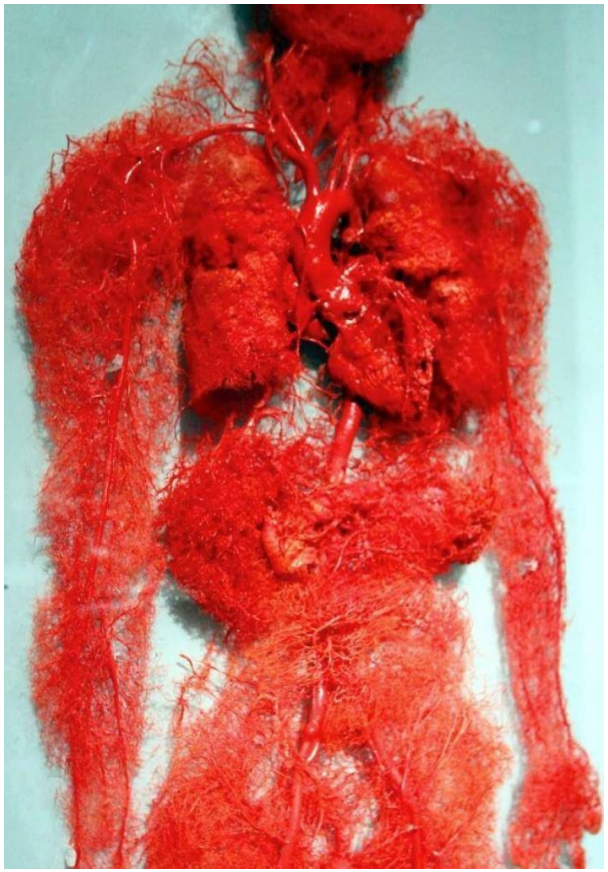
Chapter 21 (1)

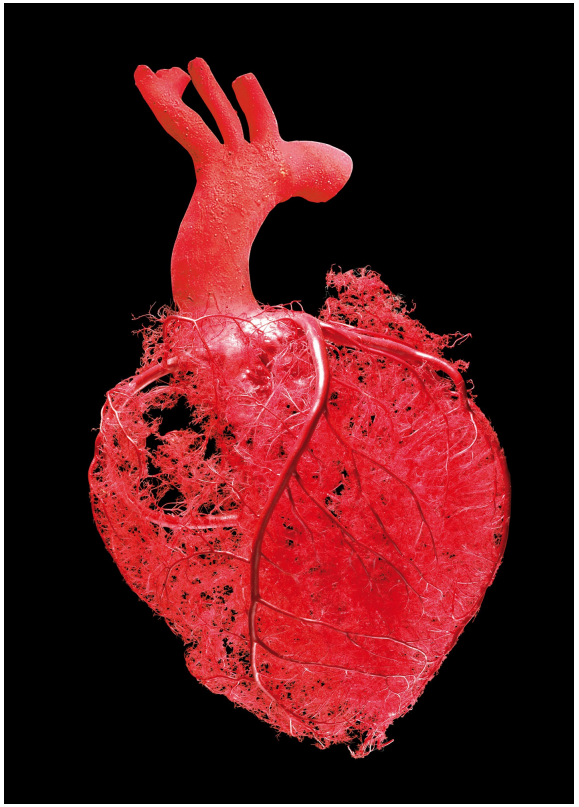
Blood Vessels and Blood Circulation

The human body has 60,000 miles of blood vessels.

This is nearly enough blood vessels to circle the earth 2 ½ times.

If you gain one pound of fat then you add another mile of blood vessels.

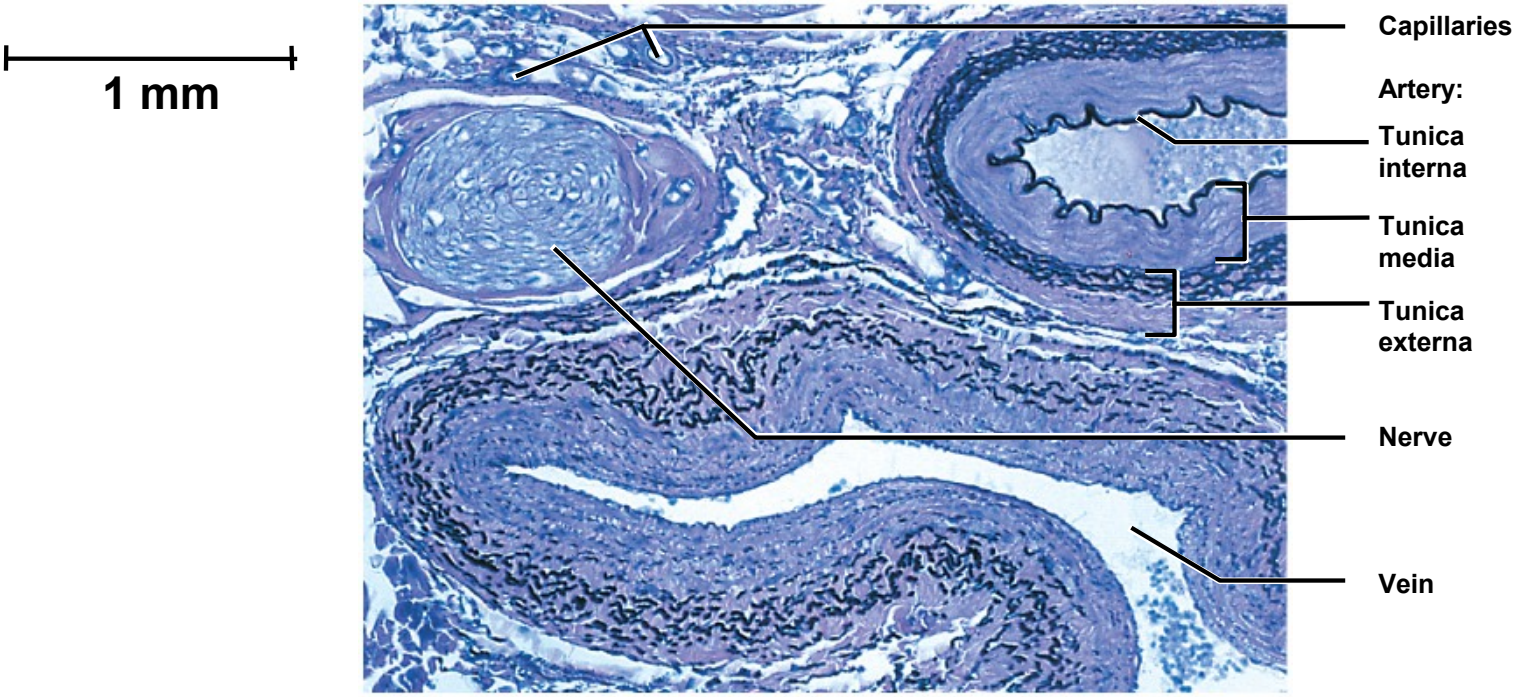




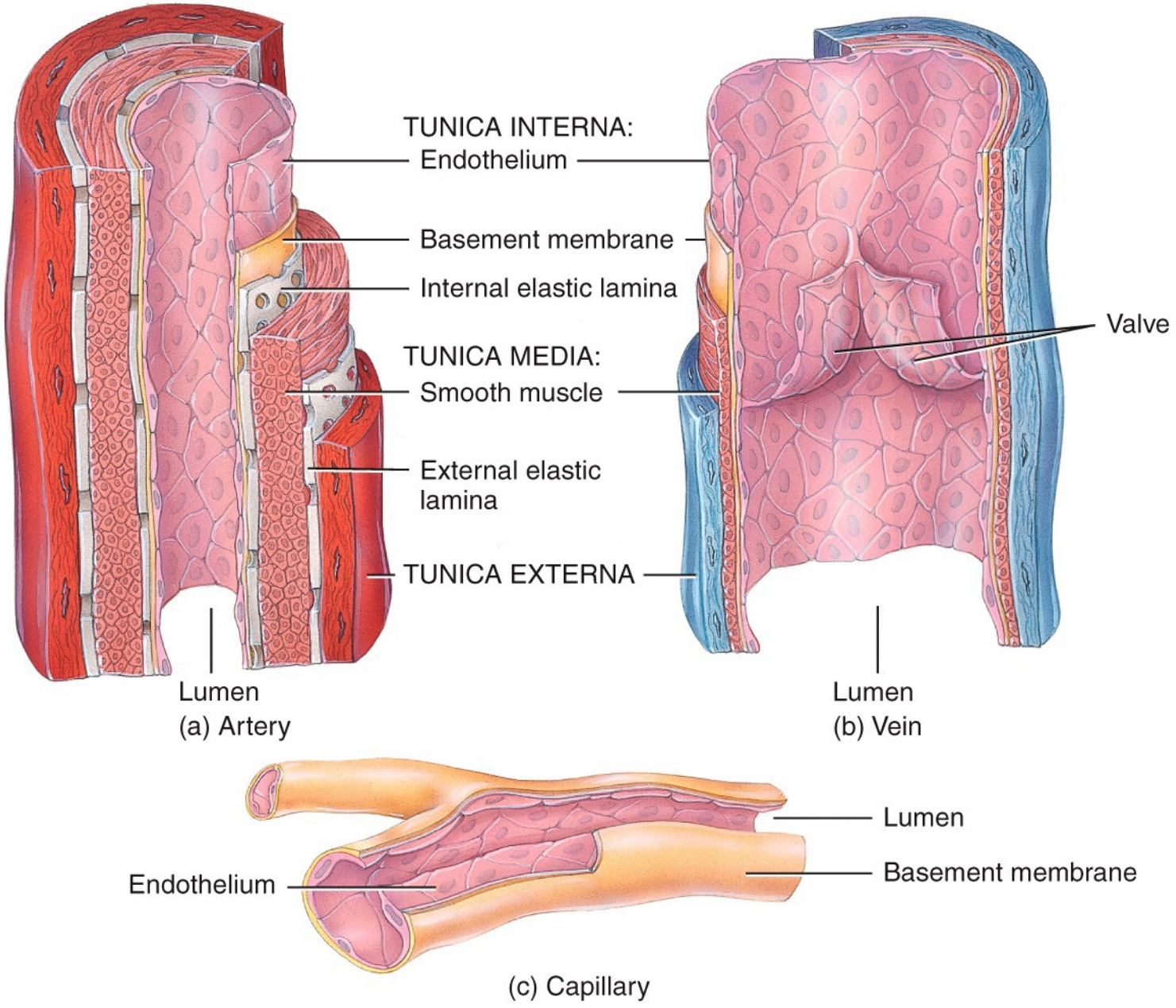
Lecture Objectives

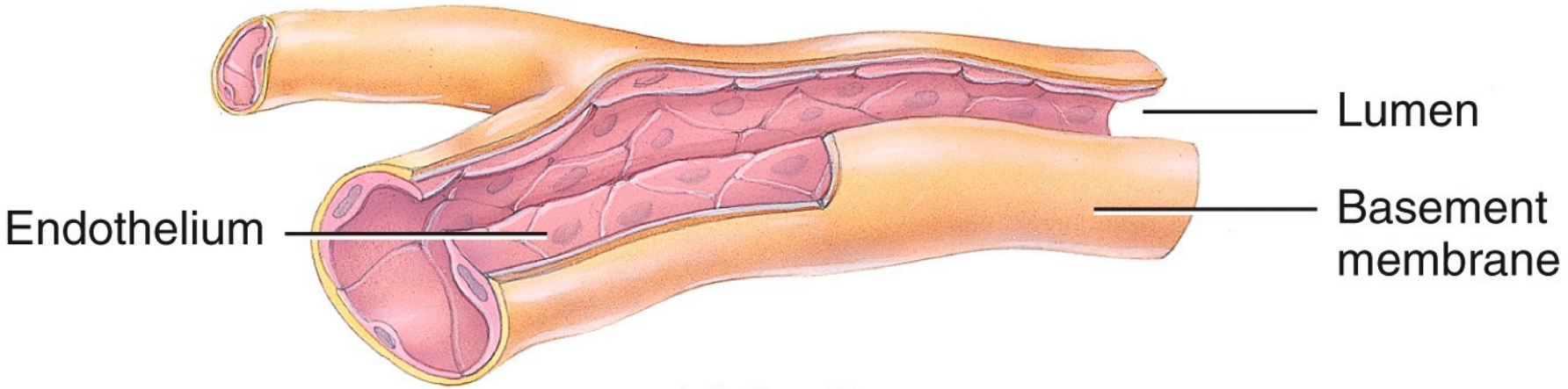
- **Compare and contrast the structure of an artery, arteriole, vein, venule, and capillary**
- **Discuss the structure and function of a capillary network**

Blood Vessels

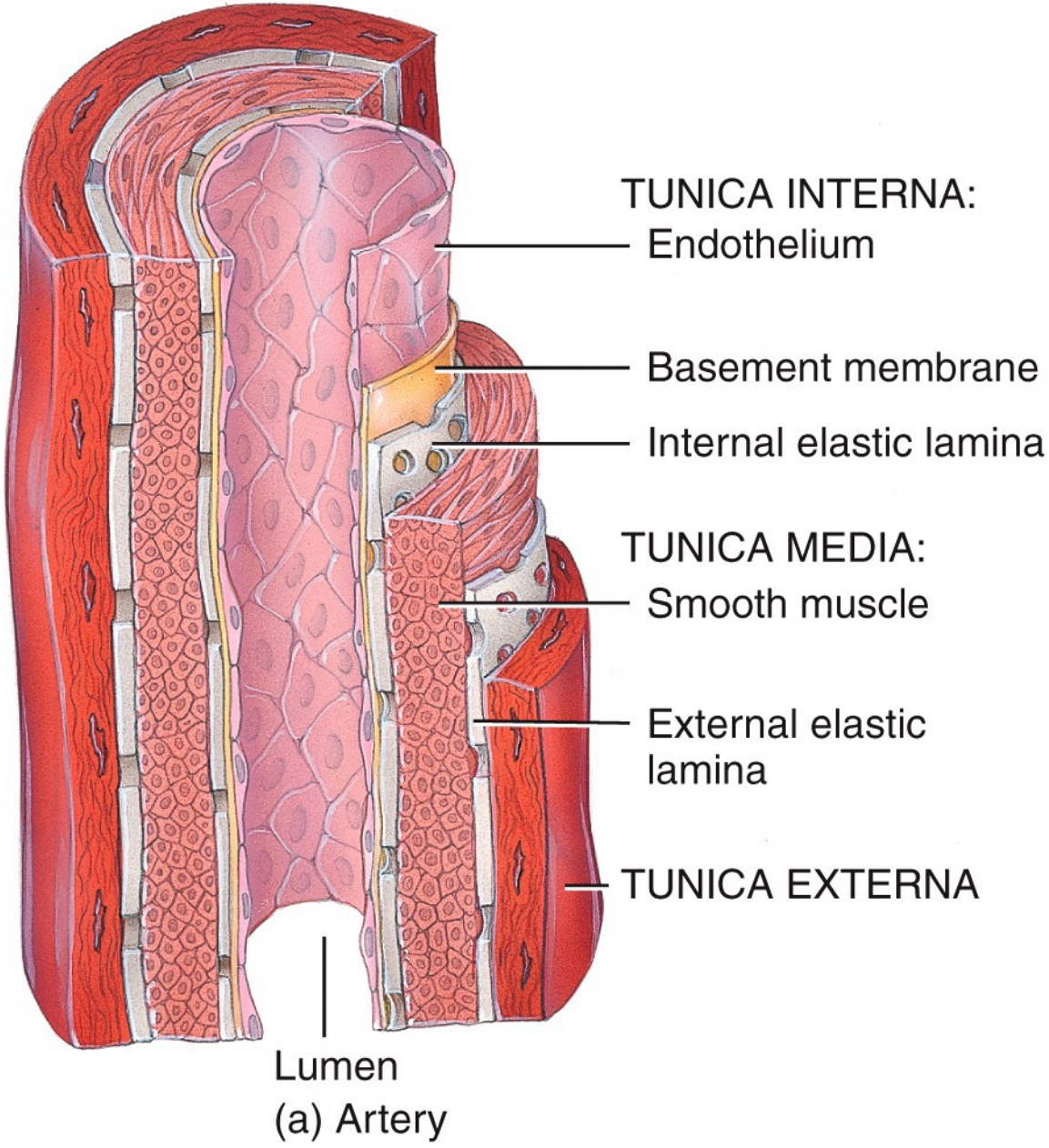


- arteries - carry blood away from heart
- veins - carry blood back to heart
- capillaries - connect smallest arteries to smallest veins
  - Capillaries allow for the exchange of fluid, ions, & small molecules between the blood and the intersticial space
- arteries and veins are composed of three tunics (layers)


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



(c) Capillary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Smooth muscle
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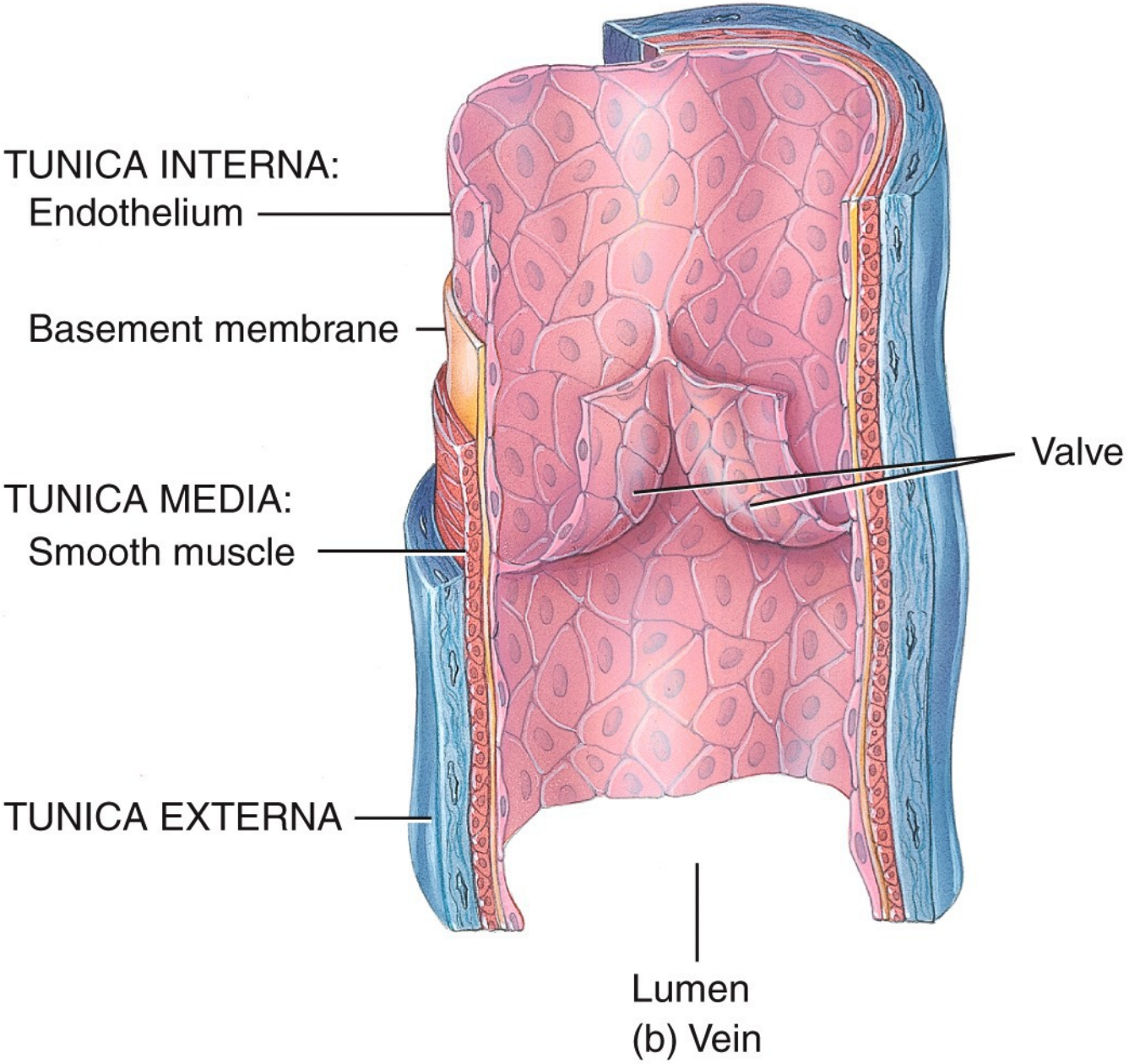
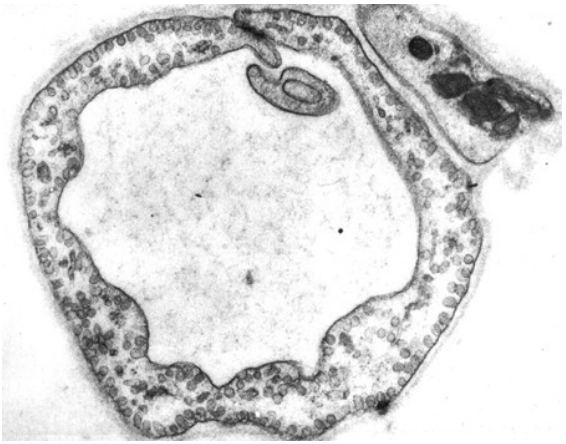
TUNICA EXTERNA
Lumen
(a) Artery


TUNICA INTERNA:
Endothelium
Basement membrane
TUNICA MEDIA:
Smooth muscle
TUNICA EXTERNA
Valve
Lumen
(b) Vein

Tunica Interna (tunica intima)



- Cells that lines the blood vessel
- **endothelium** – simple squamous epithelium overlying a basement membrane and a sparse layer of loose connective tissue
  - function as a **selectively permeable barrier**
  - normally **repels blood cells and platelets** that may adhere to it and form a clot (endothelium secrete prostacyclin – make surface "slippery")
  - when tissue around vessel is inflamed, the endothelial cells produce cell-adhesion molecules that induce leukocytes to adhere to the surface
    - allows leukocytes to congregate in tissues where their defensive actions are needed

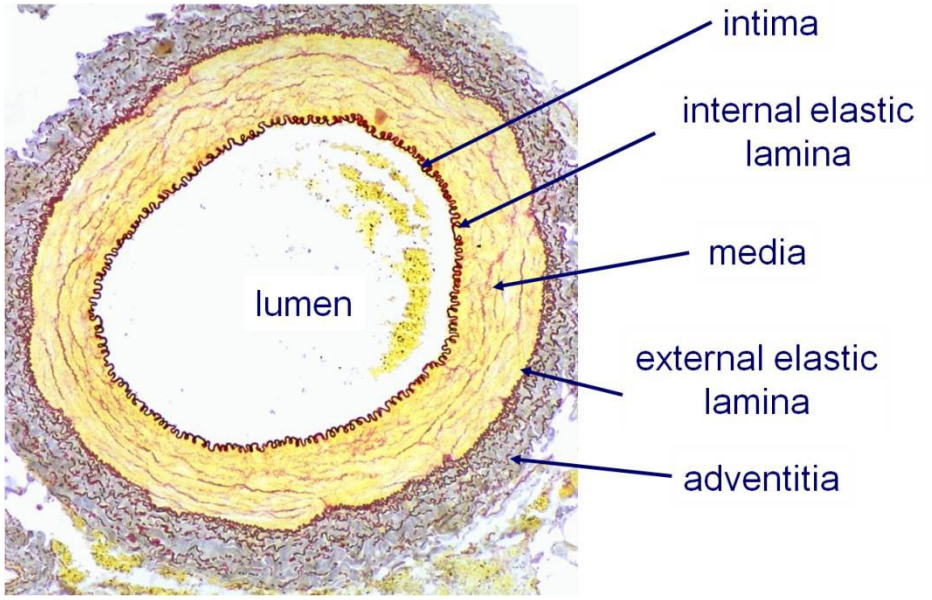
Tunica Media

- middle layer

– consists of <u>smooth muscle and connective tissue with collagen and elastic fibers</u>

– strengthens vessel and prevents blood pressure from rupturing vessels

– vasomotion – changes in diameter of the blood vessel brought about by smooth muscle action /// <u>regulated by vasomotion center in medula oblongata</u>

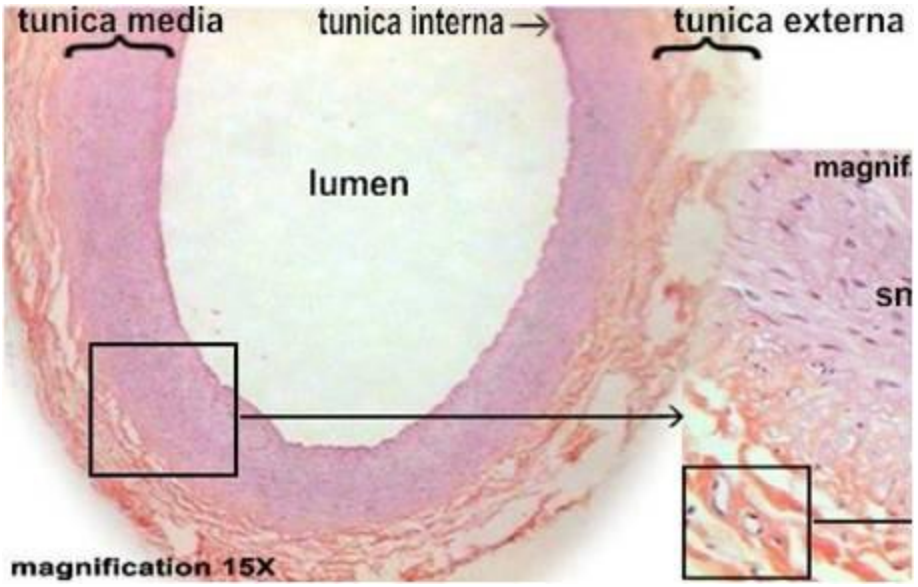


Note: at end of arterial system are small diameter vessels called arterioles // the vasomotor center is able to control blood pressure by regulating smooth muscle contraction --- this is known as peripheral resistance.

The volume of blood on the arterial side also contributes to the blood pressure.

Tunica Externa

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



Arteries

- Carry blood away from the heart
- Classified by function
  - Elastic arteries (largest – garden hose size /// also function as a pressure reservoirs)
  - Distributing arteries (medium size sometimes referred to as muscular / pencil to string size)
  - Resistance arterioles (small arteries – able to regulate blood flow into capillary beds and change blood pressure)

Distributing Arteries

Distributing arteries are also called conducting arteries

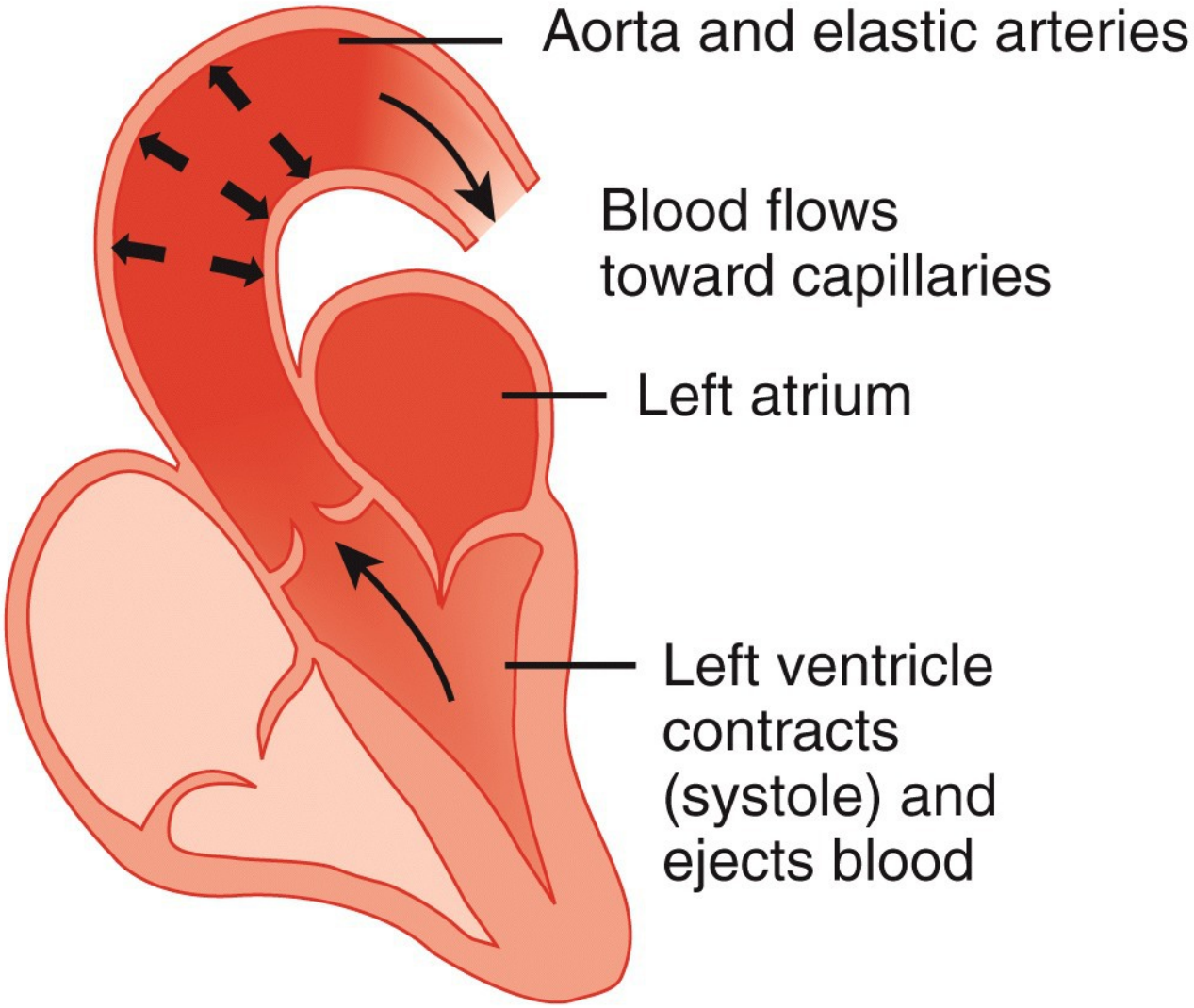
- **these arteries have "names"**
- The bigger arteries distal to pulmonary truck and aorta // e.g. common carotid, subclavian,and common iliac arteries
- have a layer of elastic tissue, **internal elastic lamina,** at the border between interna and media
- **external elastic lamina** at the border between media and externa
- expand during systole, recoil during diastole // this lessens fluctuations in blood pressure

Resistance Arteries

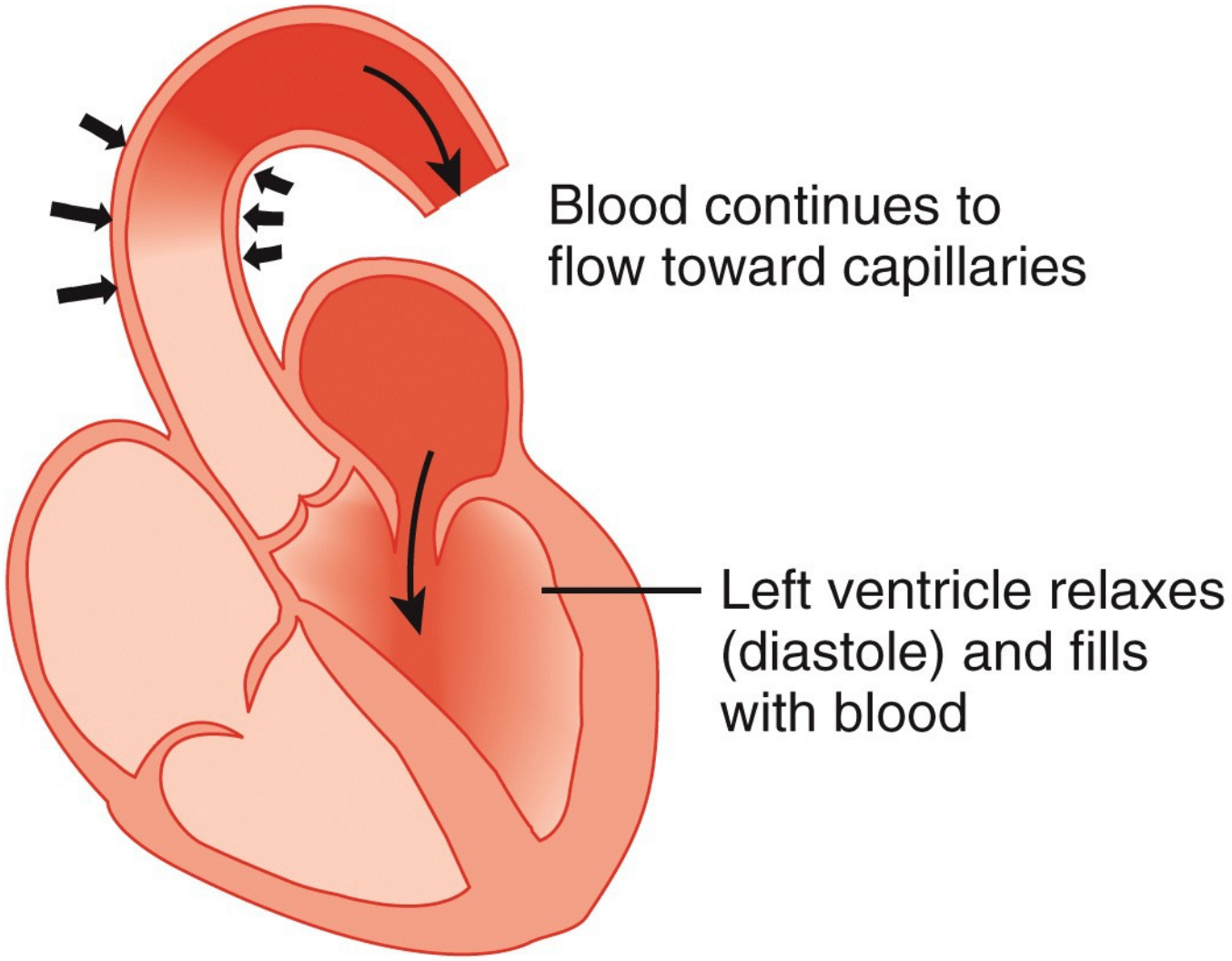
- Arteries Are Called Resistance Vessels
  - Why? // Thick smooth muscle walls
  - Resilient wall structure that can resists dilation due to high blood pressure
  - These vessels are controlled by the vasomotor center
    - Regulate blood pressure
    - Regulate blood distribution

Elastic Arteries

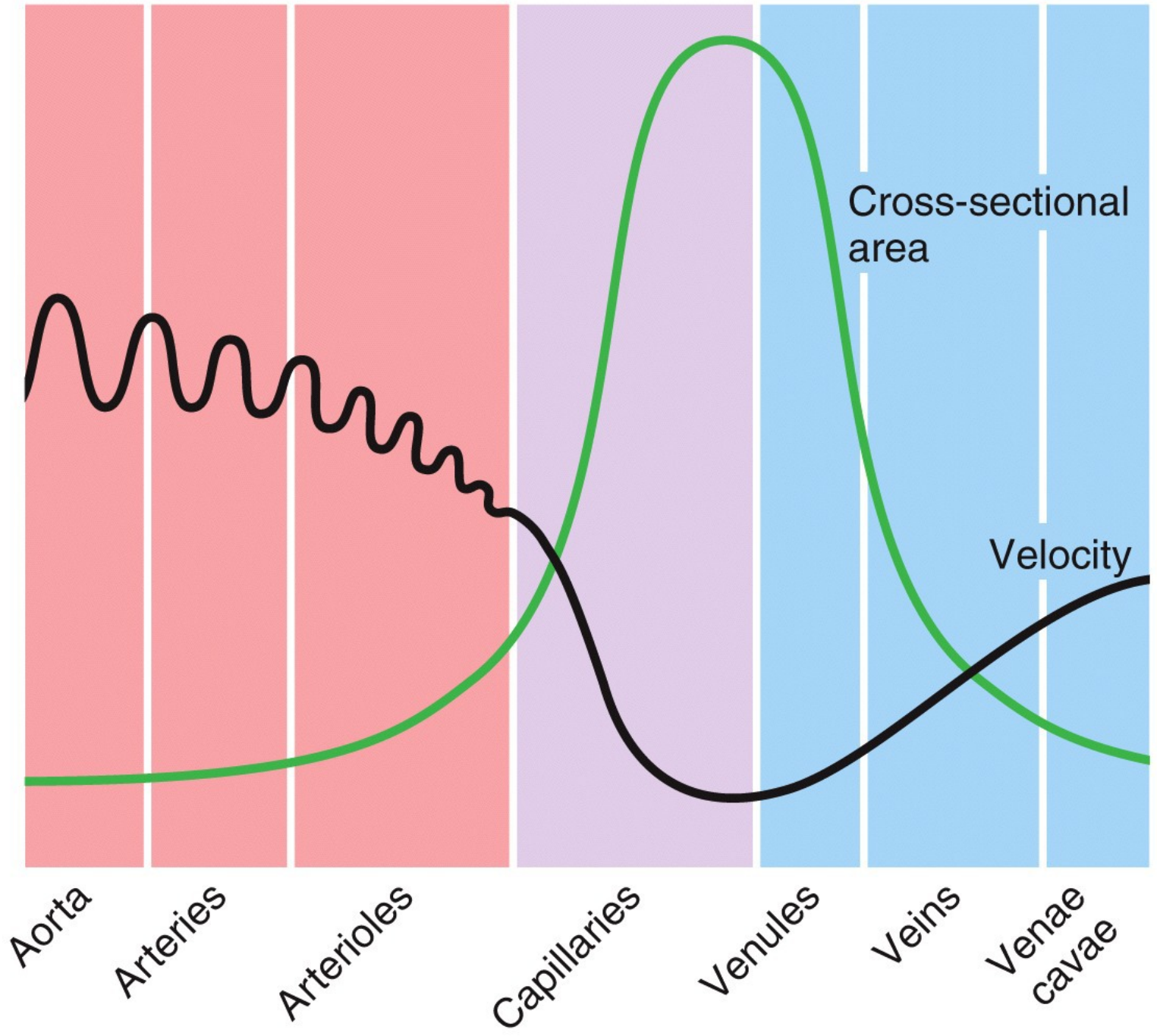
- Walls stretched as blood received by pulmonary truck and aorta
- Stretching vessel walls “stores energy” because of elastic component of the vessel wall
- Elastic recoil in pulmonary truck and aorta keep blood flowing while ventricles are in diastole



(a) Elastic aorta and arteries stretch during ventricular contraction



(b) Elastic aorta and arteries recoil during ventricular relaxation


Cross-sectional area
Velocity
Aorta
Arteries
Arterioles
Capillaries
Venules
Veins
Venae cavae

Arterial Sense Organs

- Sensory structures in the walls of the aorta and carotid arteries monitor blood pressure and blood chemistry

- *Transmit information to brain stem to regulate*

  - *1) heart rate **
  - *2) vasomotion (vasomotor center) **
  - *3) respiration*

- *Location of sense organs*
  - *carotid baroreceptor (also called carotid sinus)*
  - *aortic barorecptor (also called aortic sinus)*
  - *carotid chemoreceptor*
  - *aortic chemoreceptor*

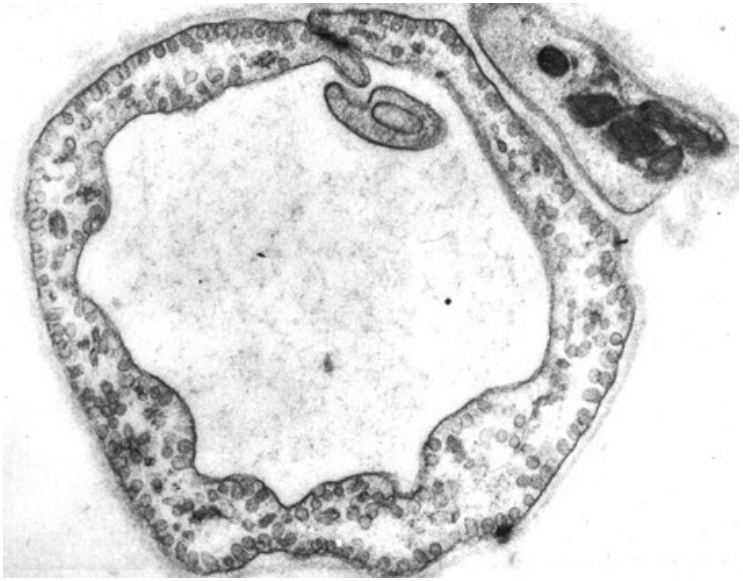
  - *Please Note: the chemorecptors are more important in regulating respiration.*

Arterial Sense Organs

- **aortic & carotid sinuses //** baroreceptors (pressure sensors)
  - most important in regulation of heart
  - in walls of internal carotid artery & aortic arch
  - monitors blood pressure – signaling brainstem
  - decreased heart rate and vessels dilation in response to high blood pressure

- **aortic & carotid bodies //** chemoreceptors
  - oval bodies near branch of common carotids
  - monitor blood chemistry
  - mainly transmit signals to the brainstem respiratory centers
  - adjust respiratory rate to stabilize pH, CO_2, and O_2
  - one to three in walls of aortic arch
  - same function as carotid bodies

Capillaries



- Site where nutrients, wastes, and hormones pass between the blood and tissue fluid through the walls of the vessels (exchange vessels)
  - the ‘business end’ of the cardiovascular system
  - composed of **endothelium and basal lamina**
  - Capillaries are absent or scarce in tendons, ligaments, epithelia, cornea and lens of the eye

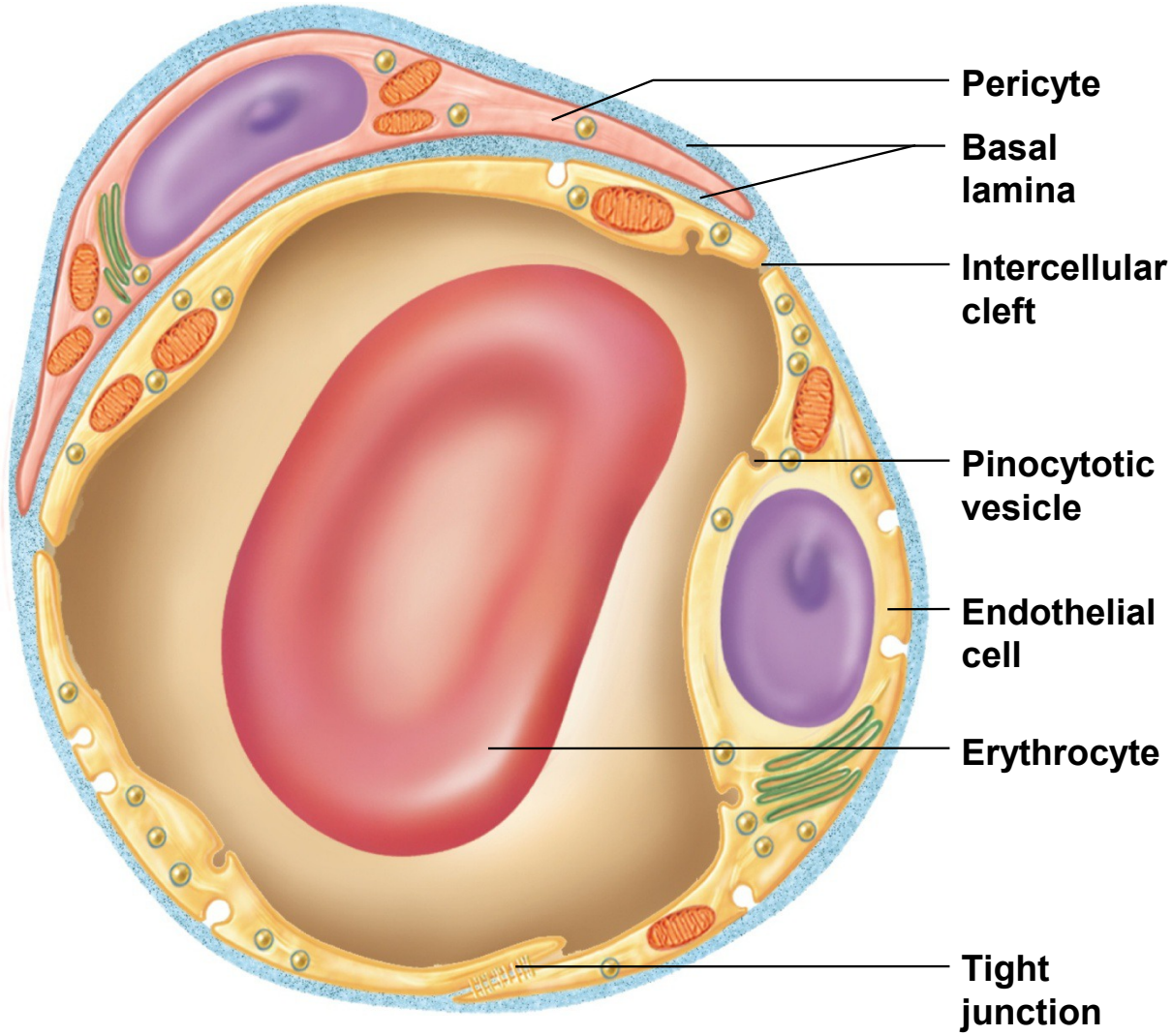
- **Three Capillary Types**
  - distinguished by ease with which substances pass through their walls
  - structural differences that account for their greater or lesser permeability

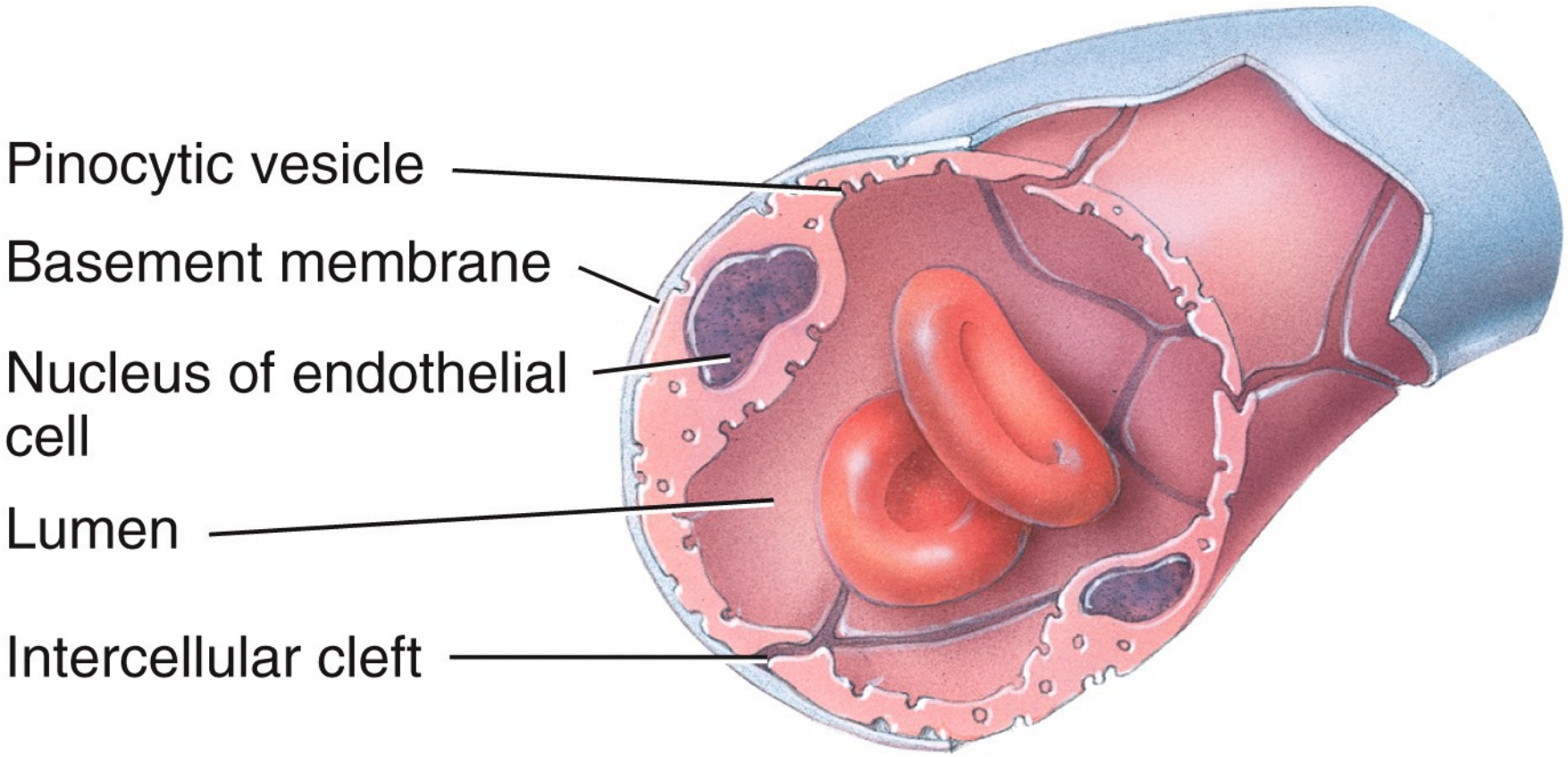
- Continuous Capillaries
- Fenestrated Capillaries
- Sinusoid Capillaries

Continuous Capillaries

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

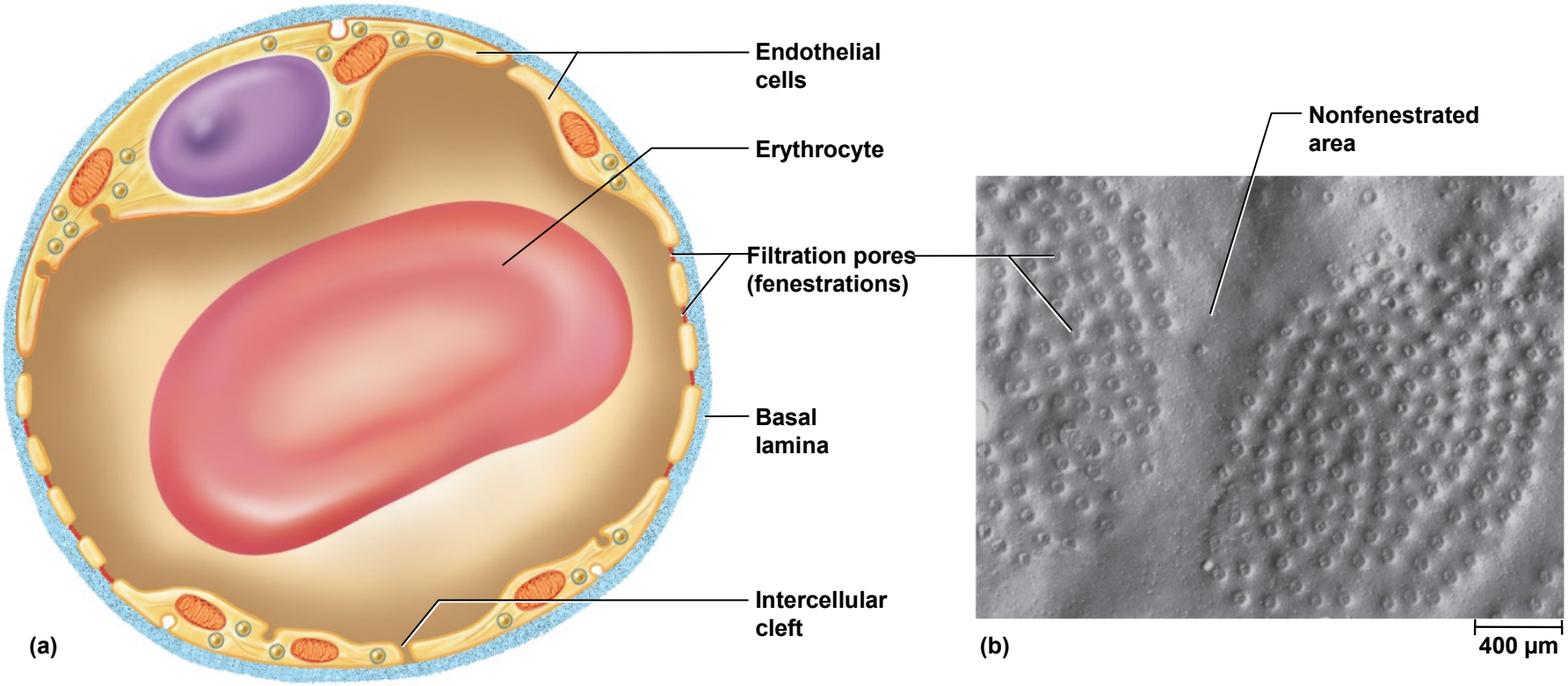
Continuous Capillary



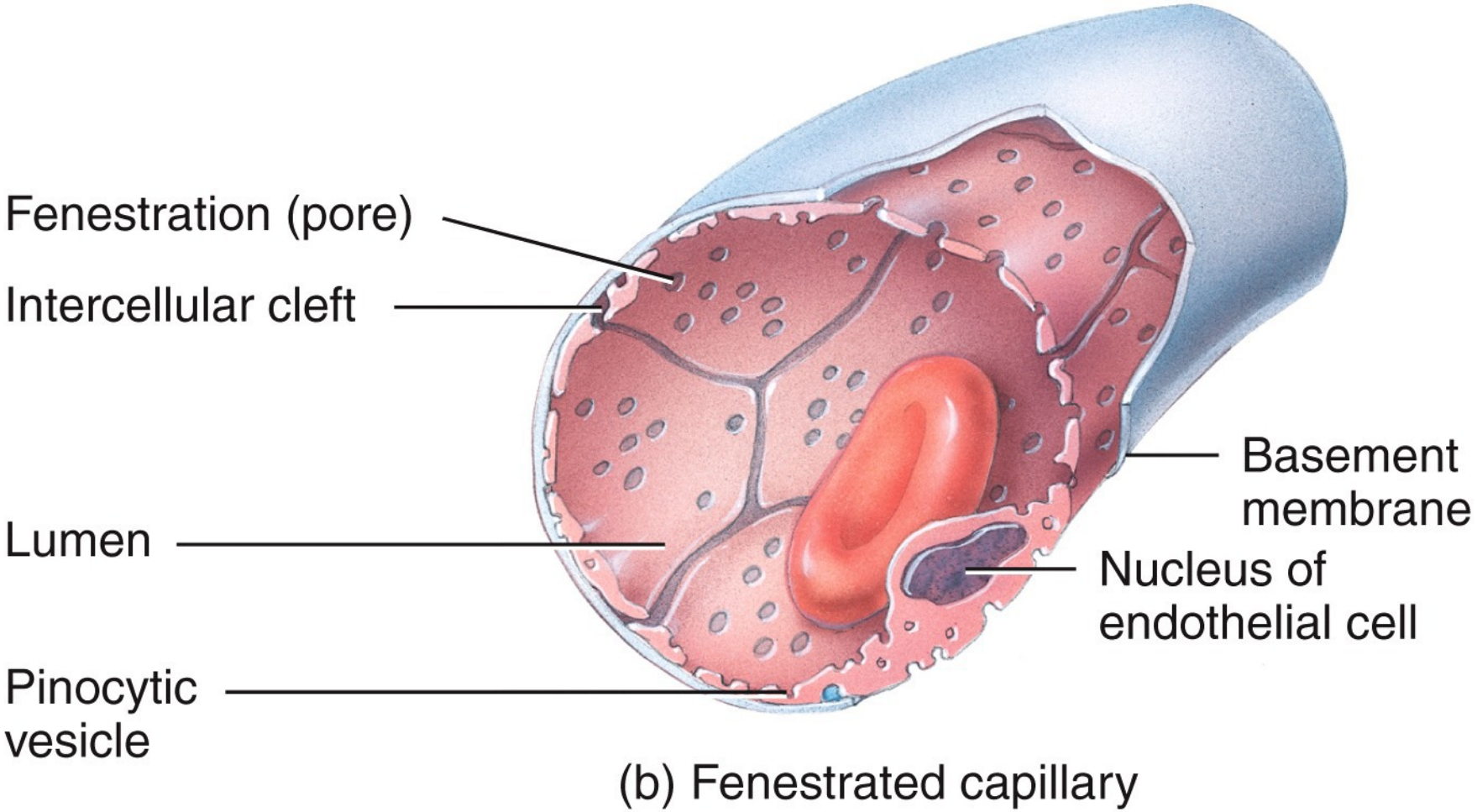


(a) Continuous capillary formed by endothelial cells

Fenestrated Capillary



b: Courtesy of S. McNutt

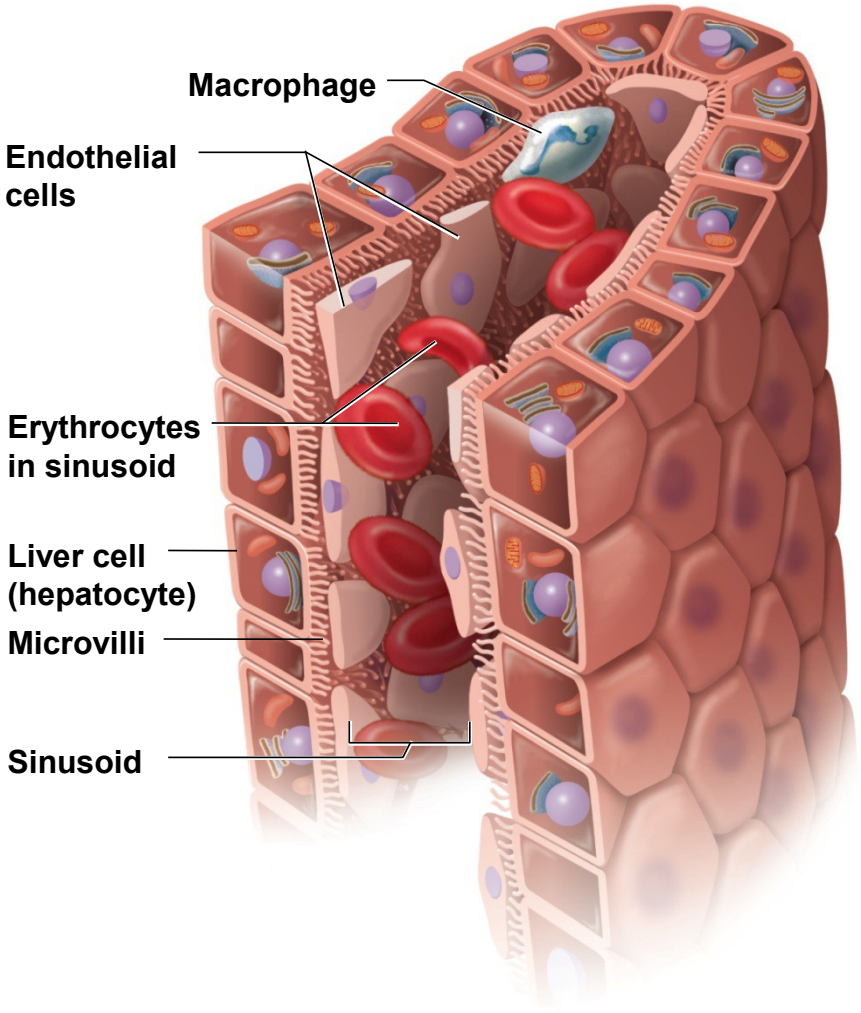


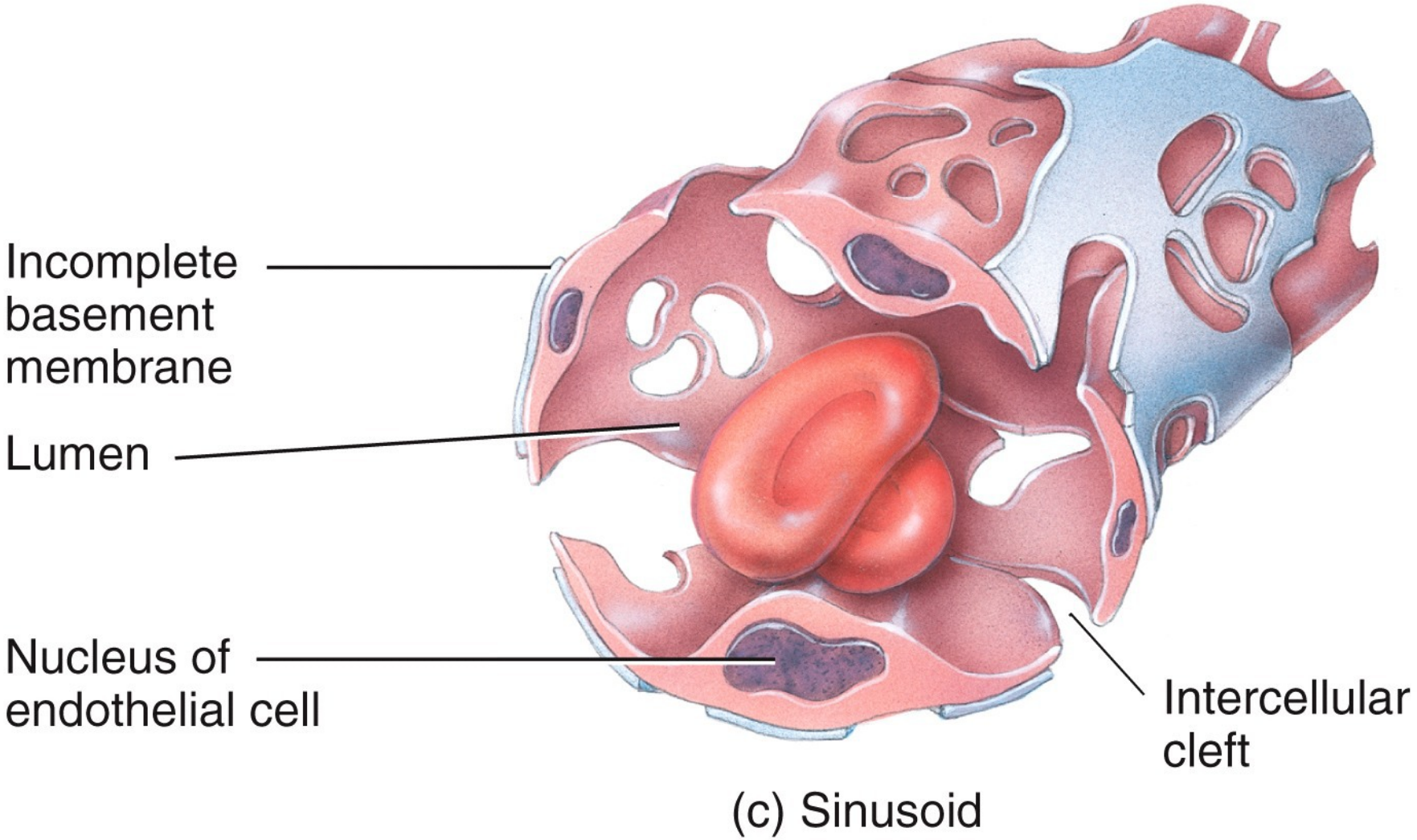
(b) Fenestrated capillary

Fenestrated Capillaries

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

Sinusoid in Liver




Incomplete basement membrane
Lumen
Nucleus of endothelial cell
Intercellular cleft

(c) Sinusoid

Sinusoids

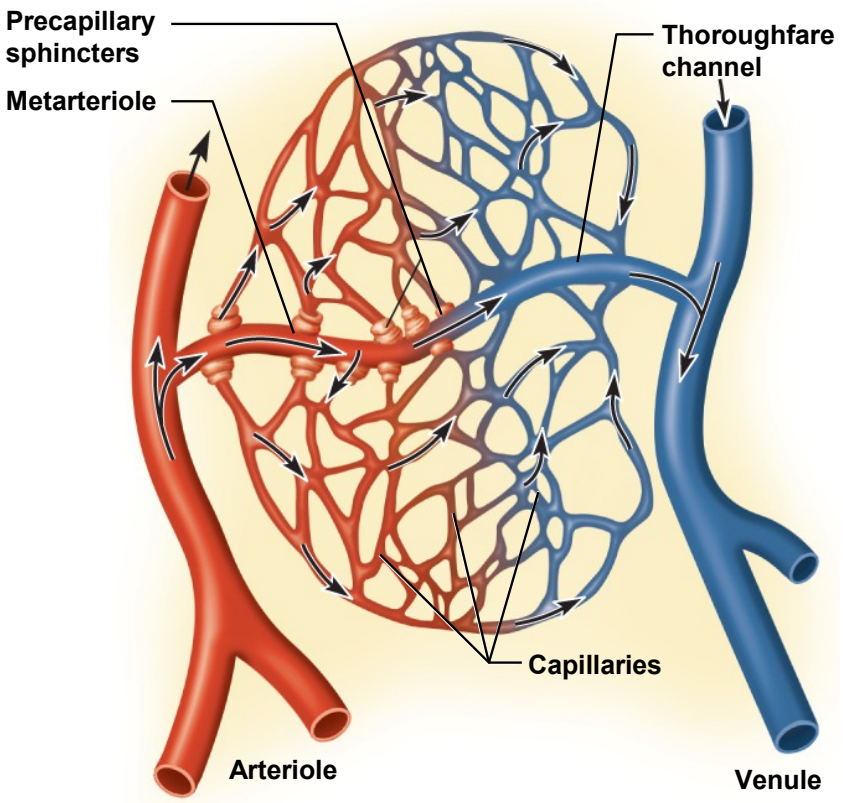
- discontinuous capillaries
- liver, bone marrow, spleen
- irregular blood-filled spaces with large fenestrations
- allow proteins (albumin), clotting factors, and new blood cells to enter the circulation

Capillary Beds

- Capillaries organized into networks called **capillary beds**
- Situated between an arteriole and venule
- A passageway connects the arteriole to the venule // two segments
  - **Metarteriole** – proximal to arteriole / no smooth muscle but smooth muscle at junction between metarteriole and capillary
    - **precapillary sphincters** control which beds are well perfused
    - when sphincters open - capillaries are well perfused with blood and engage in exchanges with the tissue fluid
    - when sphincters closed - blood bypasses the capillaries and flows through thoroughfare channel to venule
  - **Thoroughfare channel** – point beyond the metarteriole that continues through capillary bed to venule

Arterioles and Metarterioles

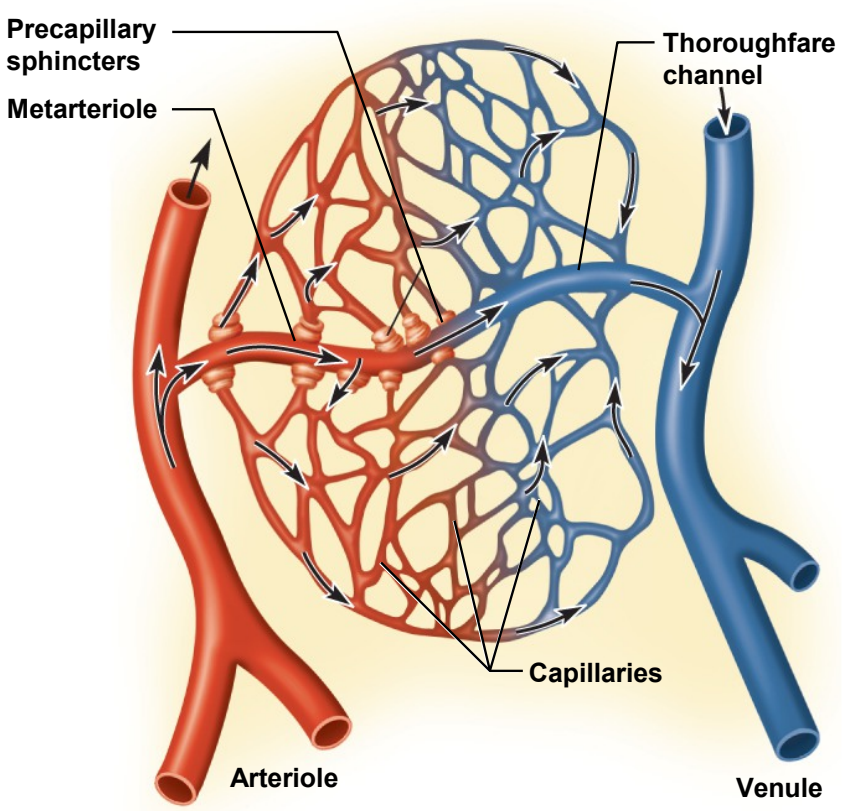
- **Arterioles**
  - Responsible for "peripheral resistance"
  - smallest arteries
  - control amount of blood flowing into various organs
  - thicker tunica media in proportion to their lumen than large arteries
  - very little tunica externa



(a) Sphincters open

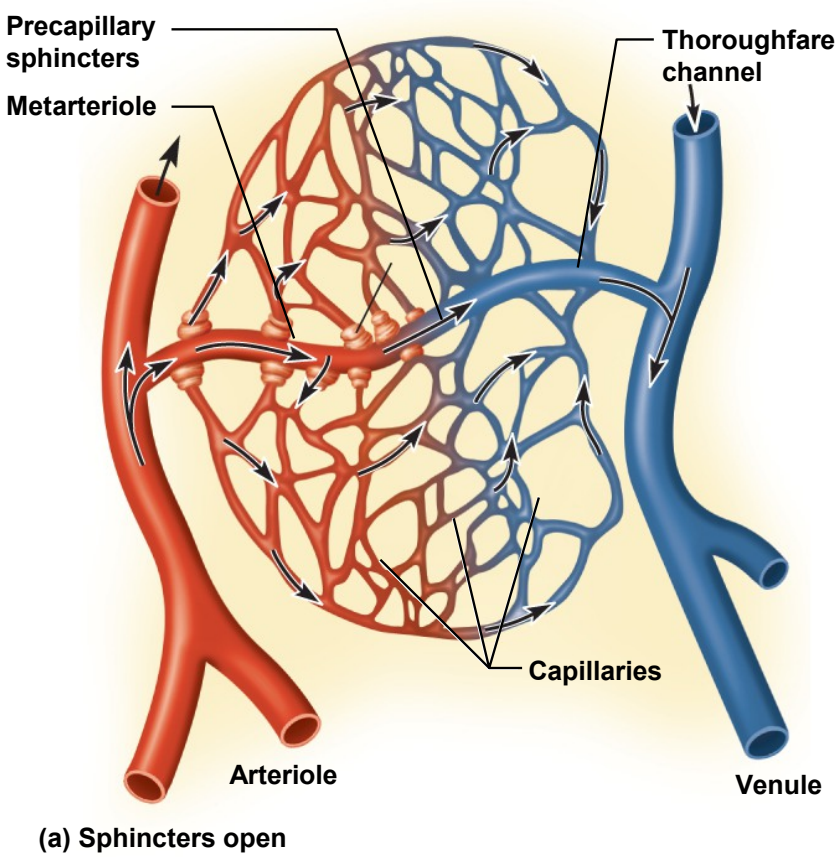
Arterioles and Metarterioles

- **Metarterioles**
  - short vessels that link arterioles to capillaries
  - muscle cells form a **precapillary sphincter** about entrance to capillary
    - constriction of these sphincters reduces or shuts off blood flow through their respective capillaries
    - diverts blood to other tissues



(a) Sphincters open

Capillary Bed Sphincters Open



(a) Sphincters open

approximately one billion capillaries

no cell more than 40 to 80 micrometers from capillary

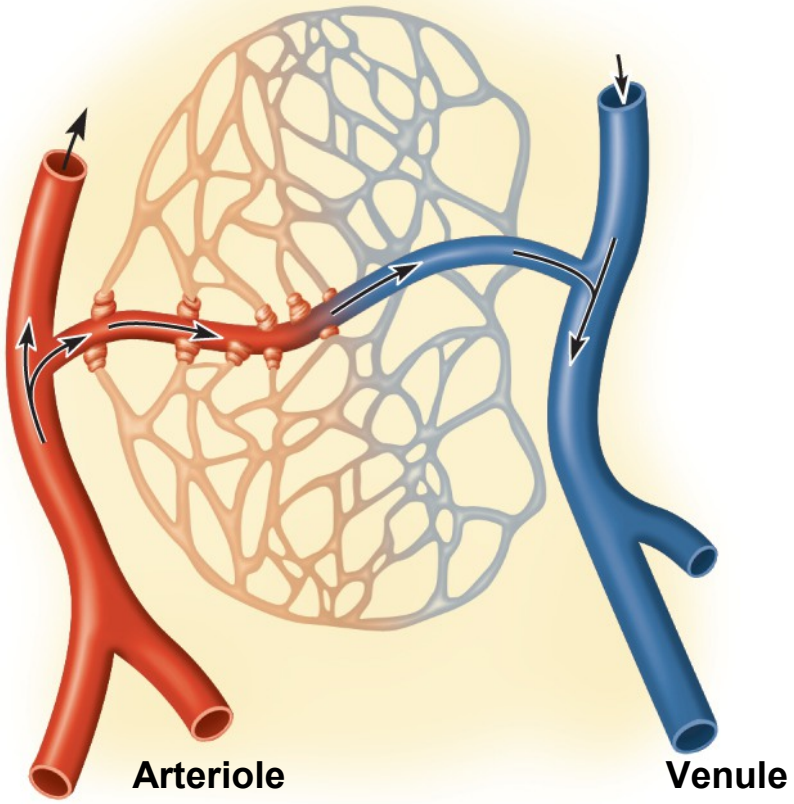
four to six cell widths

Pre-capillary sphincters are not controlled by vasomotor center

Pre-capillary sphincters regulated by “local regulation”

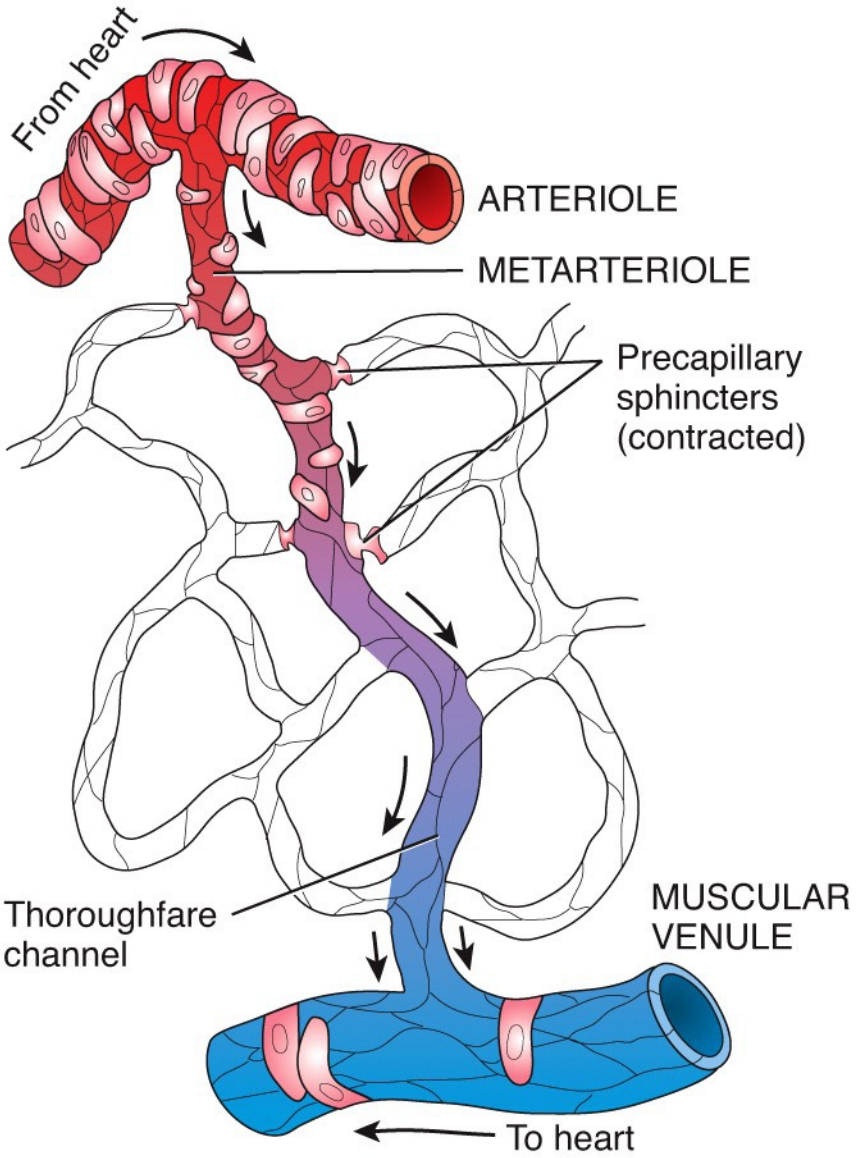
when sphincters are open, the capillaries are well perfuse /// three-fourths of the capillaries of the body are normally shut down

Capillary Bed Sphincters Closed

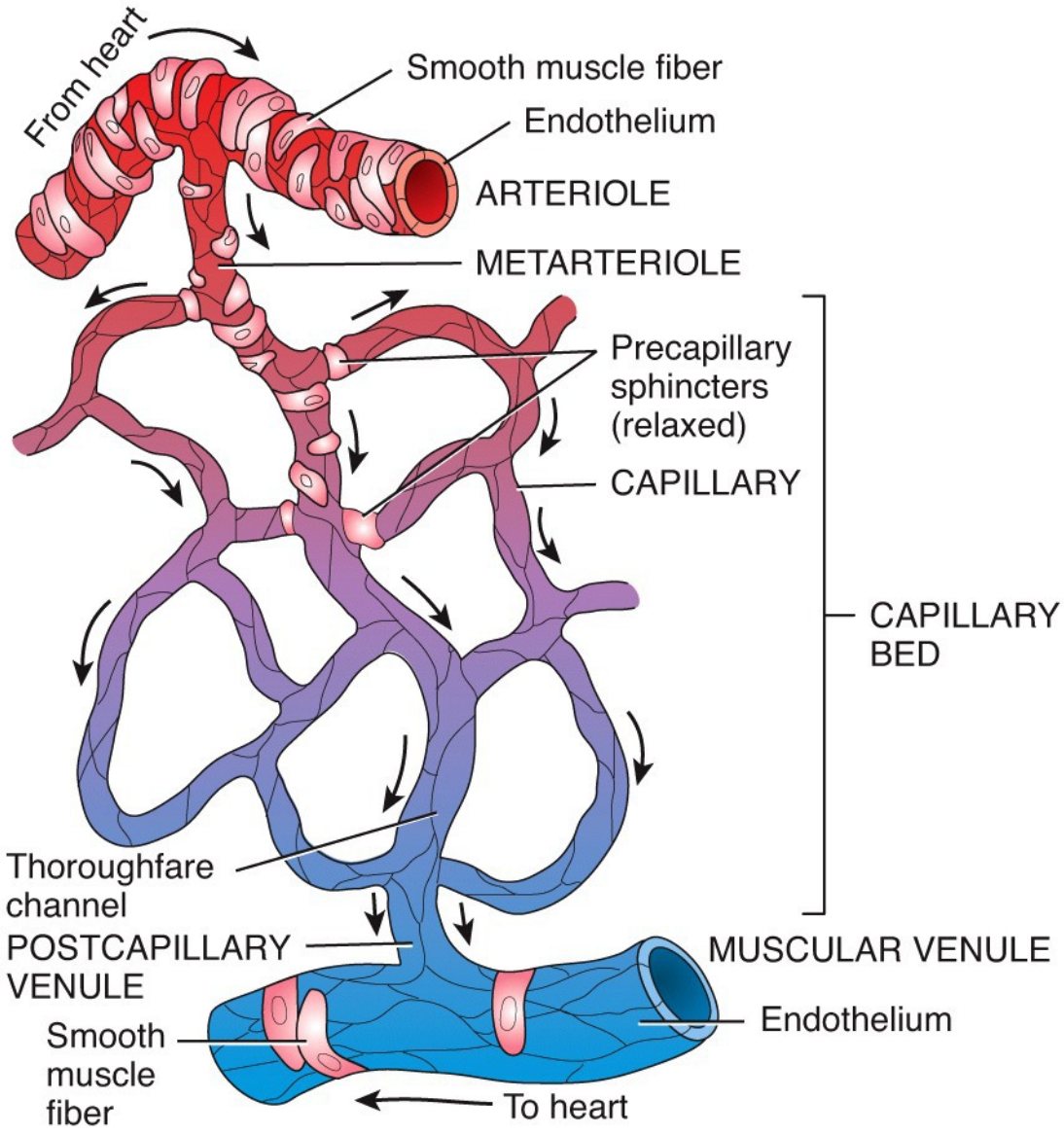


(b) Sphincters closed

when the sphincters are closed, little to no blood flow into capillary bed (e.g. when skeletal muscles at rest)



(b) Sphincters contracted: blood flowing through thoroughfare channel



(a) Sphincters relaxed: blood flowing through capillaries

Autoregulation

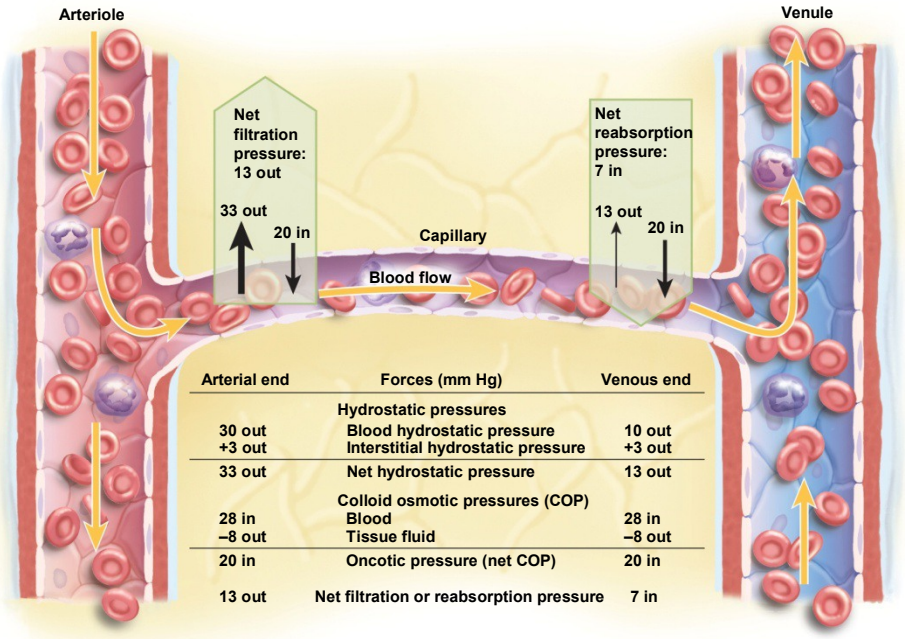
- Autoregulation = Local Control = the ability of the tissues to regulate its own blood supply

  - Metabolic Theory of Auto-Regulation

    - This principle applies to the capillary beds
    - If tissue is not adequately perfused with blood then *carbon dioxide accumulate* and stimulates vasodilation which increases perfusion
    - Bloodstream delivers oxygen and removes carbon dioxide
    - When carbon dioxide levels drop then smooth muscle constricts
    - Why does this make sense? Explain.

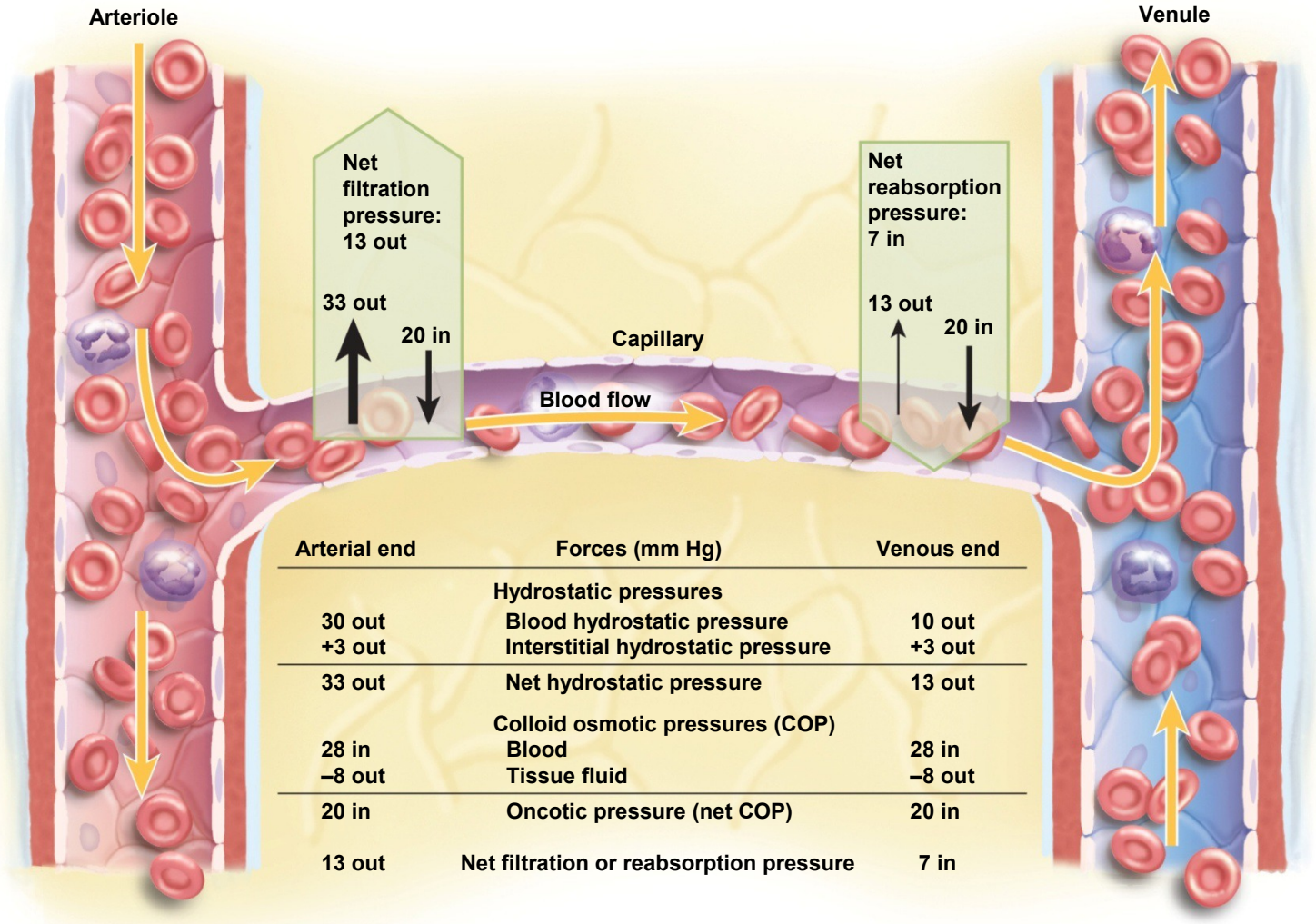
Capillary Filtration and Reabsorption

- **capillary filtration** at arterial end
- **capillary reabsorption** at venous end
- Variations within organ type
  - Location
    - Glomeruli of kidney
      - devoted to filtration
    - Alveolar capillary of lungs
      - devoted to absorption
  - activity or trauma
    - increases filtration



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

Capillary Filtration and Reabsorption



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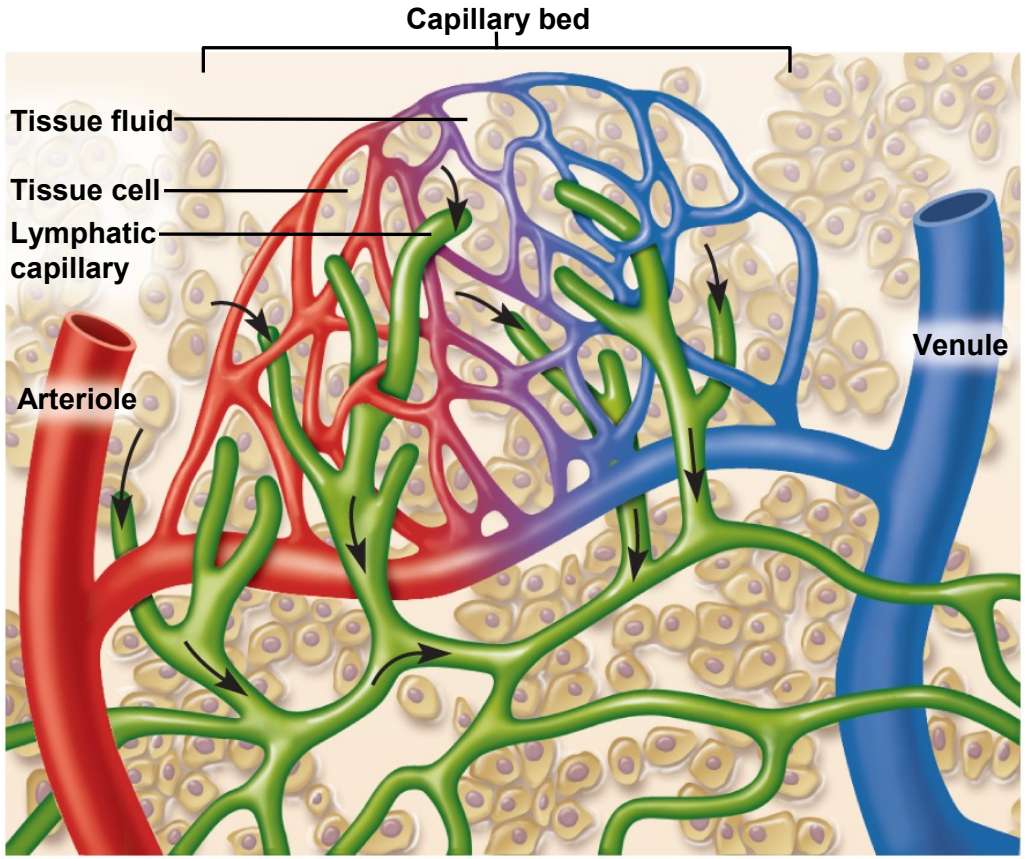
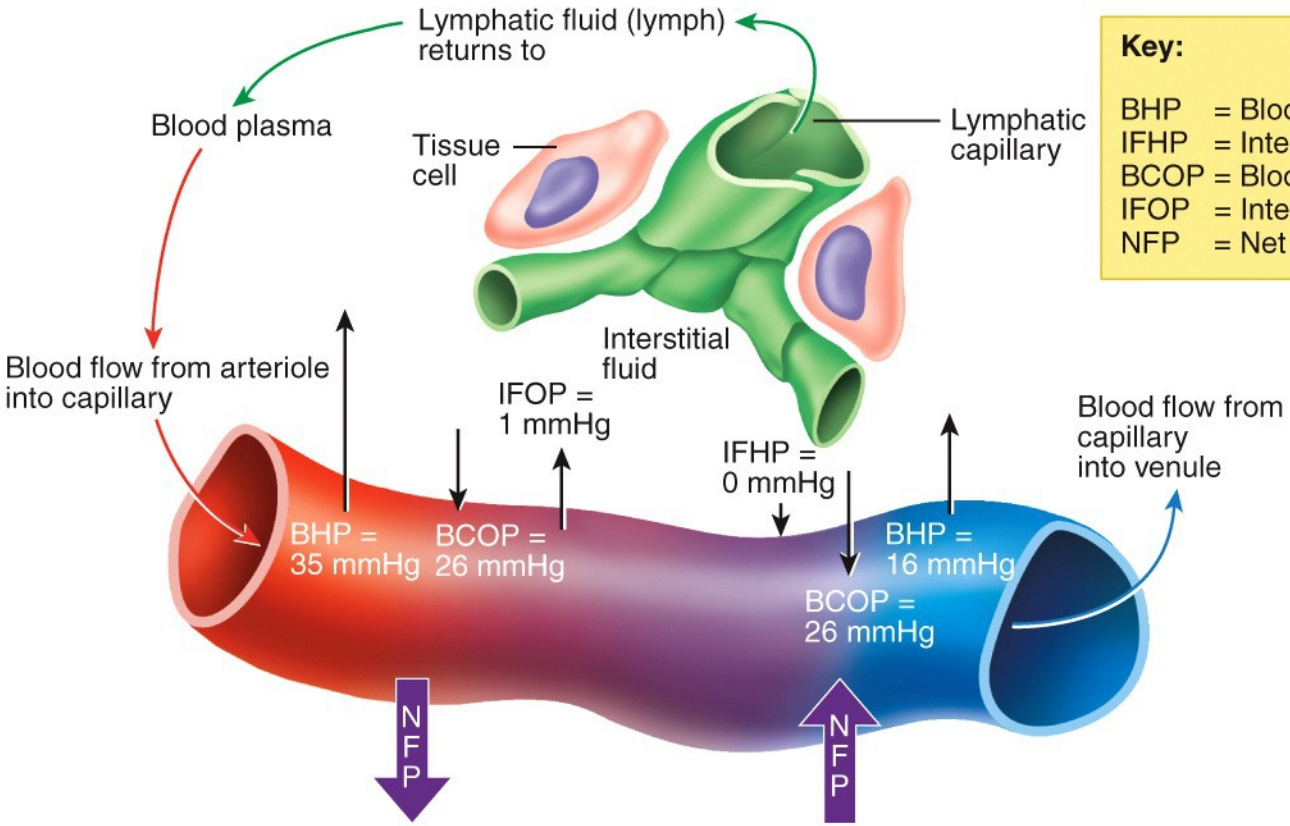
Net “6 mm Hg” out. Where does the fluid go?

Structure of a Capillary Bed with Lymphatic Capillaries and Their Afferent Vessels



How much fluid is not recovered at the end of the capillary bed?



Key:

BHP = Blood hydrostatic pressure
IFHP = Interstitial fluid hydrostatic pressure
BCOP = Blood colloid osmotic pressure
IFOP = Interstitial fluid osmotic pressure
NFP = Net filtration pressure

Net filtration at arterial end of capillaries (20 liters per day)

Net reabsorption at venous end of capillaries (17 liters per day)

Net filtration pressure (NFP) = (BHP + IFOP) − (BCOP + IFHP)

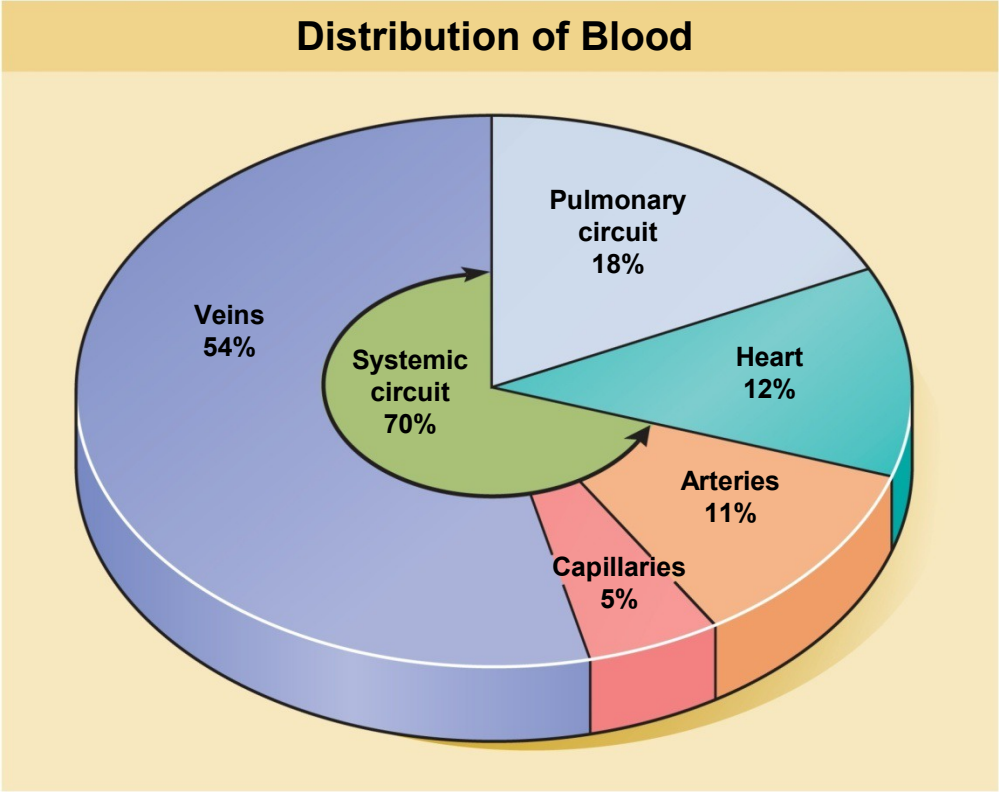
Pressures promoting filtration

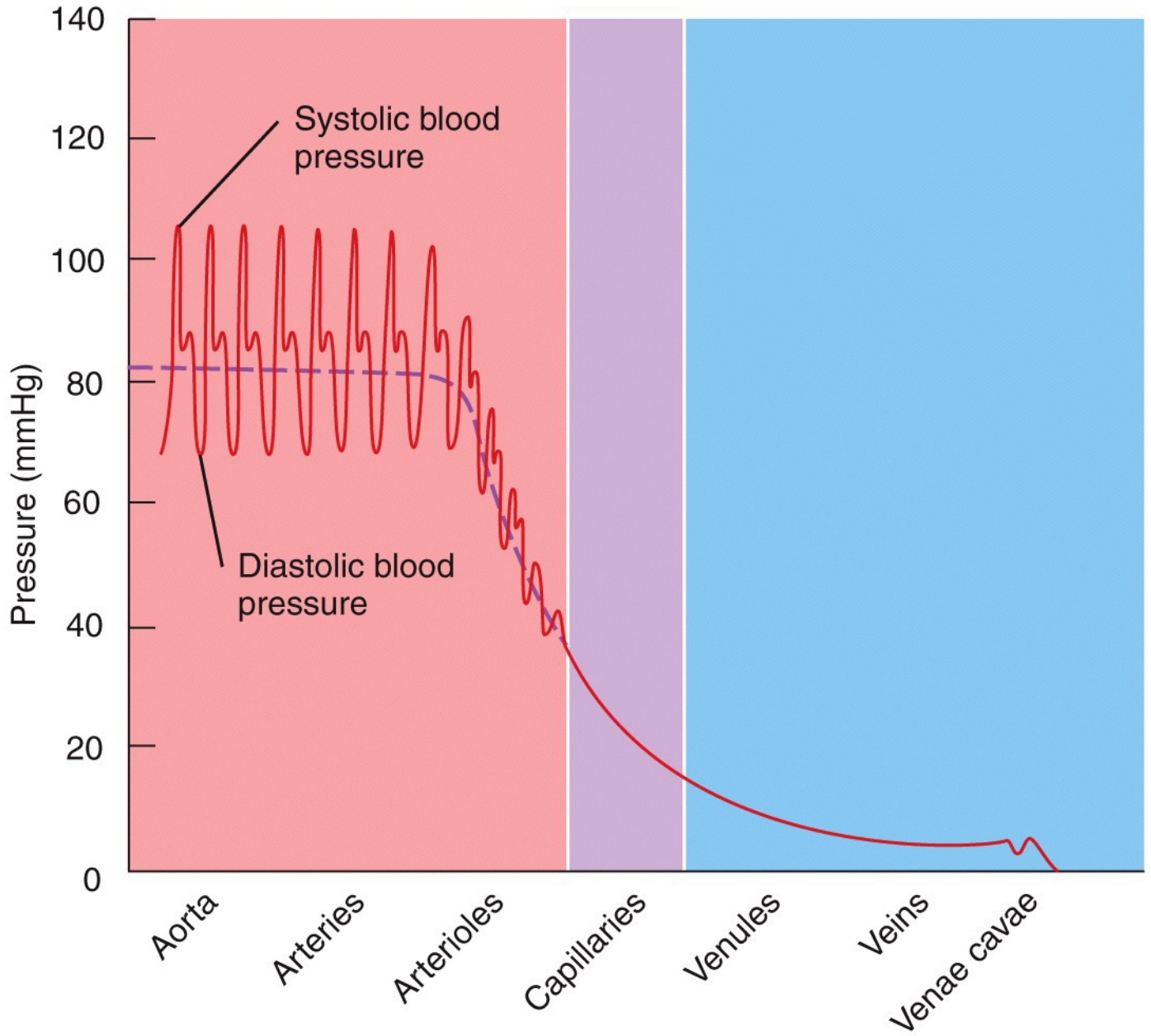
Pressures promoting reabsorption

	Arterial end	Venous end
	NFP = (35 + 1) − (26 + 0) = 10 mmHg	**NFP** = (16 + 1) − (26 + 0) = −9 mmHg
Result	Net filtration	Net reabsorption

Veins (The Capacitance Vessels)

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




140
120
100
80
60
40
20
0
Pressure (mmHg)
Systolic blood pressure
Diastolic blood pressure
Aorta
Arteries
Arterioles
Capillaries
Venules
Veins
Venae cavae

Venules & Veins

- **postcapillary venules** – smallest veins
  - even more porous than capillaries
  - also exchange fluid with surrounding tissues
  - tunica interna with a few fibroblasts and no muscle fibers
  - most leukocytes emigrate from the bloodstream through venule walls
- **muscular venules** – up to 1 mm in diameter
  - 1 or 2 layers of smooth muscle in tunica media
  - have a thin tunica externa

Venules & Veins

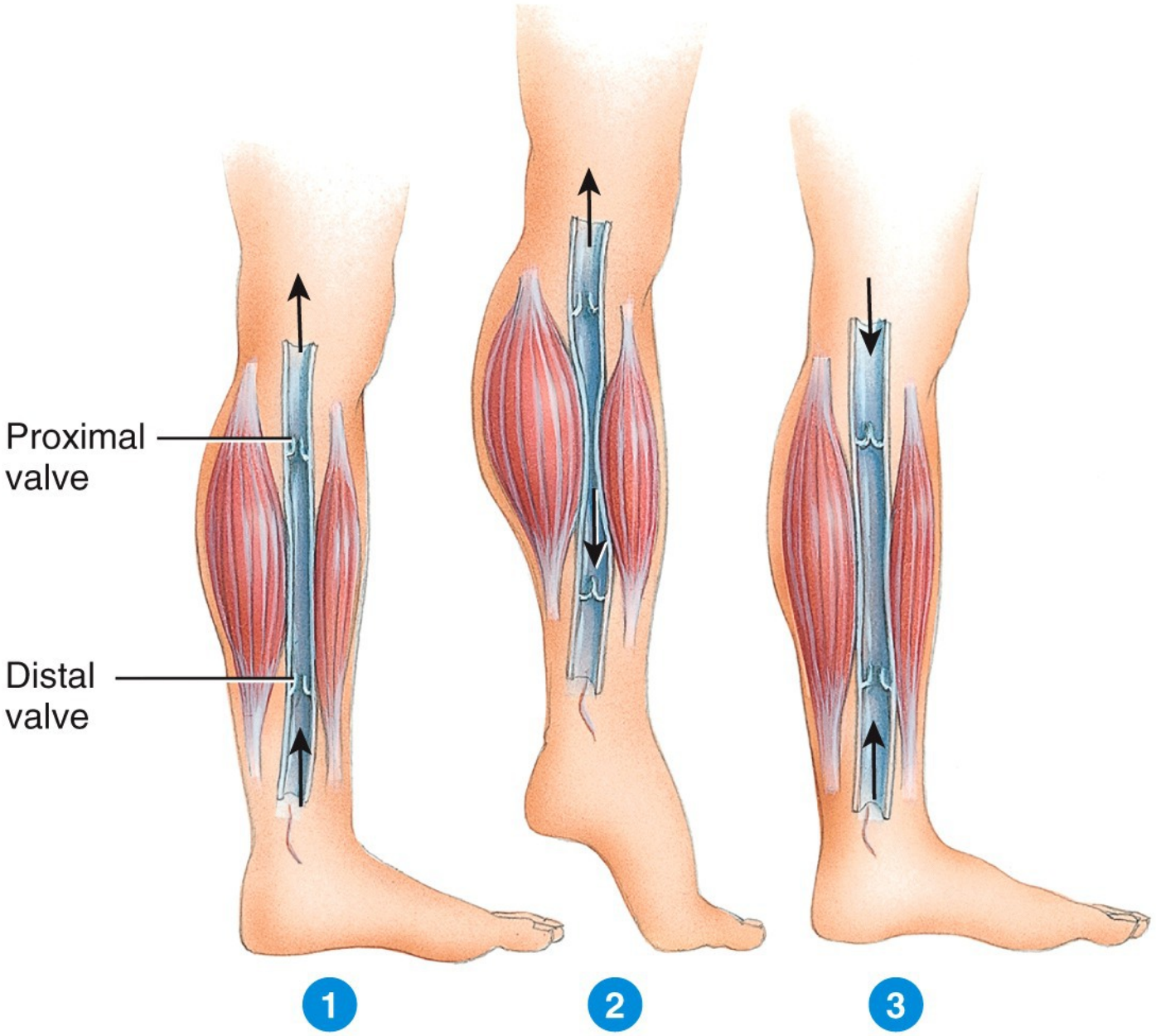
- **medium veins** – up to 10 mm in diameter
  - thin tunica media and thick tunica externa
  - tunica interna in this area forms **venous valves**
  - **varicose veins** result in part from the failure of these valves
- **large veins** – larger than 10 mm
  - some smooth muscle in all three tunics
  - thin tunica media with moderate amount of smooth muscle
  - tunica externa is thickest layer
    - contains longitudinal bundles of smooth muscle
  - Examples /// venae cavae, pulmonary veins, internal jugular veins, and renal veins

Sinuses

- Venous sinuses
  - veins with extremely thin walls
  - large lumen, and no smooth muscle
    - dural venous sinus in the brain
    - coronary sinus in the heart
  - *These vessels are not capable of vasomotion*
  - *Function as blood reservoirs*

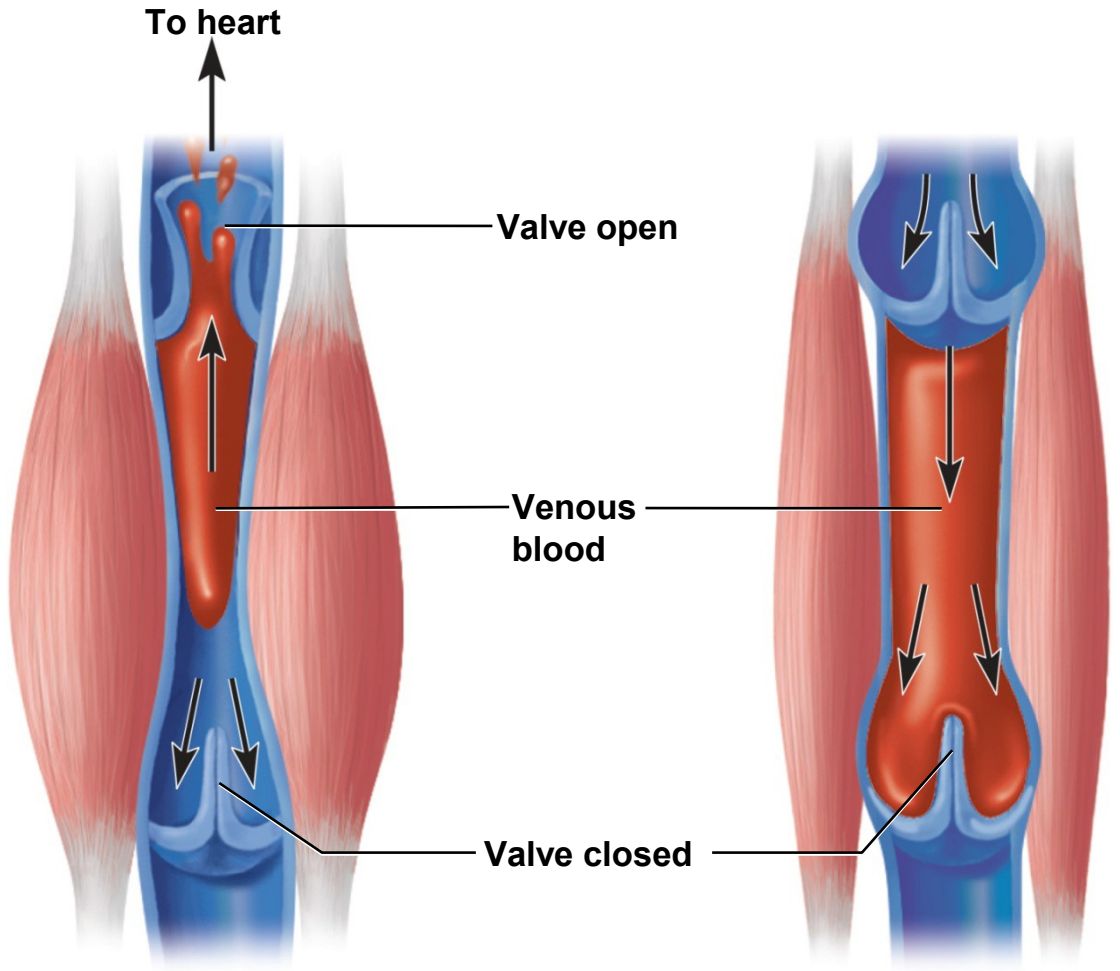
Mechanisms of Venous Return

- **Venous return** – the flow of blood back to the heart
  - pressure gradient
    - blood pressure is the most important force in venous return
    - 7-13 mm Hg venous pressure towards heart
    - venules (12-18 mm Hg) to **central venous pressure –** point where the venae cavae enter the heart (~5 mm Hg)
  - skeletal muscle pump **–** occurs in the limbs
    - contracting muscle compressed vein between muscles to move blood towards heart
    - deep veins in legs have one way valves
    - veins in arm also have valves, but fewer than in legs


Proximal valve
Distal valve
1
2
3

Skeletal Muscle Pump

Propels venous blood back toward the heart



Other Mechanisms of Venous Return

- gravity drains blood from head and neck
- thoracic (respiratory) pump
  - inhalation - thoracic cavity expands and thoracic pressure decreases, abdominal pressure increases forcing blood upward /// central venous pressure fluctuates
  - 2mm Hg- inhalation, 6mm Hg-exhalation
  - blood flows faster with inhalation
- “cardiac suction” caused by expanding atria

Venous Return and Physical Activity

- exercise increases venous return in many ways
  - heart beats faster, harder increasing CO and BP
  - vessels of skeletal muscles, lungs, and heart dilate and increase flow
  - increased respiratory rate, increased action of thoracic pump
  - increased skeletal muscle pump

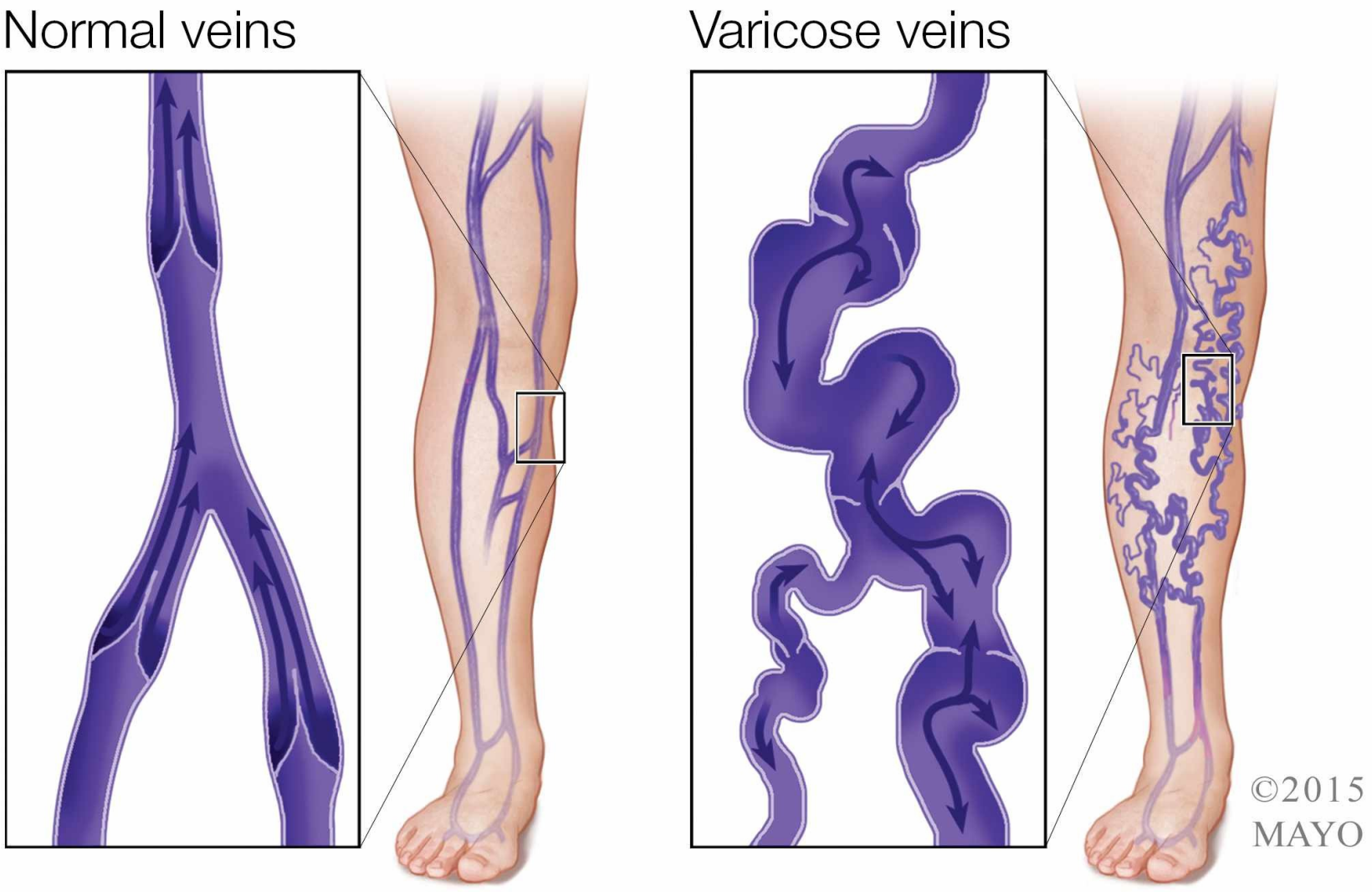
Venous Return and Physical Activity

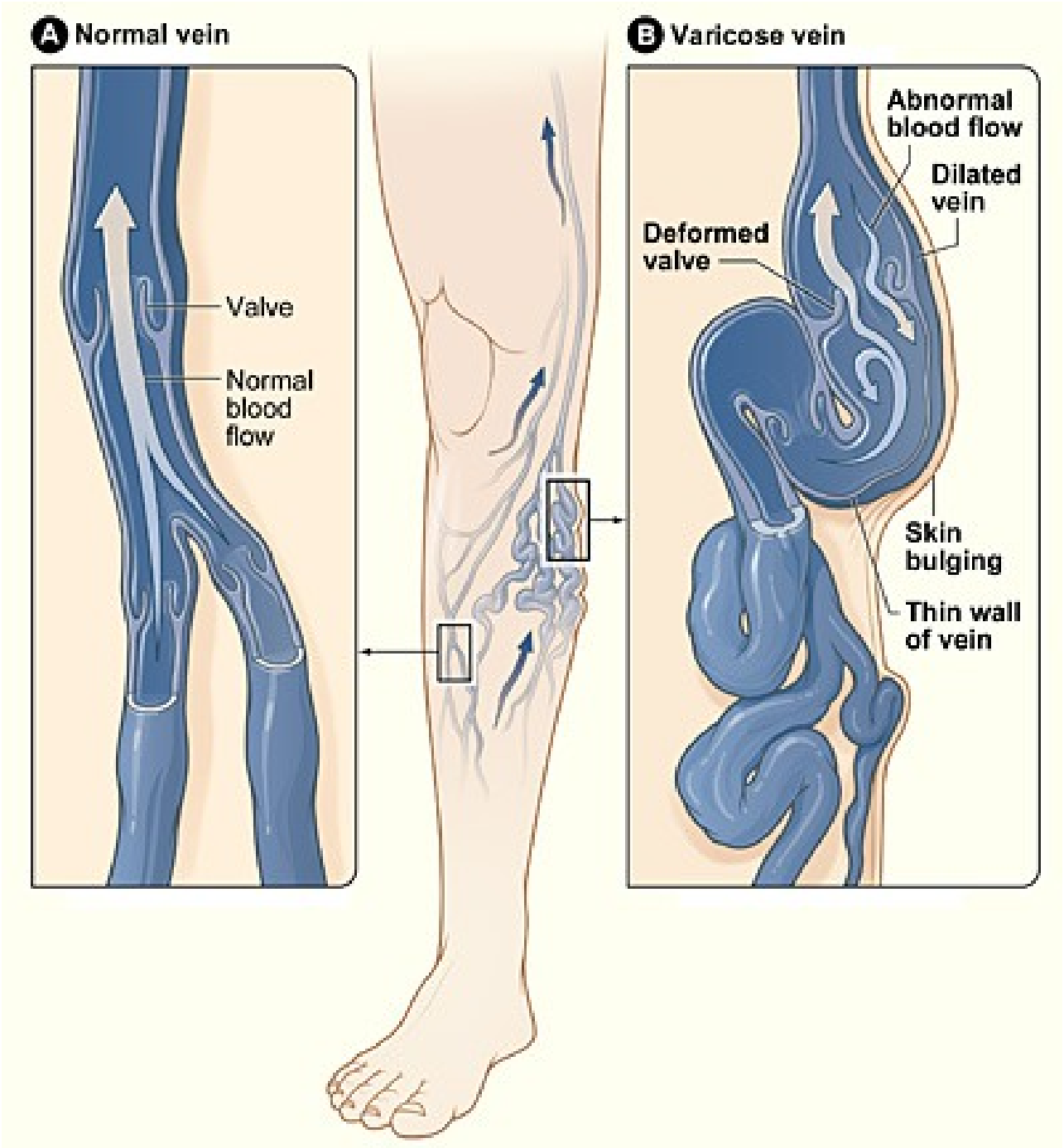
- venous pooling occurs with inactivity
  - venous pressure not great enough to force blood upward
  - with prolonged standing, may be low enough to cause dizziness or fainting
  - prevented by tensing leg muscles to activate skeletal muscle pump
  - jet pilots wear pressure suits

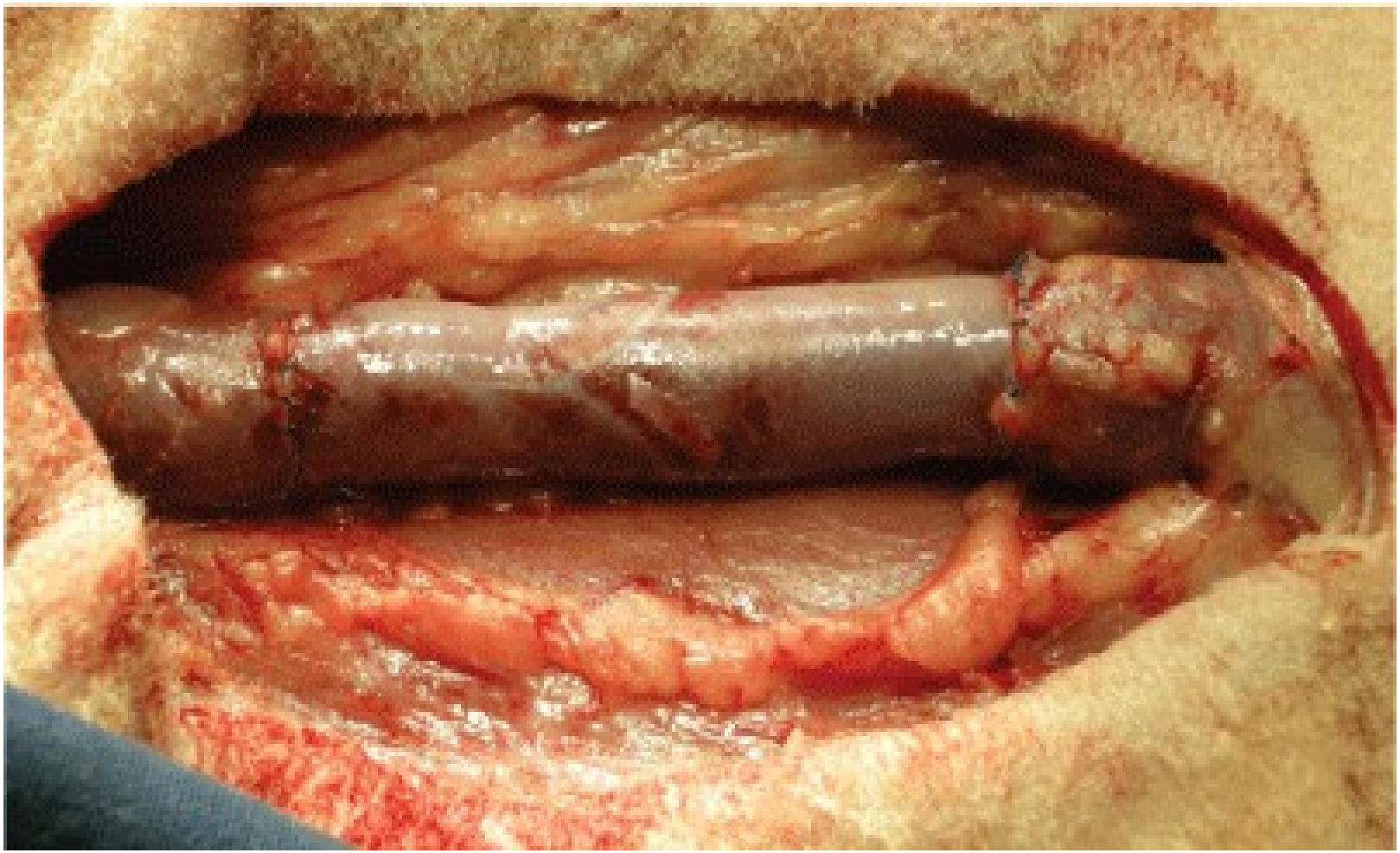
Varicose Veins

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

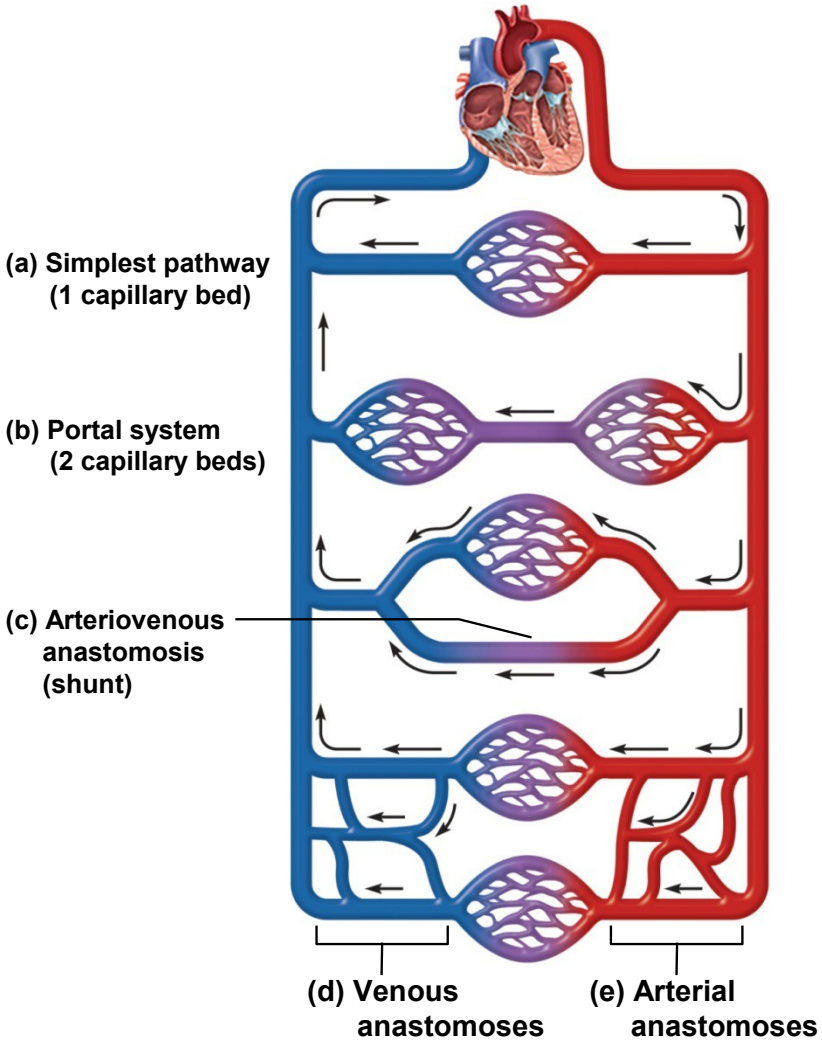
Normal and Varicose Veins




A Normal vein
Valve
Normal blood flow
B Varicose vein
Abnormal blood flow
Dilated vein
Deformed valve
Skin bulging
Thin wall of vein



Circulatory Routes



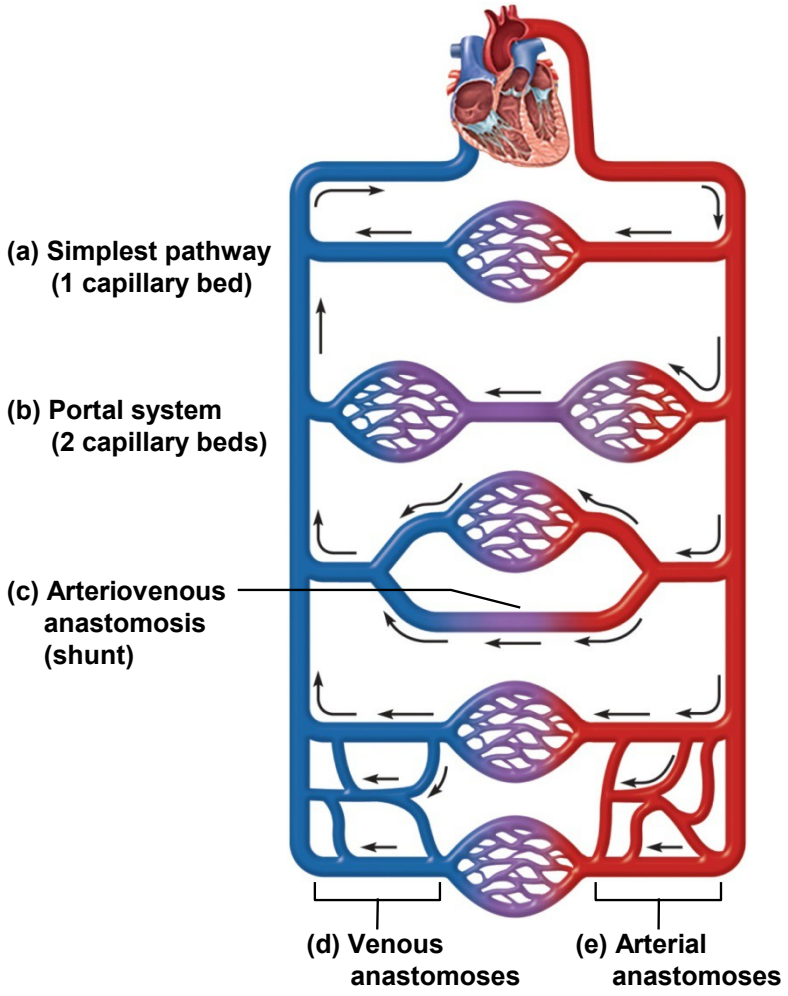
- Most common route
  - heart → arteries → arterioles → capillaries → venules → veins
  - passes through only **one network of capillaries** from the time it leaves the heart until the time it returns
- **Portal system** // blood flows through **two capillary** networks before returning to heart
  - artery → capillary → portal vein → capillary → vein
  - Three locations:
    - 1) between hypothalamus and anterior pituitary
    - 2) kidneys (peritubular capillaries)
    - 3) between intestines and liver

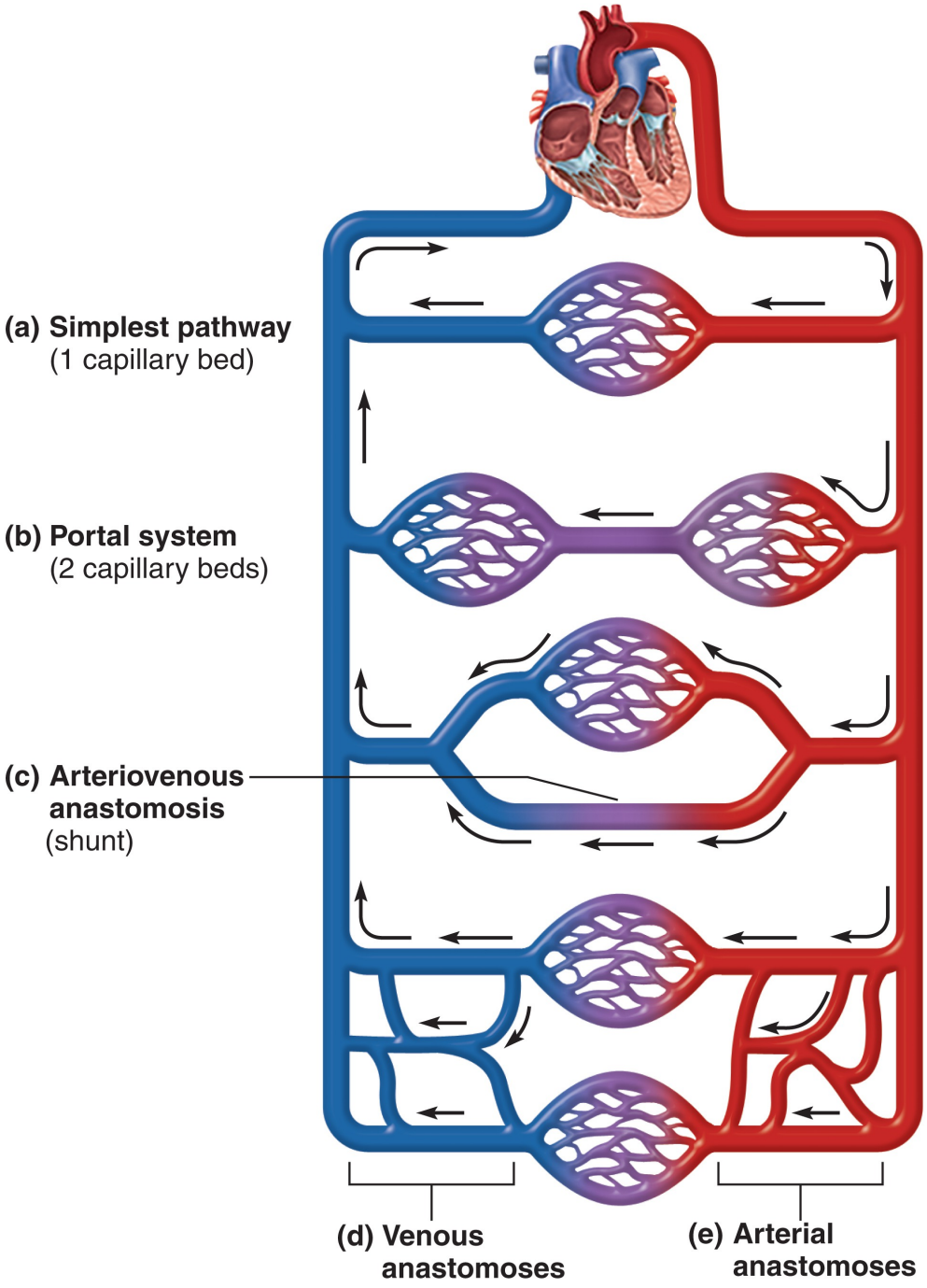
- anastomosis – the point where two blood vessels merge

- **arteriovenous anastomosis** (shunt)
  - artery flows directly into vein bypassing capillaries

- **venous anastomosis**
  - most common
  - one vein empties directly into another
  - reason vein blockage less serious than an arterial blockage

- **arterial anastomosis**
  - two arteries merge
  - provides collateral (alternative) routes of blood supply to a tissue
  - coronary circulation and around joints

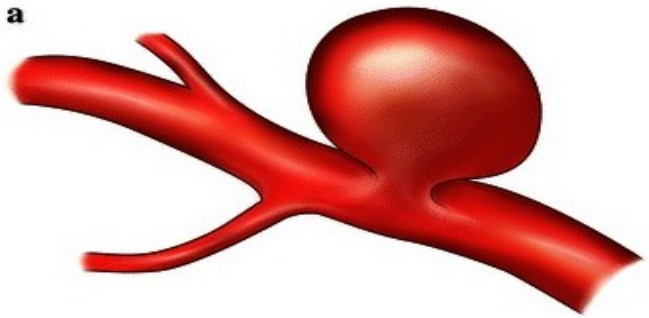




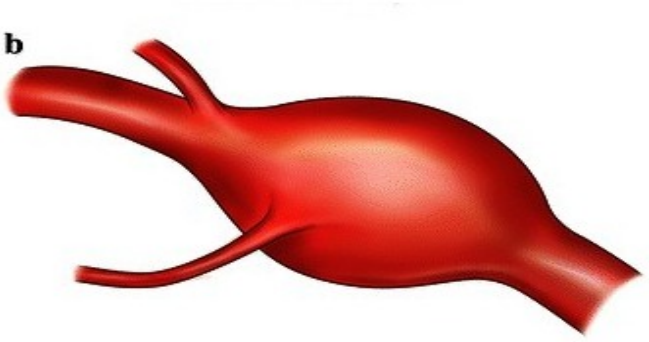
Aneurysm

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

Aneurysm



Saccular Aneurysm



Fusiform Aneurysm