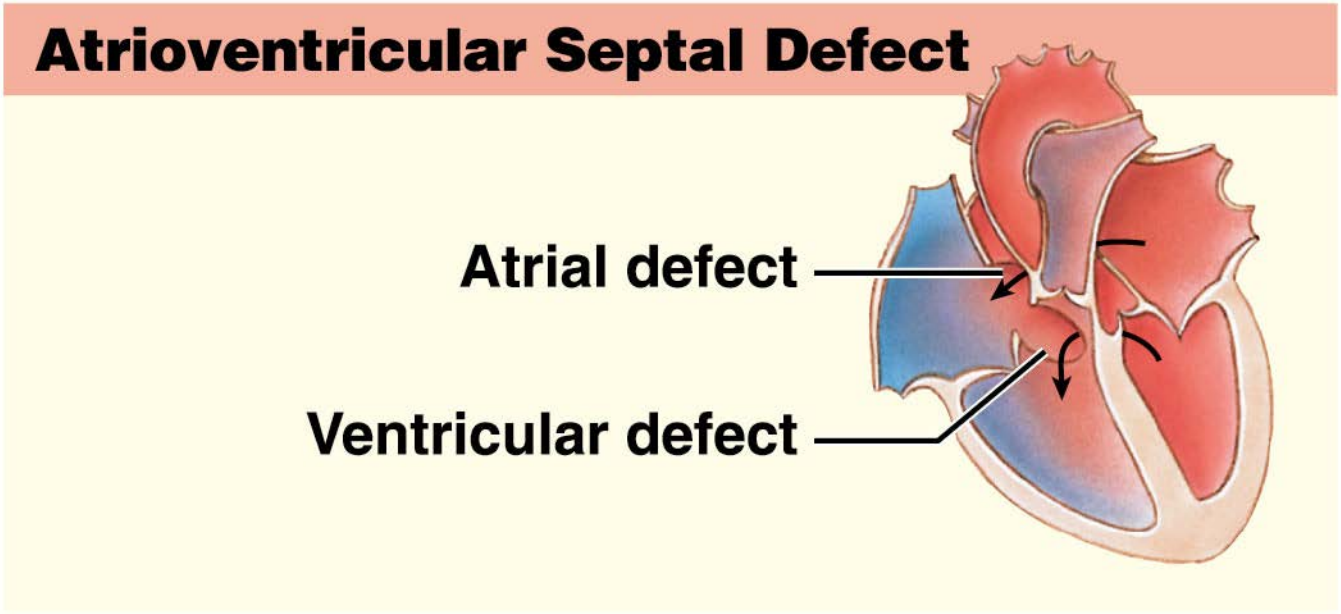


Module 19.24: Fetal circulation and congenital defects

Congenital defects (continued)

- **Atrioventricular septal defect**
  - Both atria and ventricles are incompletely separated
  - Variable results depending on extent of defect
  - May affect atrioventricular valves
  - Most commonly affects infants with Down syndrome
    - Disorder caused by presence of an extra copy of chromosome 21

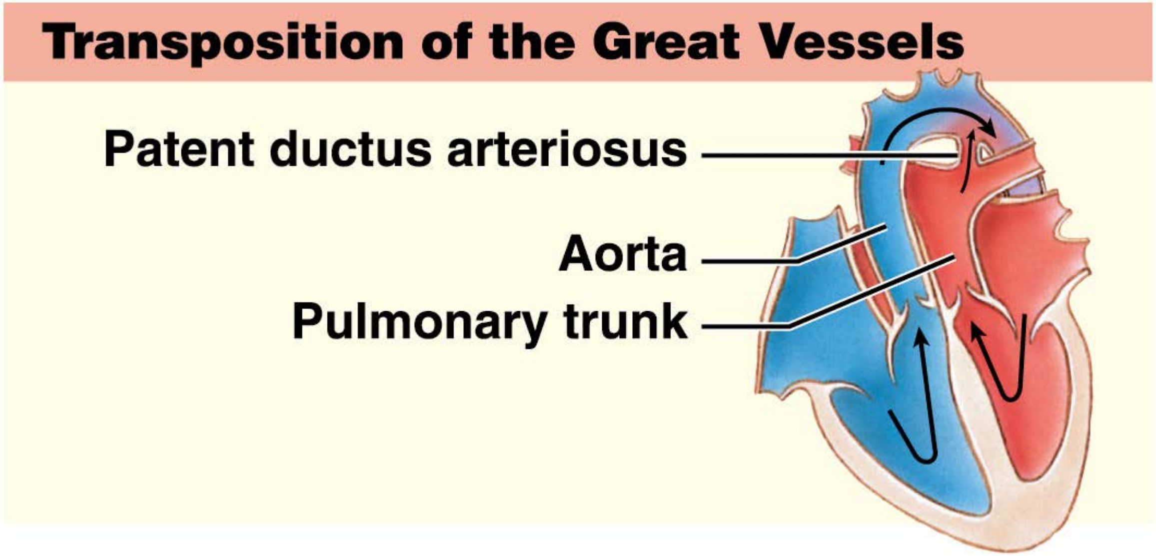
Atrioventricular septal defect



Module 19.24: Fetal circulation and congenital defects

Congenital defects (continued)

- **Transposition of the great vessels**
  - Aorta is connected to right ventricle
  - Pulmonary artery is connected to left ventricle
  - Affects 0.05 percent of newborn infants



Module 19.24: Review

A. Describe the pattern of fetal blood flow to and from the placenta.
B. Identify the six structures that are vital to fetal circulation but cease to function at birth, and describe what becomes of these structures.
C. Compare a ventricular septal defect with tetralogy of Fallot.

Learning Outcome: Describe the differences between fetal and adult circulation patterns, and identify changes in blood flow patterns at birth, and list common congenital heart problems.