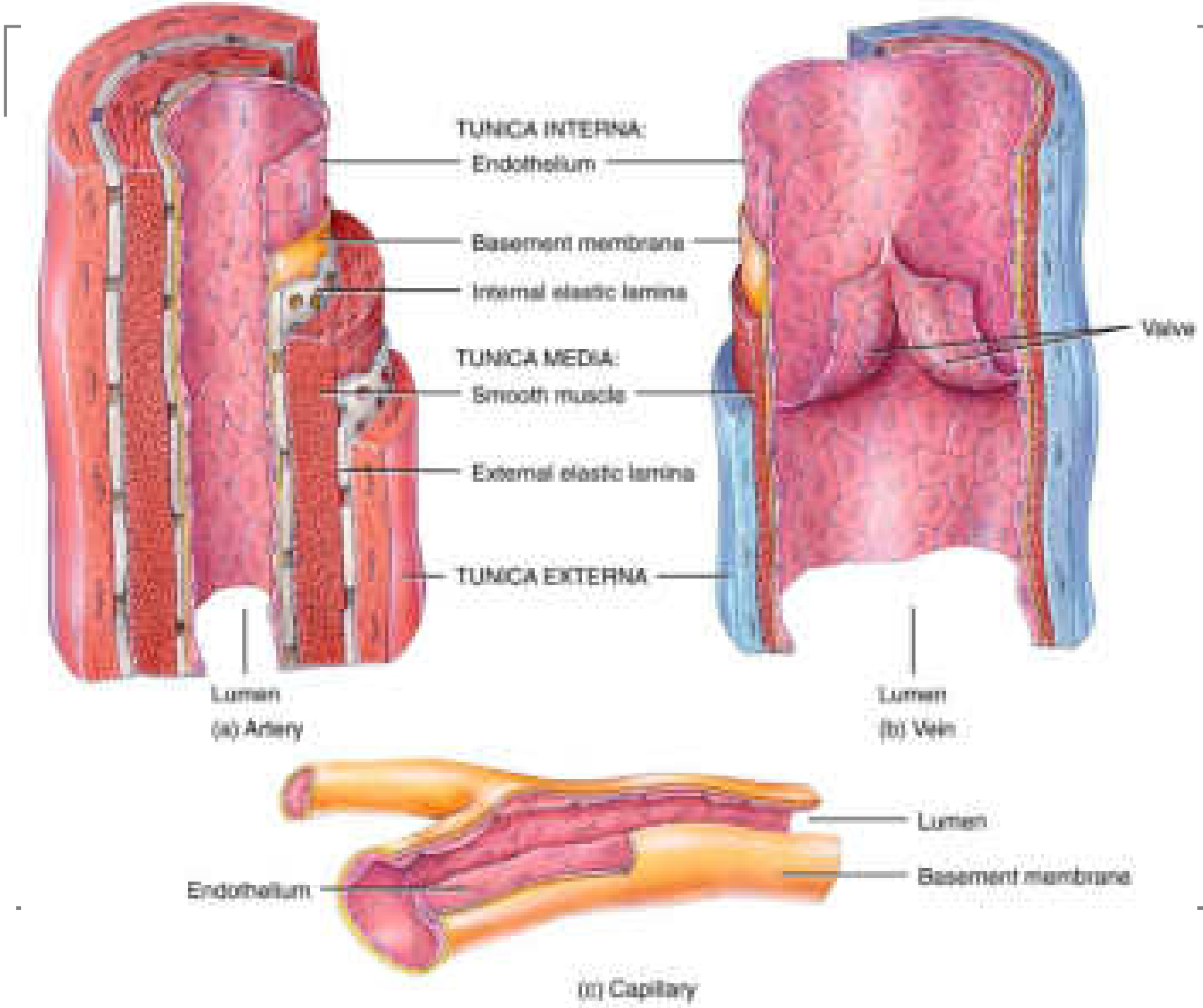
Chapter 21: The Cardiovascular System: Blood Vessels and Hemodynamics

Structure and function of blood vessels

- 5 main types
  - **Arteries** – carry blood *AWAY* from the heart
  - **Arterioles**
  - **Capillaries** – site of exchange
  - **Venules**
  - **Veins** – carry blood *TO* the heart

Basic structure

- 3 layers or tunics
  1. Tunica interna (intima)
  2. Tunica media
  3. Tunica externa
- Modifications account for 5 types of blood vessels and their structural/ functional differences


TUNICA INTERNA:
Endothelium
Basement membrane
Internal elastic lamina
TUNICA MEDIA:
Smooth muscle
External elastic lamina
TUNICA EXTERNA
Lumen
(a) Artery
Valve
Lumen
(b) Vein
Lumen
Basement membrane
Endothelium
(c) Capillary

Structure

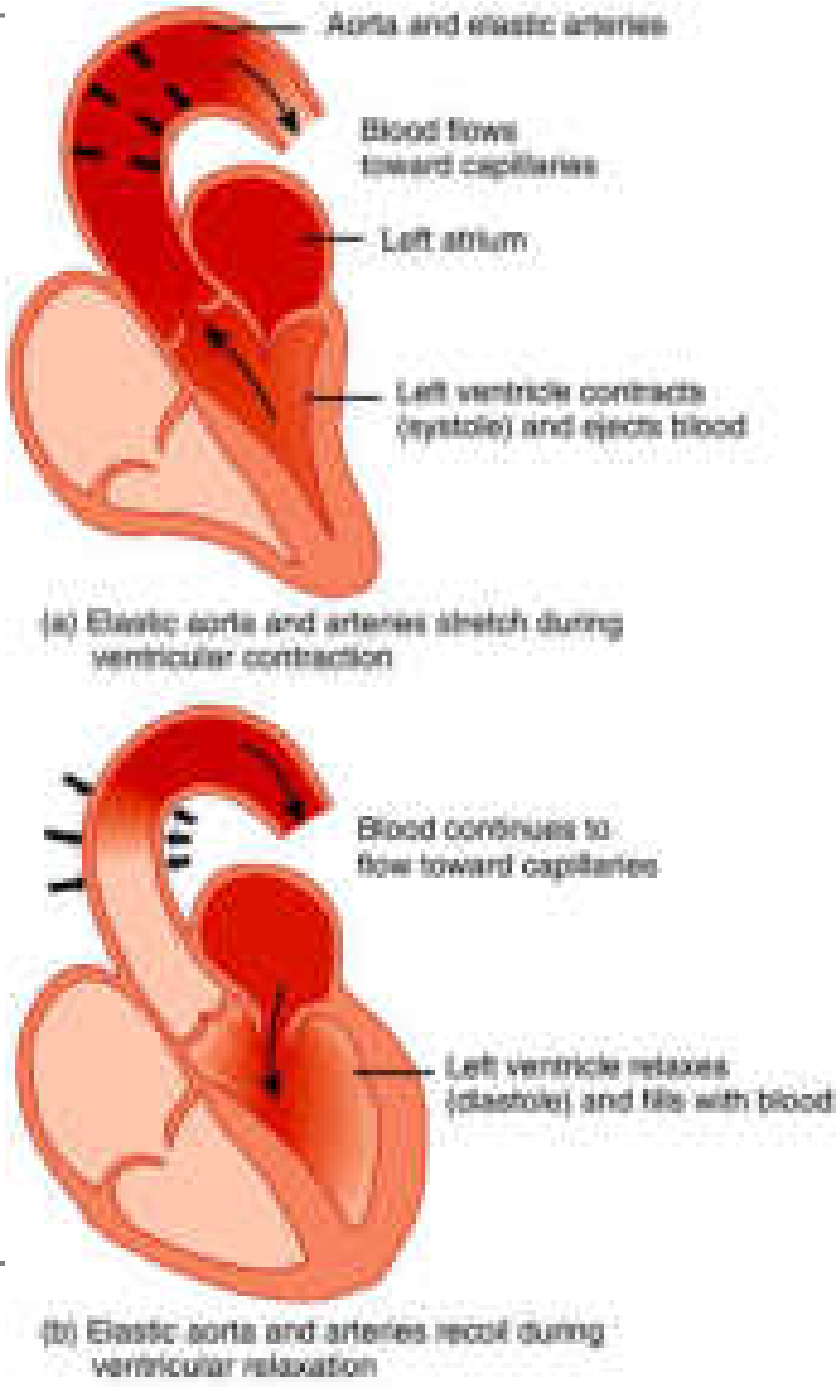
- Tunica interna (intima)
  - Inner lining in direct contact with blood
  - Endothelium continuous with endocardial lining of heart
  - Active role in vessel-related activities
- Tunica media
  - Muscular and connective tissue layer
  - Greatest variation among vessel types
  - Smooth muscle regulates diameter of lumen
- Tunica externa
  - Elastic and collagen fibers
  - Vasa vasorum
  - Helps anchor vessel to surrounding tissue

Arteries

- 3 layers of typical blood vessel
- Thick muscular-to-elastic tunica media
- High compliance – walls stretch and expand in response to pressure without tearing
- Vasoconstriction – decrease in lumen diameter
- Vasodilation – increase in lumen diameter

Elastic Arteries

- Largest arteries
- Largest diameter but walls relatively thin
- Function as pressure reservoir
- Help propel blood forward while ventricles relaxing
- Also known as conducting arteries – conduct blood to medium-sized arteries



Arteries

- Muscular arteries
  - Tunica media contains more smooth muscle and fewer elastic fibers than elastic arteries
  - Walls relatively thick
  - Capable of great vasoconstriction/ vasodilatation to adjust rate of blood flow
  - Also called distributing arteries
- Anastomoses
  - Union of the branches of 2 or more arteries supplying the same body region
  - Provide alternate routes – collateral circulation

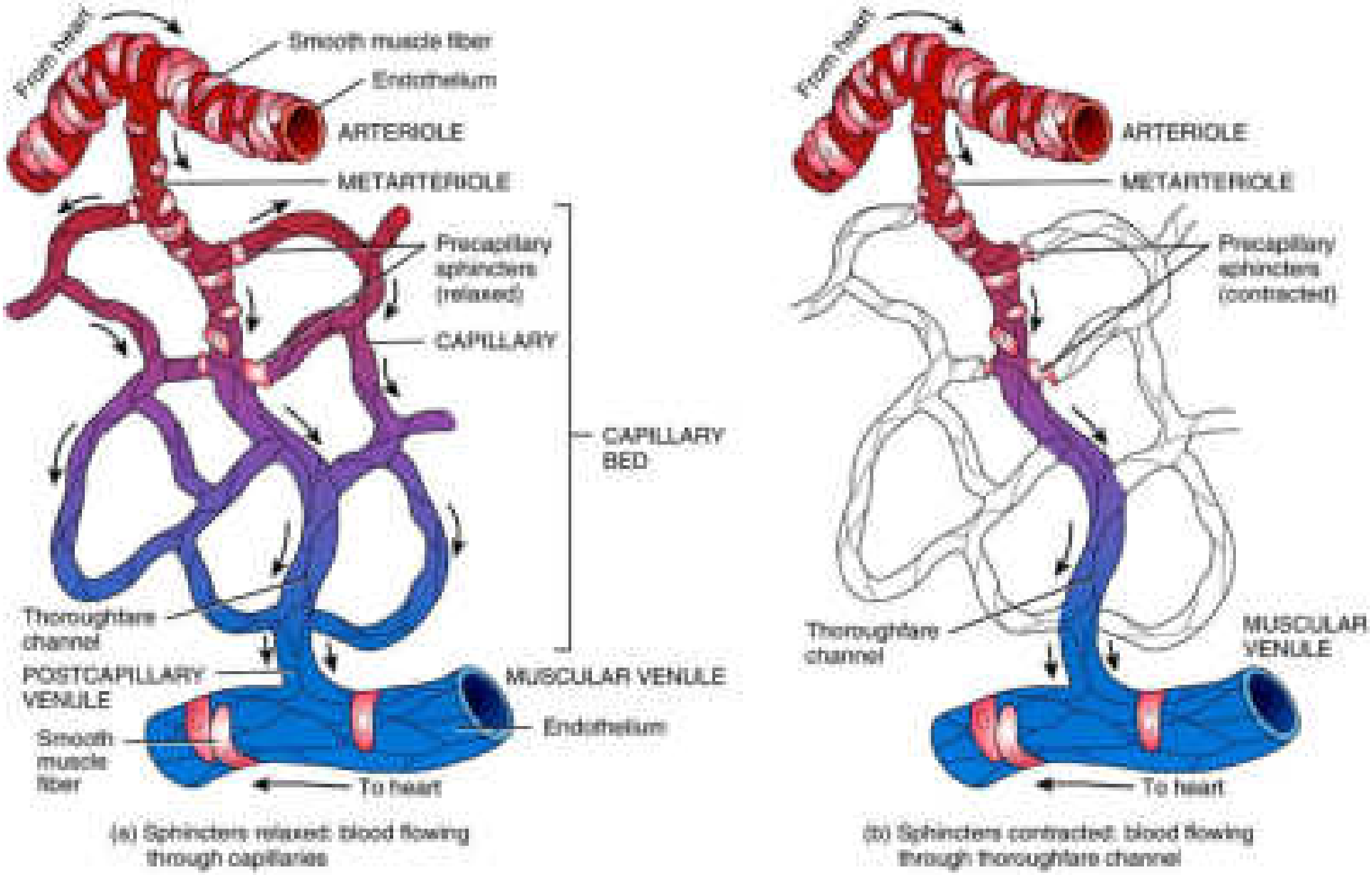
Arterioles

- Abundant microscopic vessels
- Metarteriole has precapillary sphincter which monitors blood flow into capillary
- Sympathetic innervation and local chemical mediators can alter diameter and thus blood flow and resistance
- Resistance vessels – resistance is opposition to blood flow
- Vasoconstriction can raise blood pressure

Capillaries

- Capillaries
  - Smallest blood vessels connect arterial outflow and venous return
  - Microcirculation – flow from metarteriole through capillaries and into postcapillary venule
  - Exchange vessels – primary function is exchange between blood and interstitial fluid
  - Lack tunica media and tunica externa
    - Substances pass through just one layer of endothelial cells and basement membrane
  - Capillary beds – arise from single metarteriole
    - Vasomotion – intermittent contraction and relaxation
    - Throughfare channel – bypasses capillary bed

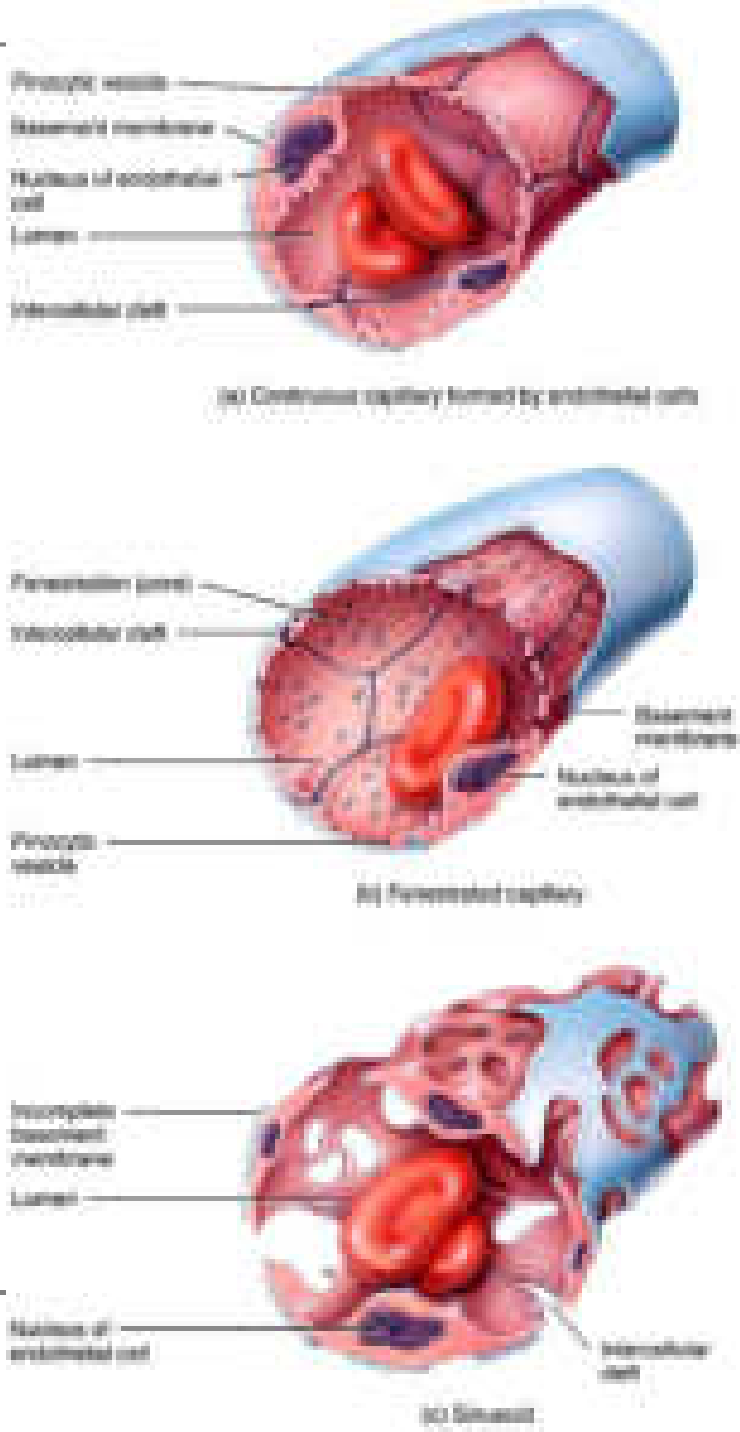
Arteries, Capillaries, and Venule



Types of Capillaries

- 3 types

1. **Continuous**
   - Endothelial cell membranes from continuous tube
2. **Fenestrated**
   - Have fenestrations or pores
3. **Sinusoids**
   - Wider and more winding
   - Unusually large fenestrations

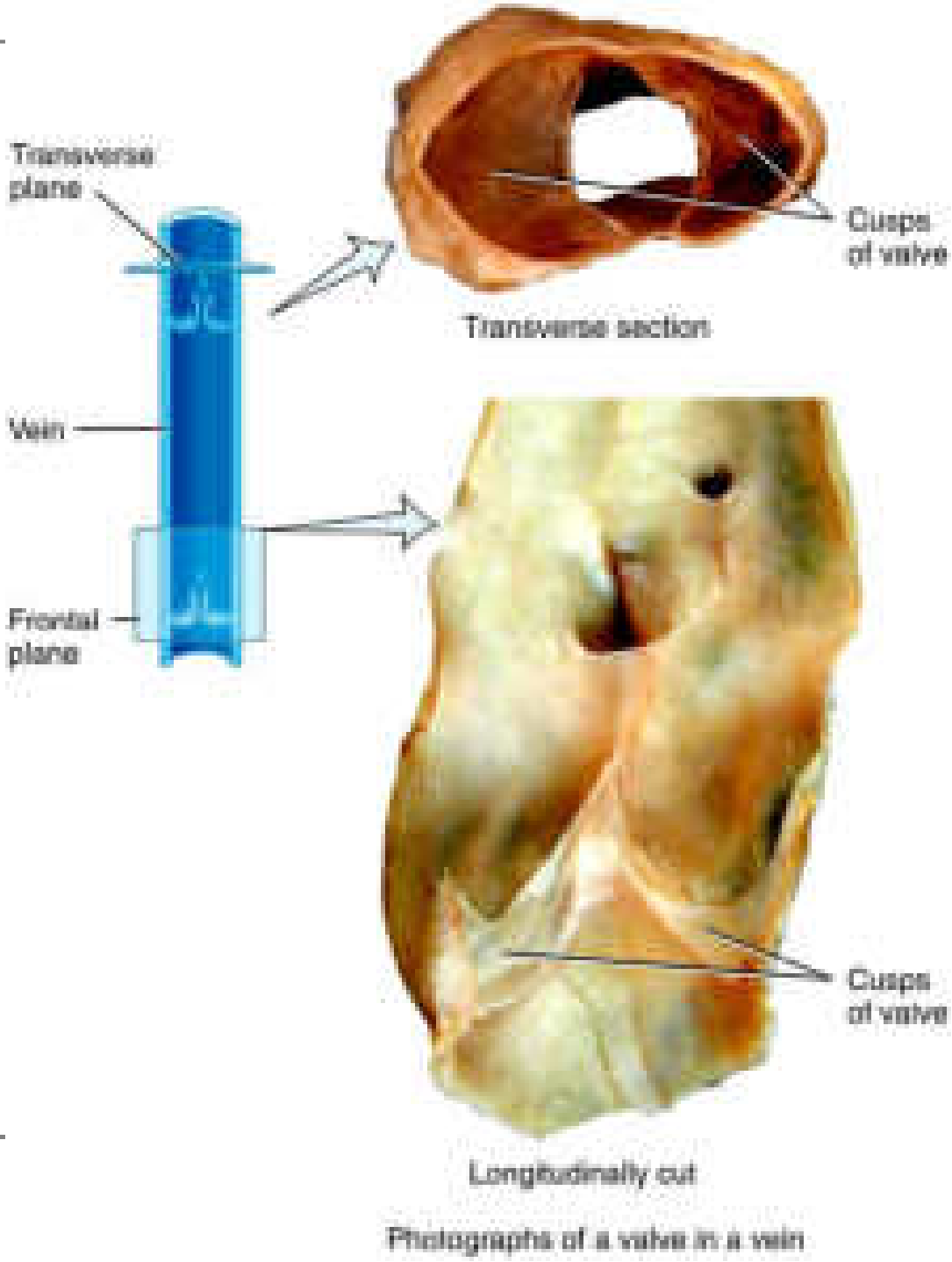


- Portal vein – blood passes through second capillary bed
  - Hepatic or hypophyseal
- Venules
  - Thinner walls than arterial counterparts
  - Postcapillary venule – smallest venule
  - Form part of microcirculatory exchange unit with capillaries
  - Muscular venules have thicker walls with 1 or 2 layers of smooth muscle

Veins

- Structural changes not as distinct as in arteries
- In general, very thin walls in relation to total diameter
- Same 3 layers
  - Tunica interna thinner than arteries
  - Tunica interna thinner with little smooth muscle
  - Tunica externa thickest layer
- Not designed to withstand high pressure
- Valves – folds on tunica interna forming cusps
  - Aid in venous return by preventing backflow

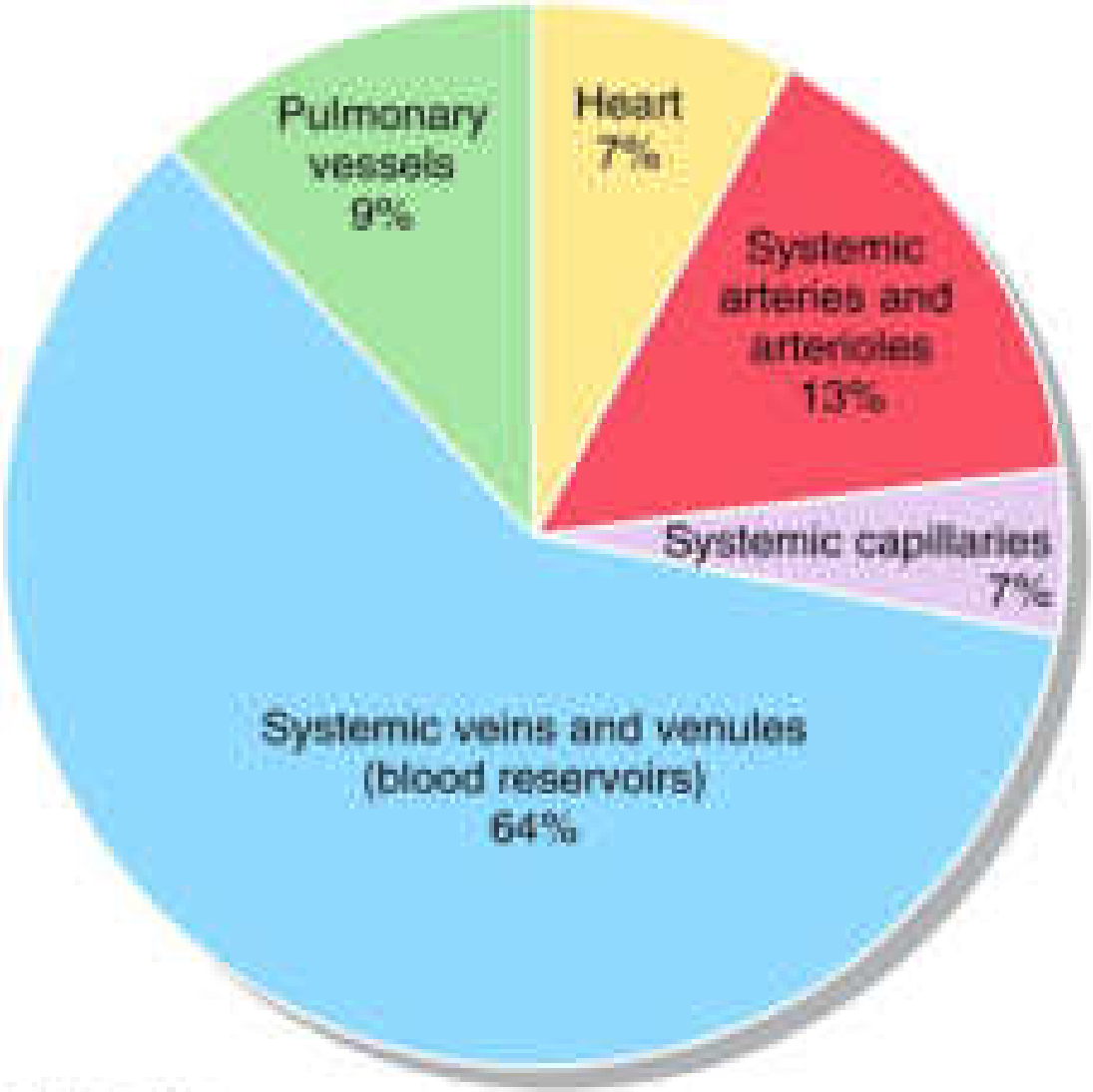
Venous Valves



Photographs of a valve in a vein

Blood Distribution

- Largest portion of blood at rest is in systemic veins and venules
  - Blood reservoir
- Venoconstriction reduces volume of blood in reservoirs and allows greater blood volume to flow where needed



Capillary exchange

- Movement of substances between blood and interstitial fluid
- 3 basic methods
  1. Diffusion
  2. Transcytosis
  3. Bulk flow

Diffusion

- Most important method
- Substances move down their concentration gradient
  - O_2 and nutrients from blood to interstitial fluid to body cells
  - CO_2 and wastes move from body cells to interstitial fluid to blood
- Can cross capillary wall through intracellular clefts, fenestrations or through endothelial cells
  - Most plasma proteins cannot cross
  - Except in sinusoids – proteins and even blood cells leave
  - Blood-brain barrier – tight junctions limit diffusion

Transcytosis

- Small quantity of material
- Substances in blood plasma become enclosed within pinocytotic vessicles that enter endothelial cells by endocytosis and leave by exocytosis
- Important mainly for large, lipid-insoluble molecules that cannot cross capillary walls any other way

Bulk Flow

- Passive process in which large numbers of ions, molecules, or particles in a fluid move together in the same direction
- Based on pressure gradient
- Diffusion is more important for solute exchange
- Bulk flow more important for regulation of relative volumes of blood and interstitial fluid
- **Filtration** – from capillaries into interstitial fluid
- **Reabsorption** – from interstitial fluid into capillaries

NFP = (BHP + IFOP) – (BCOP + IFHP)

- Net filtration pressure (NFP) balance of 2 pressures

1. 2 pressures promote filtration
   - Blood hydrostatic pressure (BHP) generated by pumping action of heart
     - Falls over capillary bed from 35 to 16 mmHg
   - Interstitial fluid osmotic pressure (IFOP)
     - 1 mmHg

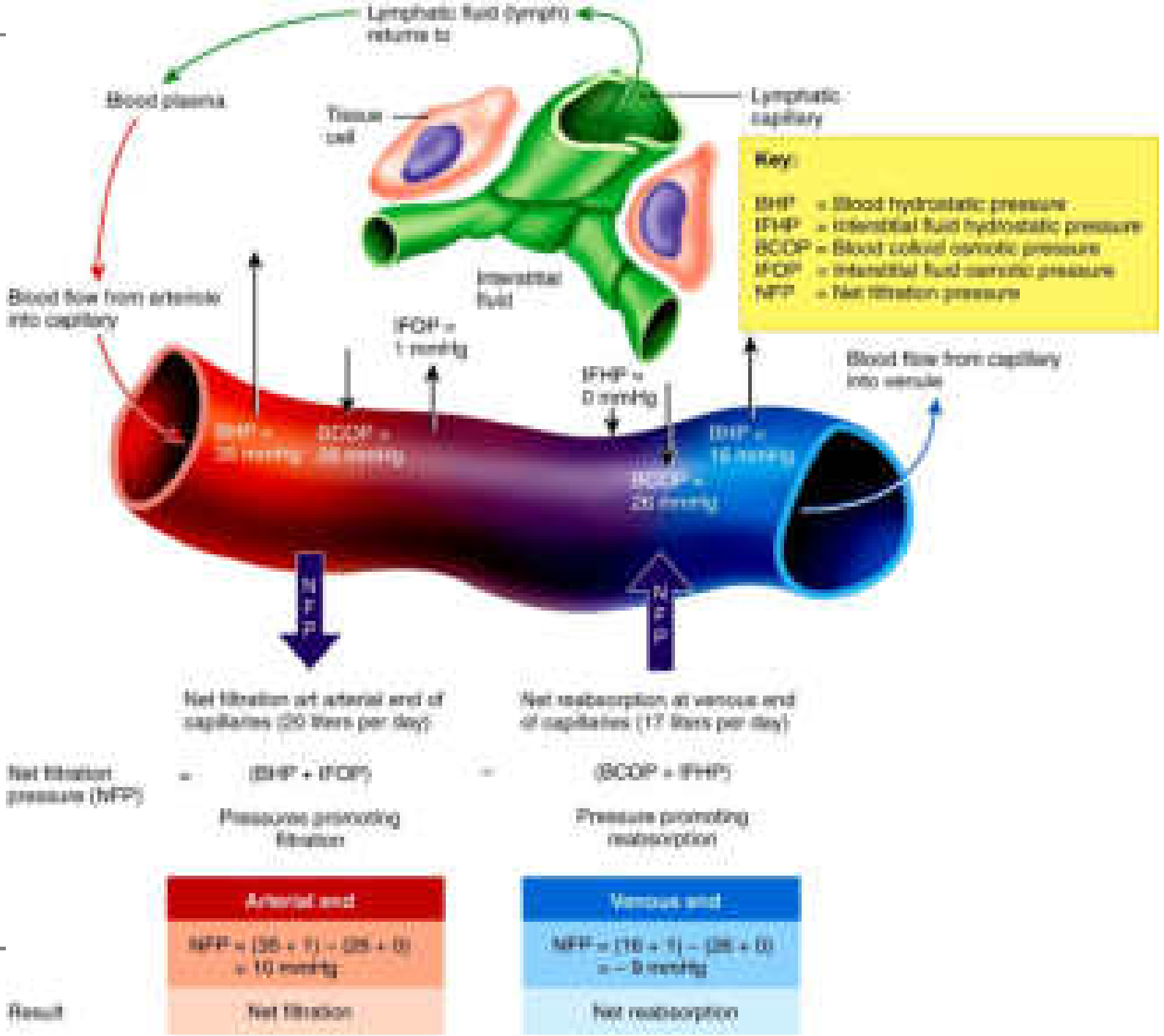
NFP = (BHP + IFOP) – (BCOP + IFHP)

2. 2 pressures promote reabsorption
   - Blood colloid osmotic pressure (BCOP) promotes reabsorption
     - Due to presence of blood plasma proteins to large to cross walls
     - Averages 36 mmHg
   - Interstitial fluid hydrostatic pressure (IFHP)
     - Close to zero mmHg

Starling's Law

- Nearly as much reabsorbed as filtered
  - At the arterial end, net outward pressure of 10 mmHg and fluid leaves capillary (filtration)
  - At the venous end, fluid moves in (reabsoprtion) due to -9 mmHg
  - On average, about 85% of fluid filtered in reabsorpbed
  - Excess enters lymphatic capillaries (about 3L/ day) to be eventually returned to blood

Dynamics of Capillary Exchange

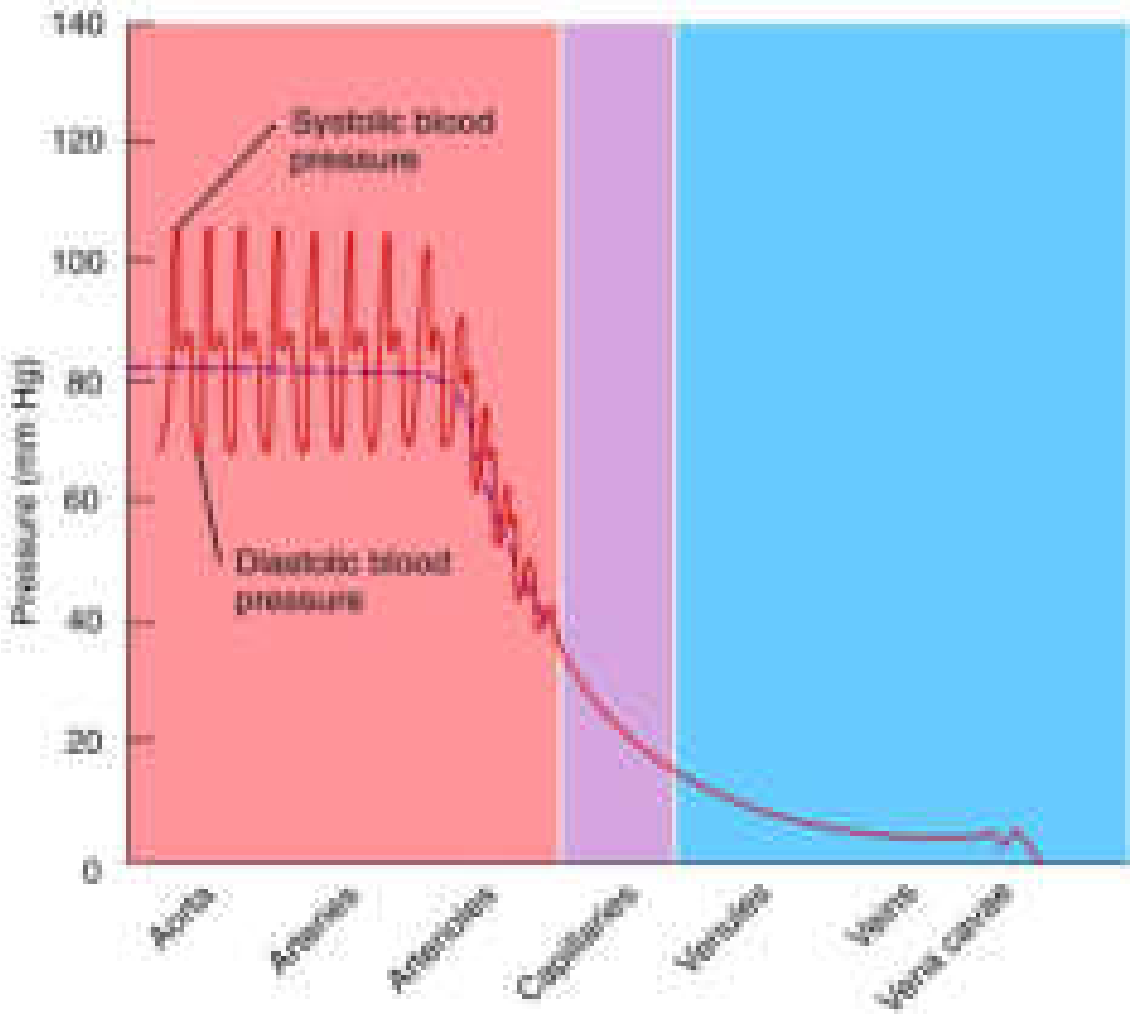


Hemodynamics: Factors affecting blood flow

- **Blood flow** – volume of blood that flows through any tissue in a given period of time (in mL/min)
- Total blood flow is cardiac output (CO)
  - Volume of blood that circulates through systemic (or pulmonary) blood vessels each minute
- CO = heart rate (HR) x stroke volume (SV)
- Distribution of CO depends on
  - Pressure differences that drive blood through tissue
    - Flows from higher to lower pressure
  - Resistance to blood flow in specific blood vessels
    - Higher resistance means smaller blood flow

Blood Pressure

- Contraction of ventricles generates blood pressure
- **Systolic BP** – highest pressure attained in arteries during systole
- **Diastolic BP** – lowest arterial pressure during diastole
- Pressure falls progressively with distance from left ventricle
- Blood pressure also depends on total volume of blood



Vascular resistance

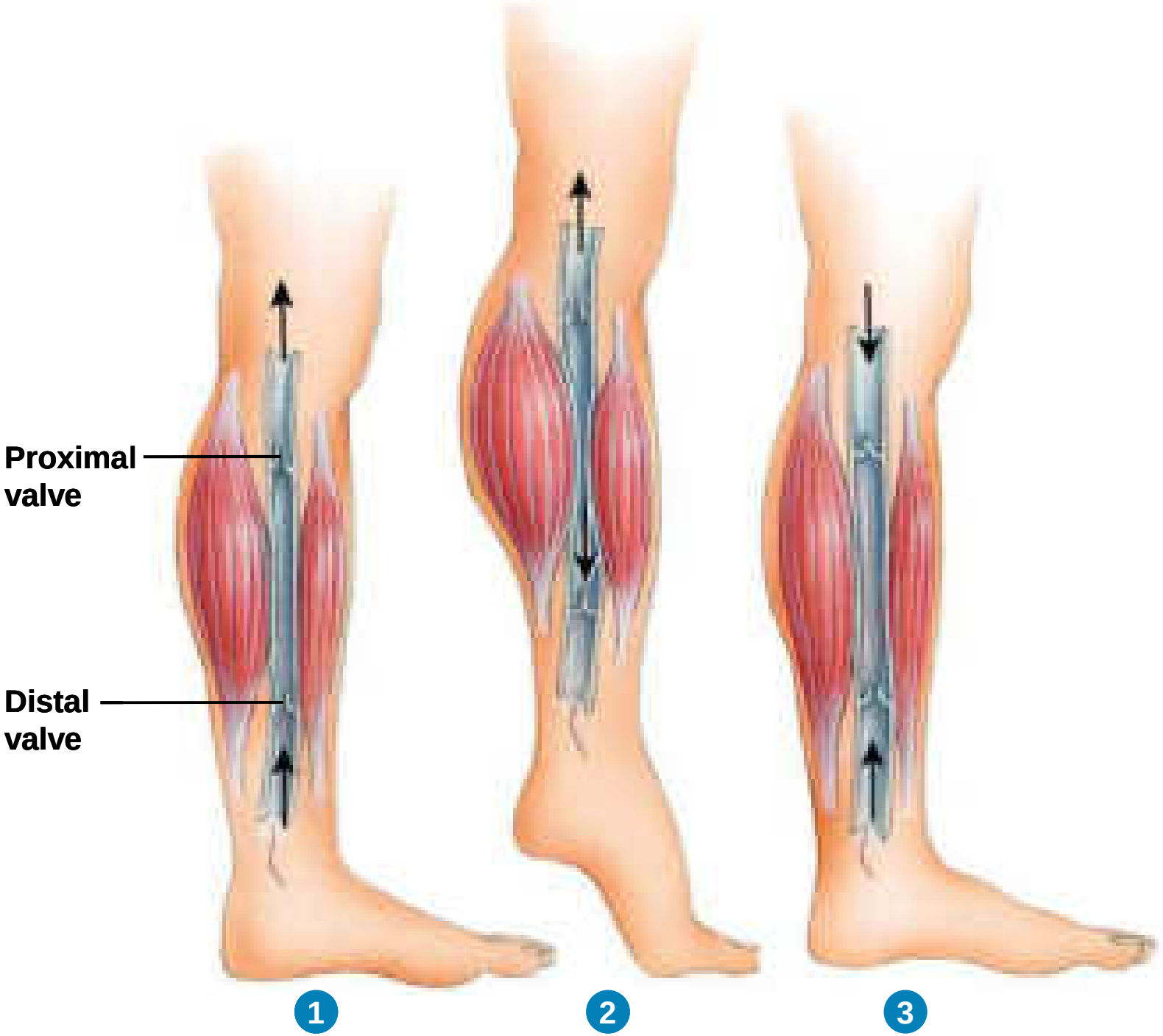
- Opposition to blood flow due to friction between blood and walls of blood vessels
- Depends on
  1. **Size of lumen** – vasoconstriction males lumen smaller meaning greater resistance
  2. **Blood viscosity** – ratio of RBCs to plasma and protein concentration, higher viscosity means higher resistance
  3. **Total blood vessel length** – resistance directly proportional to length of vessel
     - 400 miles of additional blood vessels for each 2.2lb. of fat

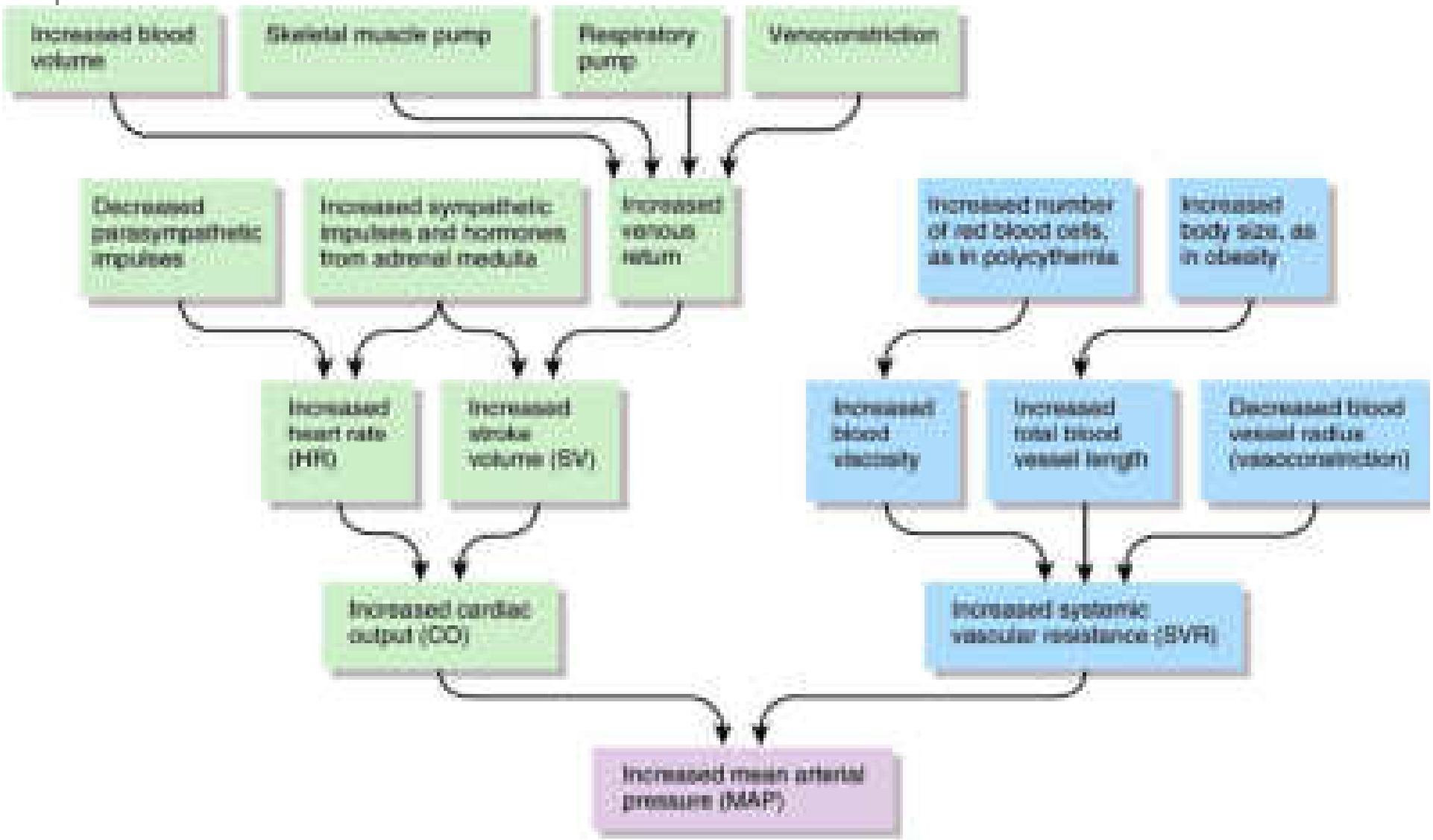
Venous return

- Volume of blood flowing back to heart through systemic veins
- Occurs due to pressure generated by constriction of left ventricle
- Small pressure difference from venule (16 mmHg) to right ventricle (0 mmHg) sufficient

Skeletal Muscle Pump

- 2 other mechanisms
  - Skeletal muscle pump – milks blood in 1 direction due to valves
  - Respiratory pump – due to pressure changes in thoracic and abdominal cavities

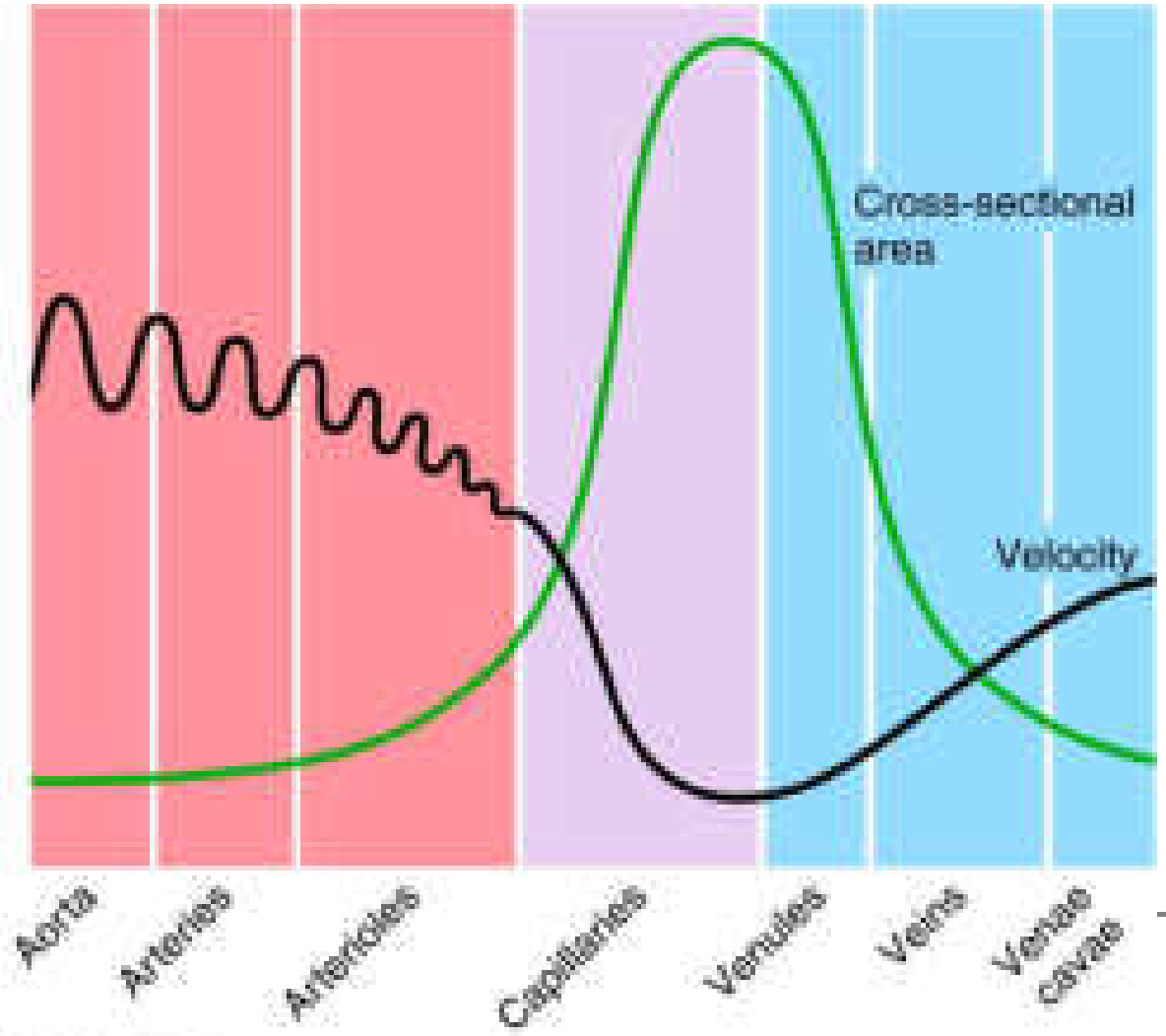

Proximal valve
Distal valve
1
2
3


Increased blood volume
Skeletal muscle pump
Respiratory pump
Vasoconstriction
Decreased parasympathetic impulses
Increased sympathetic impulses and hormones from adrenal medulla
Increased venous return
Increased number of red blood cells, as in polycythemia
Increased body size, as in obesity
Increased heart rate (HR)
Increased stroke volume (SV)
Increased blood viscosity
Increased total blood vessel length
Decreased blood vessel radius (vasoconstriction)
Increased cardiac output (CO)
Increased systemic vascular resistance (SVR)
Increased mean arterial pressure (MAP)

Velocity of blood flow

- Speed in cm/sec in inversely related to cross-sectional area
- Velocity is slowest where total cross sectional area is greatest
- Blood flow becomes slower farther from the heart
- Slowest in capillaries
- Aids in exchange
- **Circulation time** – time required for a drop of blood to pass from right atrium, through pulmonary and systemic circulation and back to right atrium
  - Normally 1 minute at rest

Relationship between Velocity of Blood Flow and Total Cross-sectioned area in Different Types of Blood Vessels



Control of blood pressure and blood flow

- Interconnected negative feedback systems control blood pressure by adjusting
  - heart rate
  - stroke volume
  - systemic vascular resistance
  - blood volume
- Some act faster that others
- Some shorter- or longer-term

Role of cardiovascular center (CV)

- In medulla oblongata
- Helps regulate heart rate and stroke volume
- Also controls neural, hormonal, and local negative feedback systems that regulate blood pressure and blood flow to specific tissues
- Groups of neurons regulate heart rate, contractility of ventricles, and blood vessel diameter
- Cardiostimulatory and cardioinhibitory centers
- Vasomotor center control blood vessel diameter
- Receives input from both higher brain regions and sensory receptors

CV Center

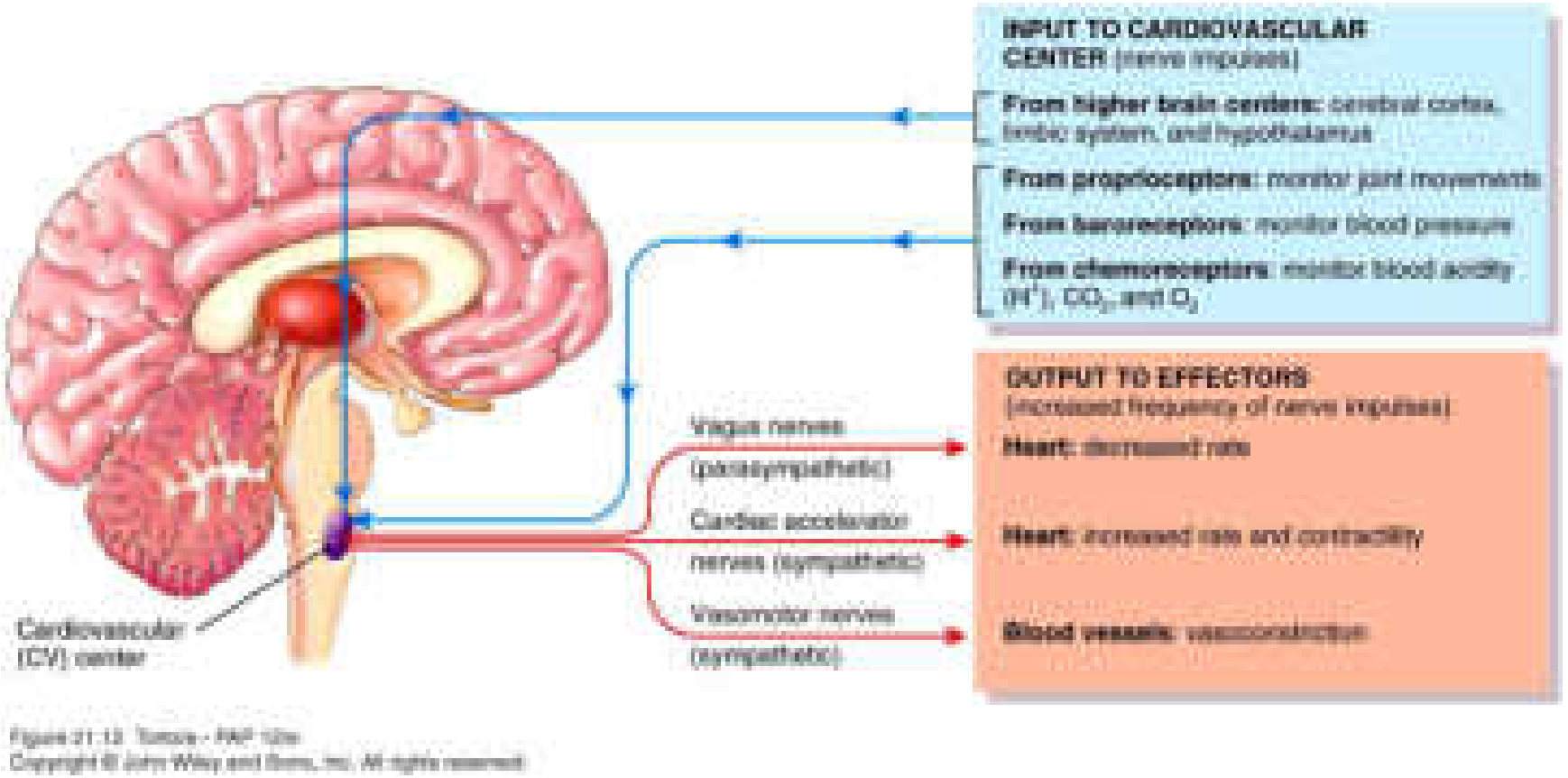


Figure 21.13 Tortora - PAP 12e

3 main types of sensory receptors

- Proprioceptors – monitor movements of joints and muscles to provide input during physical activity
- Baroreceptors – monitor pressure changes and stretch in blood vessel walls
- Chemoreceptors – monitor concentration of various chemicals in the blood

- Output from CV flows along neurons of ANS
  - Sympathetic (stimulatory) opposes parasympathetic (inhibitory)

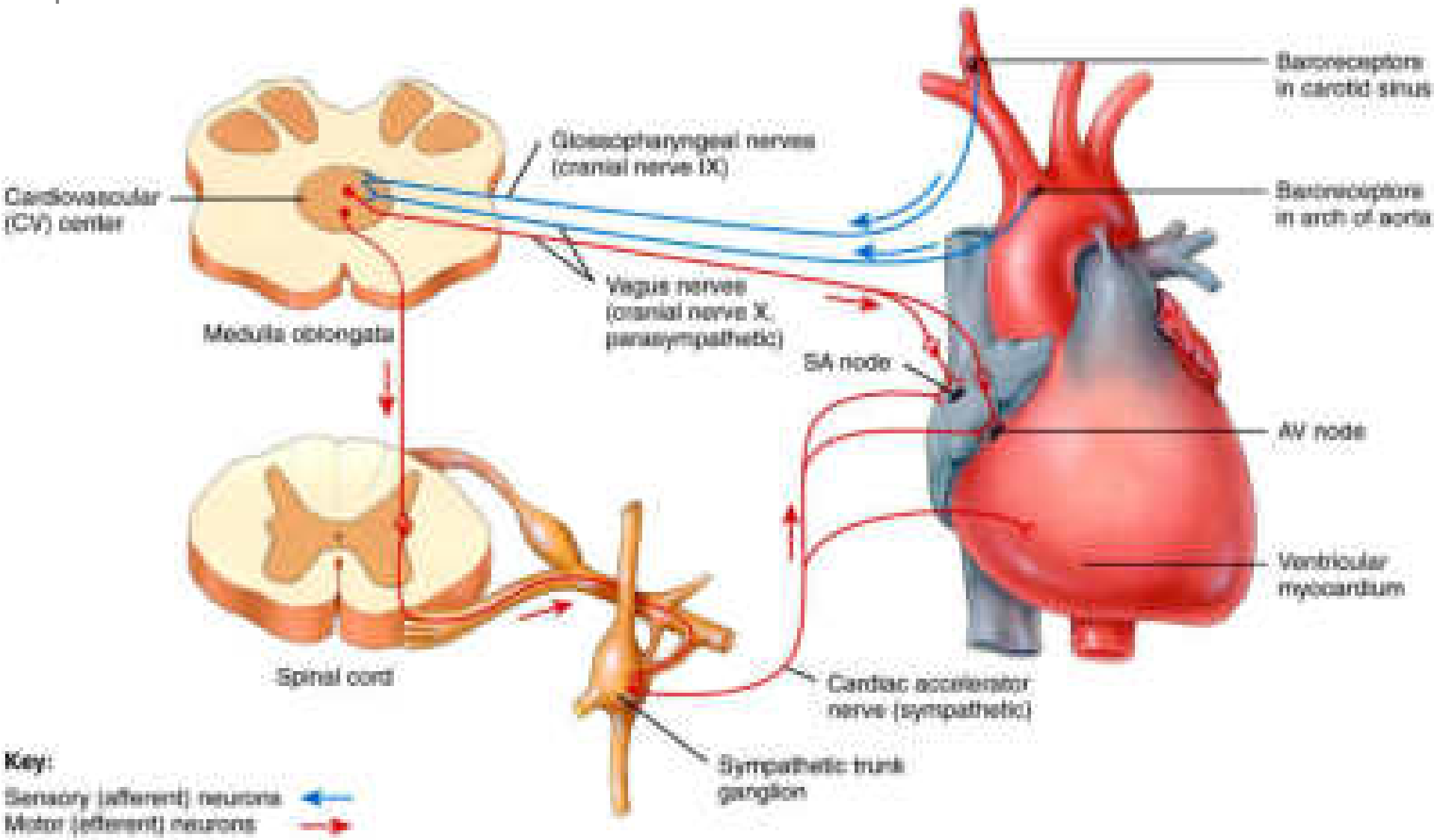
Neural regulation of blood pressure

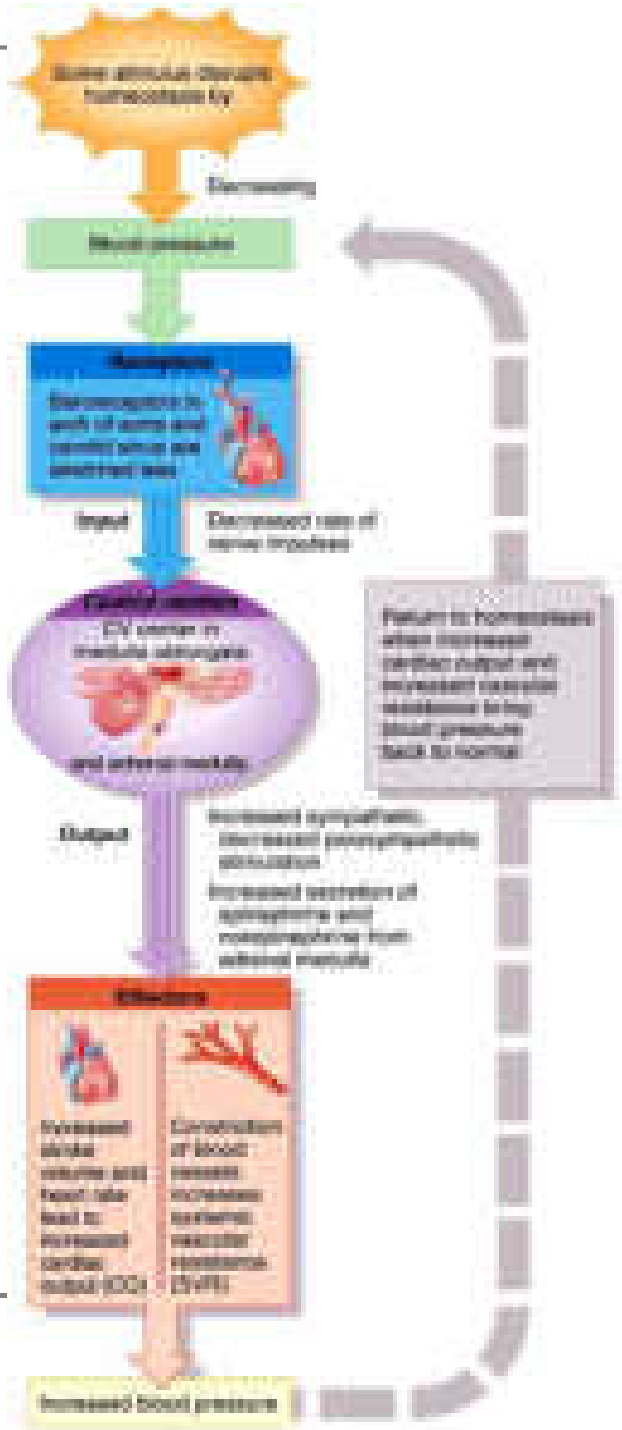
- Negative feedback loops from 2 types of reflexes

1. Baroreceptor reflexes
   - Pressure-sensitive receptors in internal carotid arteries and other large arteries in neck and chest
     - *Carotid sinus* reflex helps regulate blood pressure in *brain*
     - *Aortic reflex* regulates *systemic* blood pressure
   - When blood pressure falls, baroreceptors stretched less, slower rate of impulses to CV
   - CV decreases parasympathetic stimulation and increases sympathetic stimulation

Neural regulation of blood pressure

2. Chemoreceptor reflexes
   - Receptors located close to baroreceptors of carotid sinus (carotid bodies) and aortic arch (aortic bodies)
   - Detect hypoxia (low **O_2**), hypercapnia (high **CO_2**), acidosis (high **H^+**) and send signals to CV
   - CV increases sympathetic stimulation to arterioles and veins, producing vasoconstriction and an increase in blood pressure
   - Receptors also provide input to respiratory center to adjust breathing rate


Baroreceptors in carotid sinus
Glossopharyngeal nerves (cranial nerve IX)
Cardiovascular (CV) center
Baroreceptors in arch of aorta
Vagus nerves (cranial nerve X, parasympathetic)
Medulla oblongata
SA node
AV node
Ventricular myocardium
Spinal cord
Cardiac accelerator nerve (sympathetic)
Sympathetic trunk ganglion
Key:
Sensory (afferent) neurons
Motor (efferent) neurons


Some stimulus disrupts homeostasis by
Decreasing
Blood pressure
Baroreceptors
Input
Decreased rate of nerve impulses
CV center in medulla oblongata
and adrenal medulla
Output
Increased sympathetic, decreased parasympathetic stimulation
Increased secretion of epinephrine and norepinephrine from adrenal medulla
Effectors
Increased cardiac output
Constriction of blood vessels
Increased blood pressure
Return to homeostasis when increased cardiac output and increased vascular resistance bring blood pressure back to normal

Hormonal regulation of blood pressure

- Renin-angiotensin-aldosterone (RAA) system
  - Renin (released by kidney when blood volume falls or blood flow decreases) and angiotensin converting enzyme (ACE) act on substrates to produce active hormone angiotensin II
  - Raises BP by **vasoconstriction** and **secretion of aldosterone** (increases water reabsorption in kidneys to raise blood volume and pressure)

Hormonal regulation of blood pressure

- Epinephrine and norepinephrine
  - Adrenal medulla releases in response to sympathetic stimulation
  - Increase cardiac output by increasing rate and force of heart contractions
- Antidiuretic hormone (ADH) or vasopressin
  - Produced by hypothalamus, released by posterior pituitary
  - Response to dehydration or decreased blood volume
  - Causes vasoconstriction which increases blood pressure

Atrial natriuretic peptide (ANP)

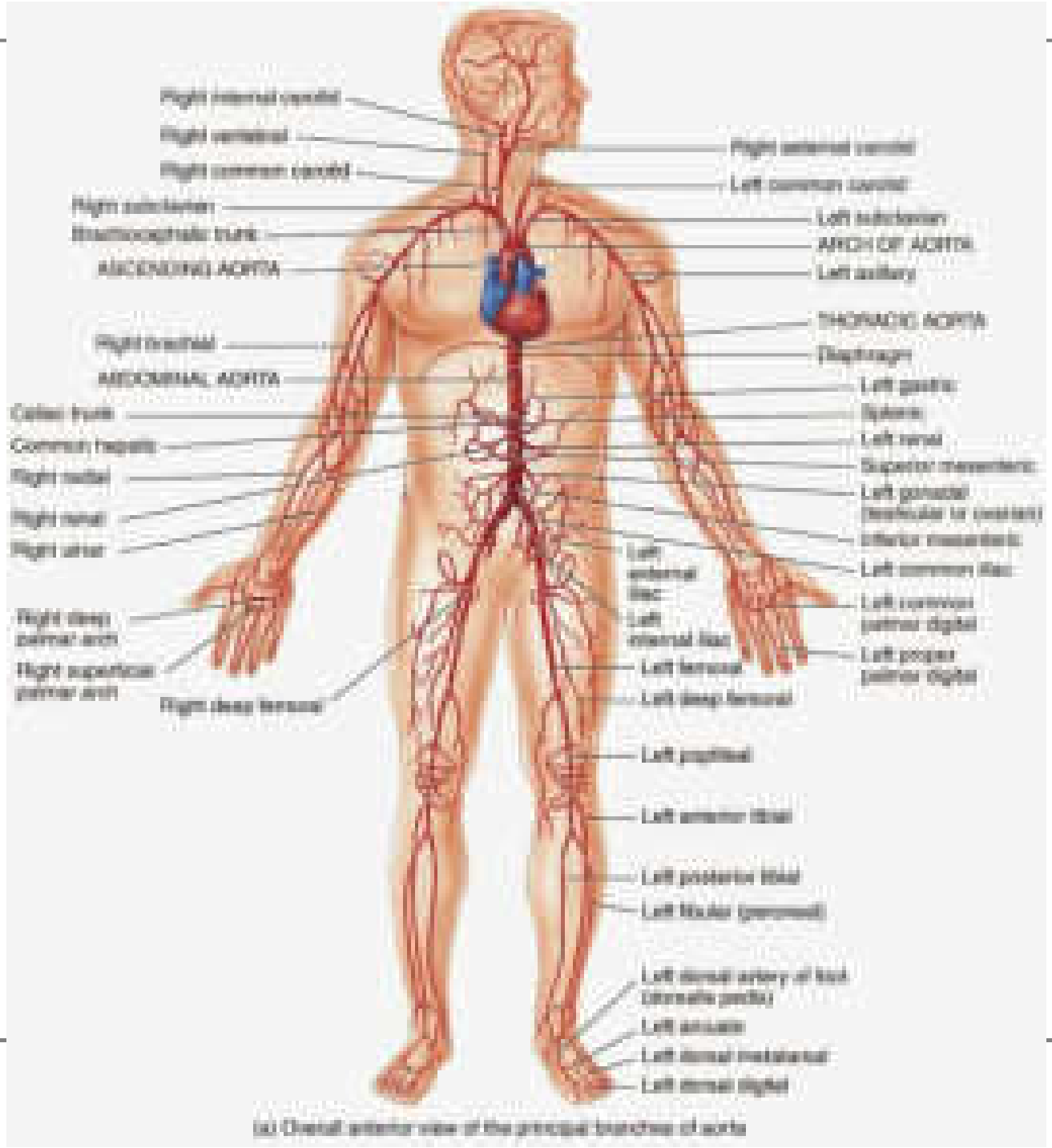
- Released by cells of atria
- Lowers blood pressure by causing vasodilation and promoting loss of salt and water in urine
- Reduces blood volume

Autoregulation of blood pressure

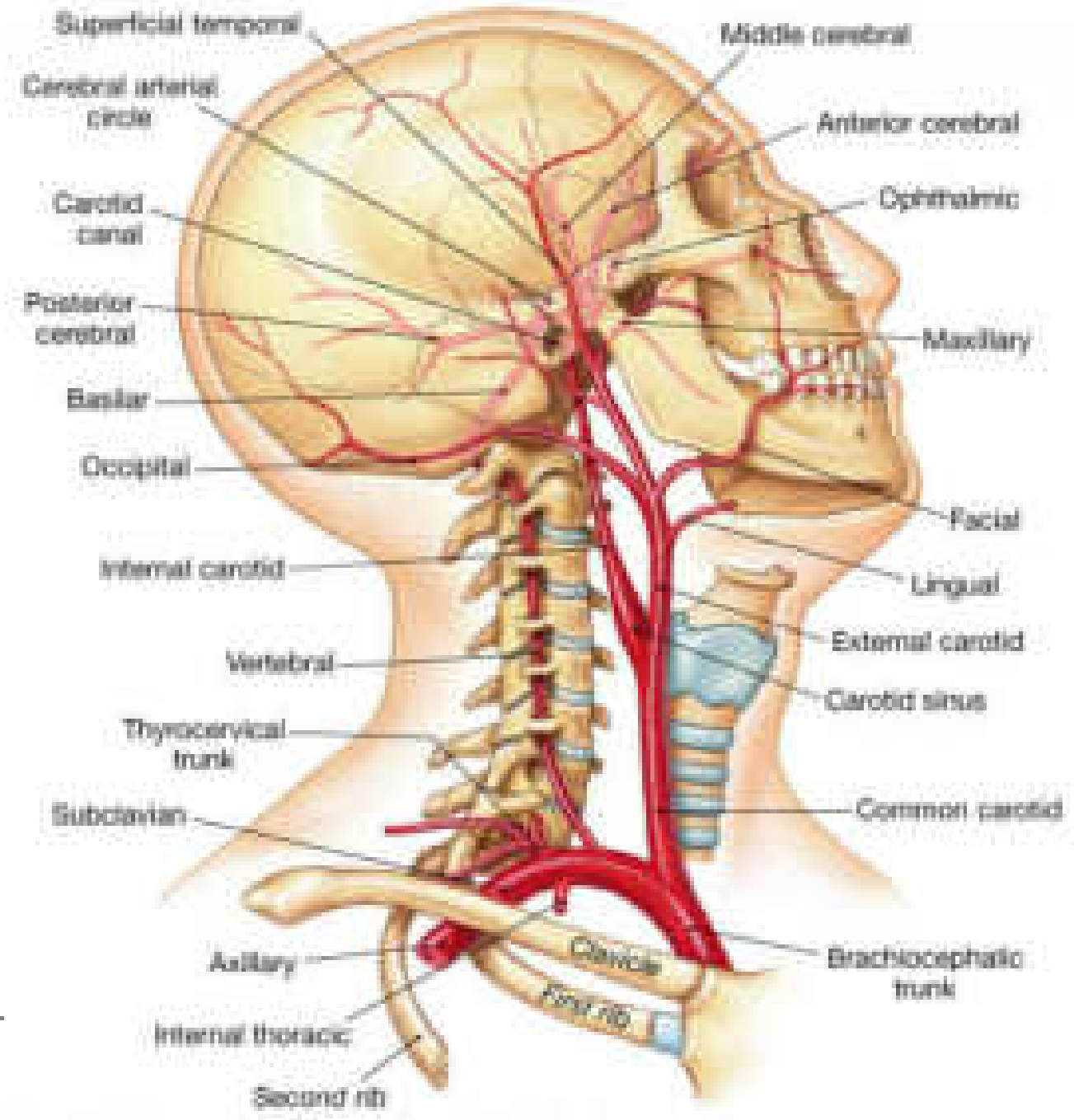
- Ability of tissue to automatically adjust its blood flow to match metabolic demands
- Demand of O_2 and nutrients can rise tenfold during exercise in heart and skeletal muscles
- Also controls regional blood flow in the brain during different mental and physical activities
- 2 general types of stimuli
  1. **Physical** – temperature changes, myogenic response
  2. **Vasodilating and vasoconstricting - chemicals** alter blood vessel diameter

Circulation

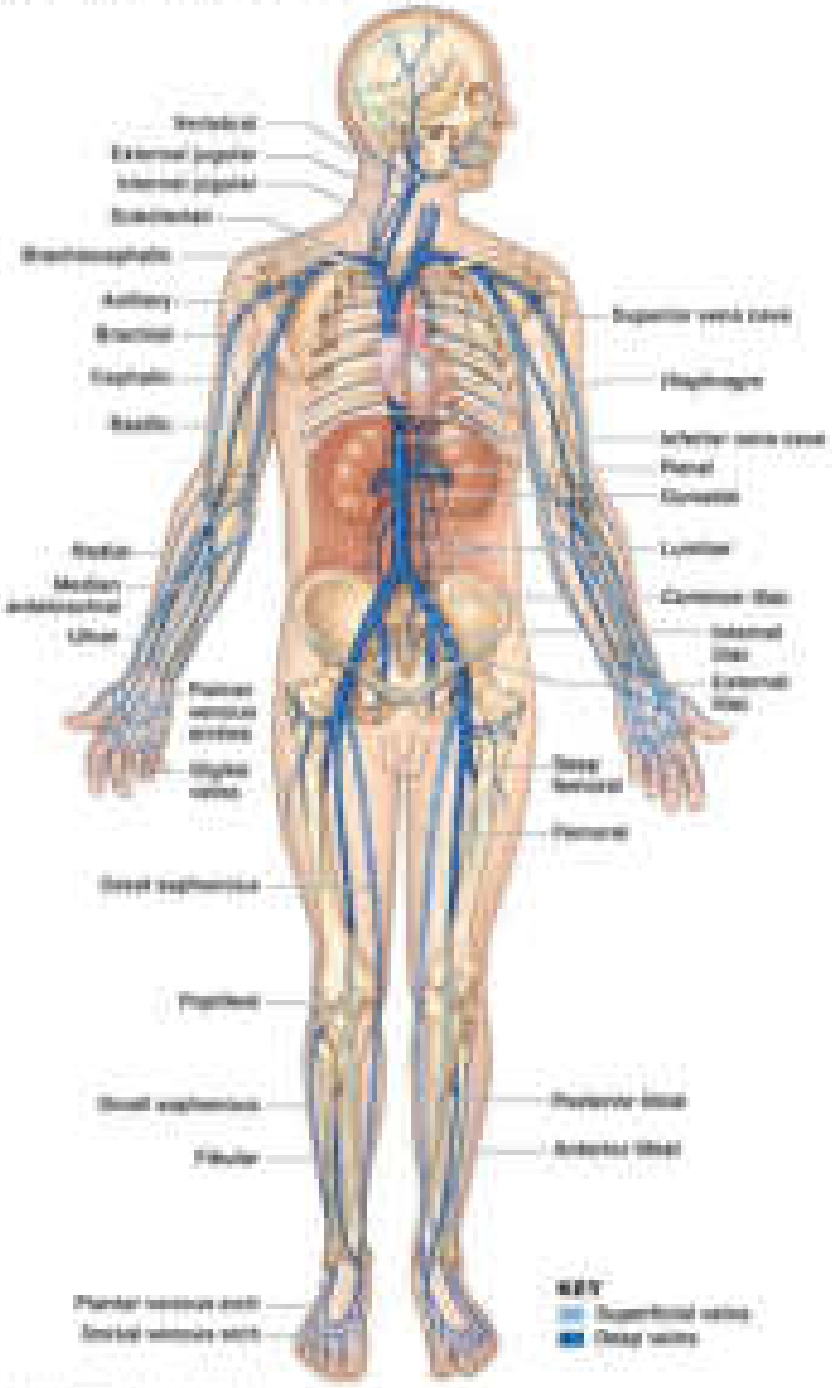
- Important difference between pulmonary and systemic circulation in autoregulatory response
  - Systemic blood vessel walls dilate in response to low O_2 to increase O_2 delivery
  - Walls of pulmonary blood vessels constrict under low O_2 to ensure most blood flows to better ventilated areas of lung

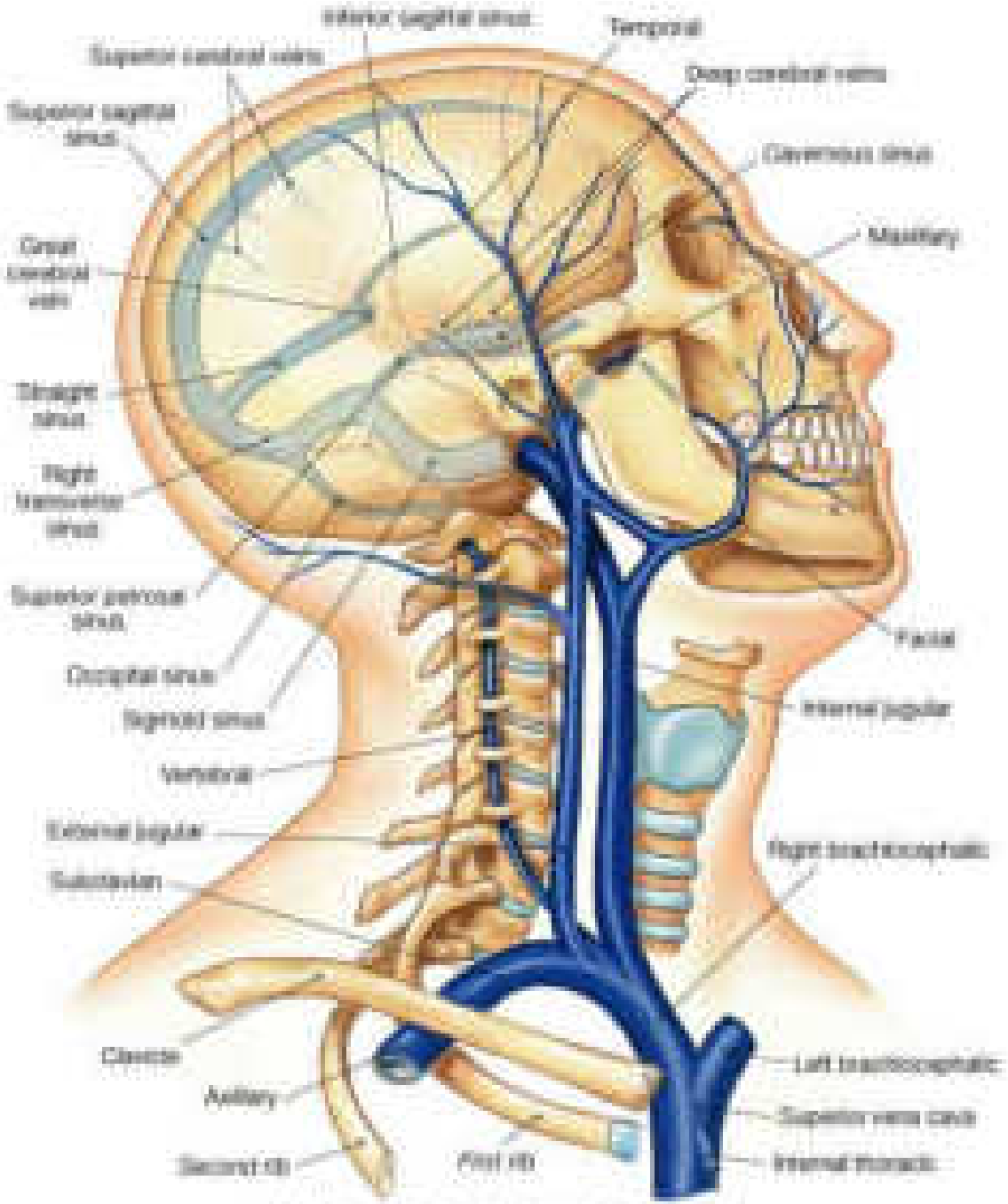


(a) Overall anterior view of the principal branches of aorta


Superficial temporal
Middle cerebral
Cerebral arterial circle
Anterior cerebral
Carotid canal
Ophthalmic
Posterior cerebral
Maxillary
Basilar
Occipital
Facial
Internal carotid
Lingual
External carotid
Vertebral
Carotid sinus
Thyrocervical trunk
Subclavian
Common carotid
Clavicle
Axillary
Brachiocephalic trunk
First rib
Internal thoracic
Second rib

An overview of the systemic venous system

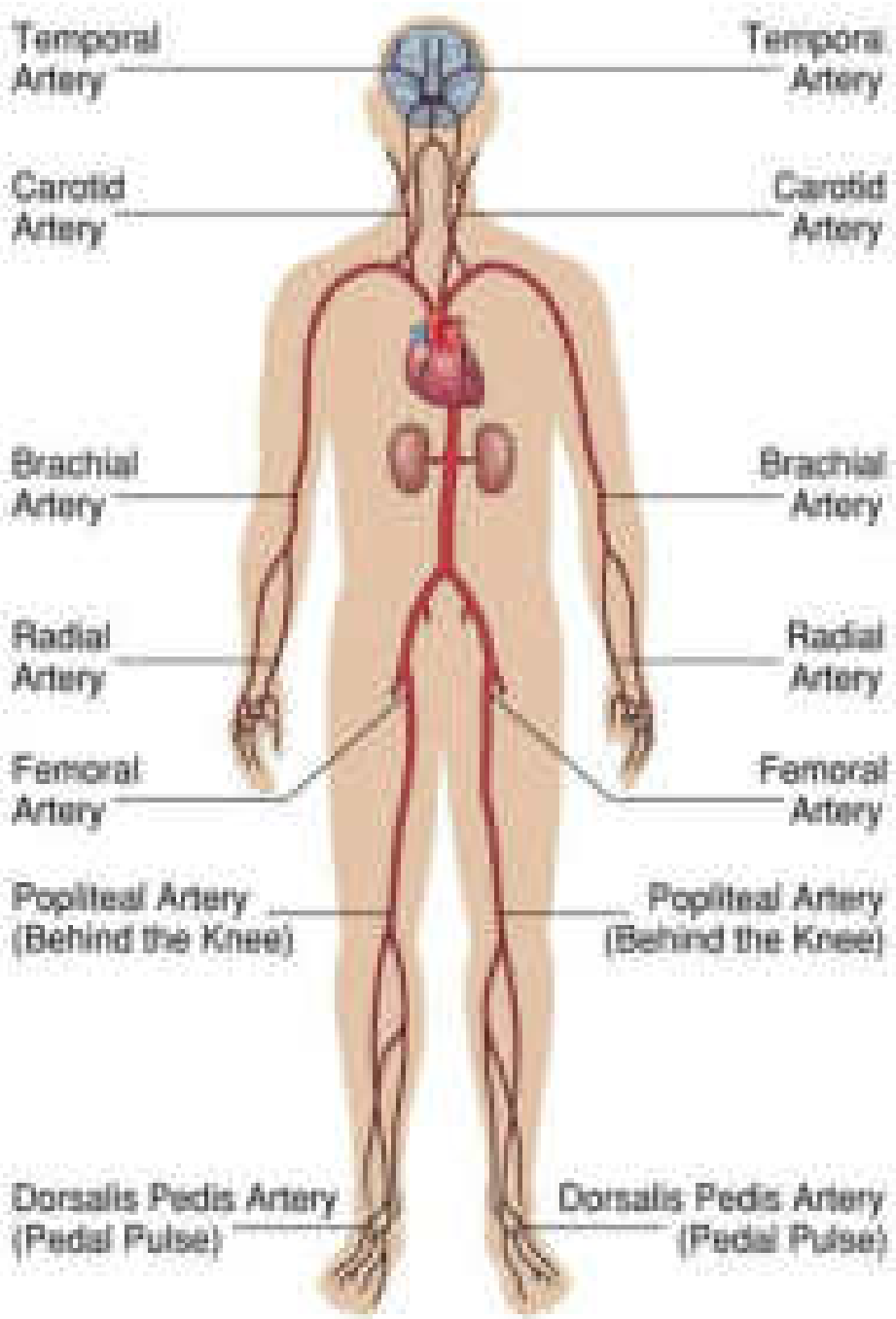




(a) Veins of the head and neck, lateral view

MEASURING PULSE

- Major arterial or pulse sites



Measurement of blood pressure