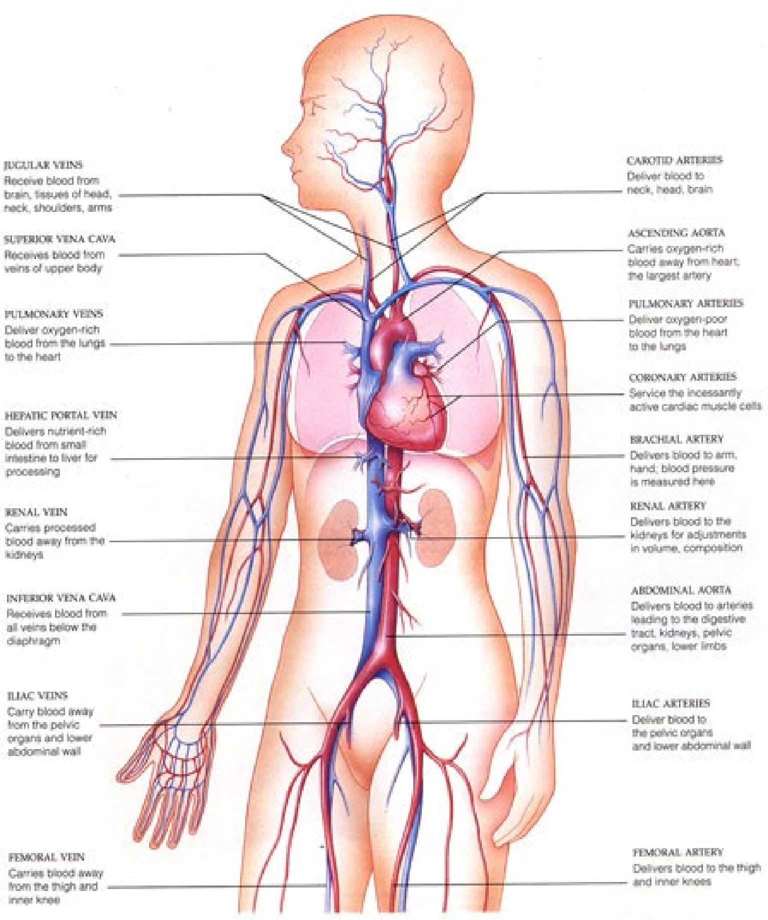
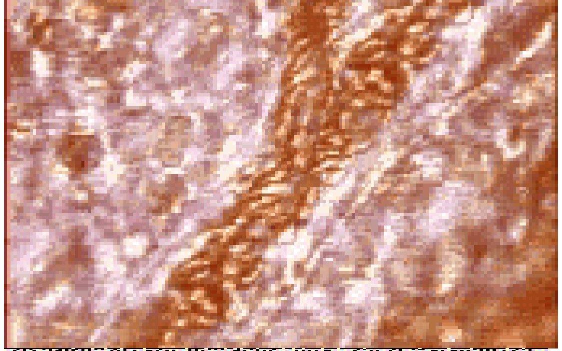
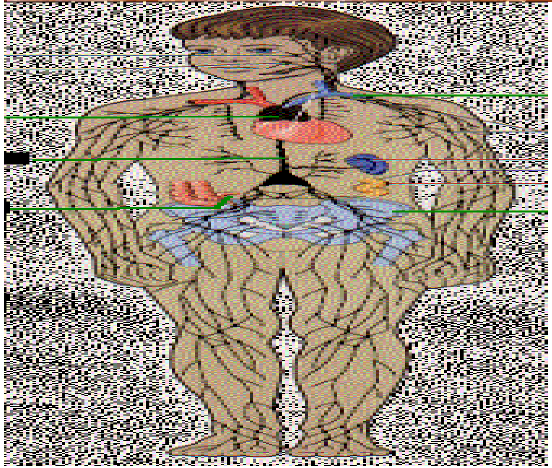
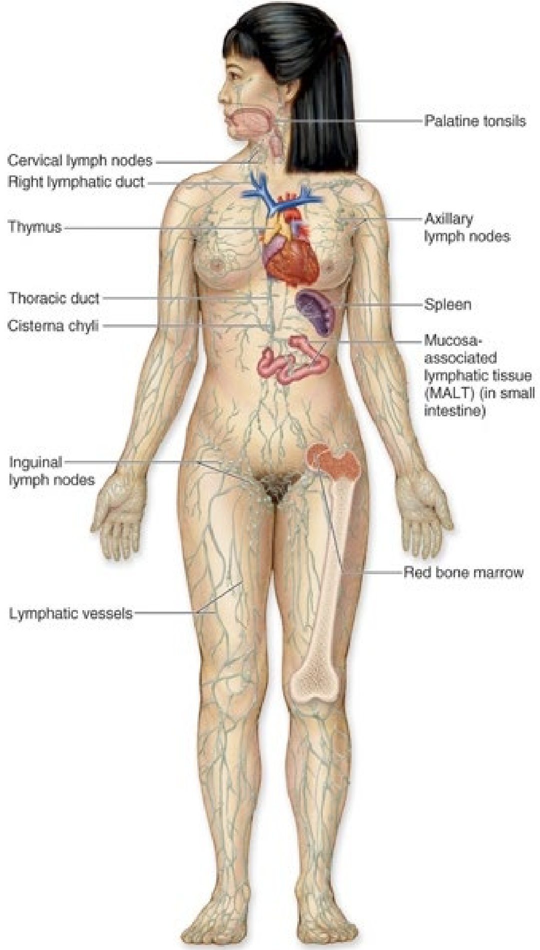


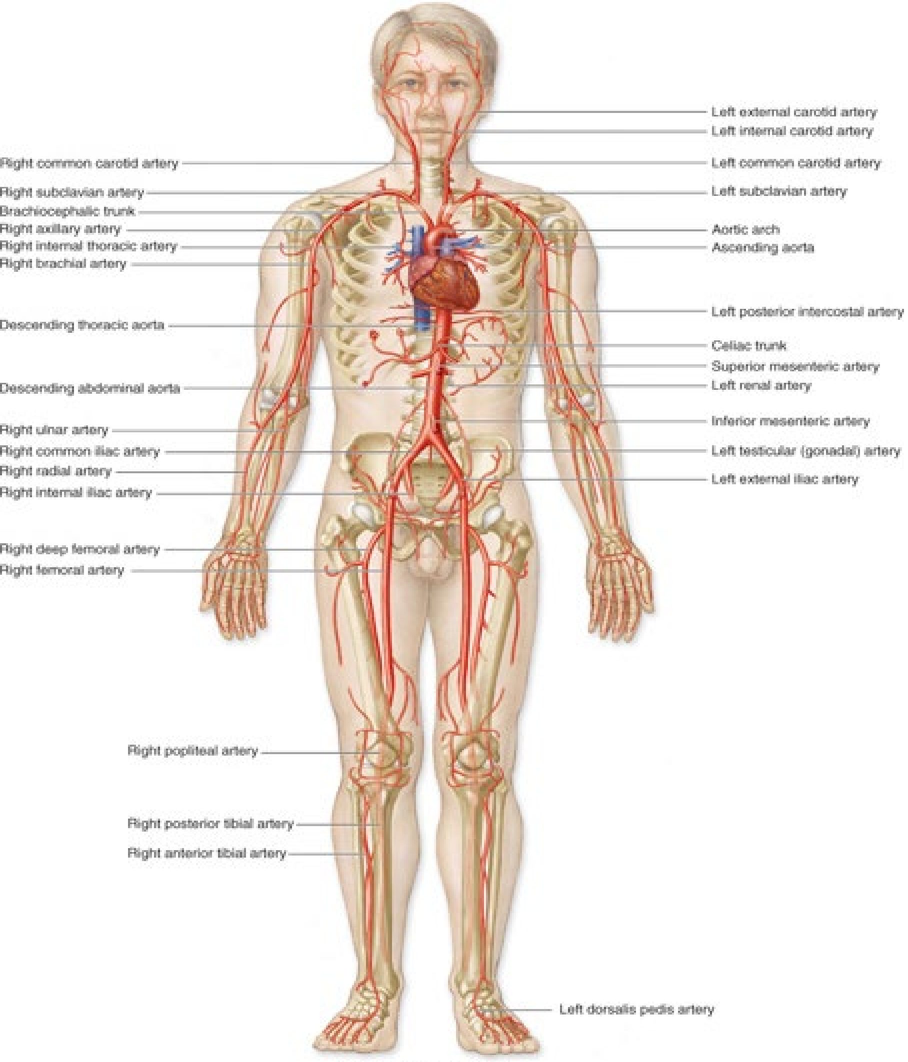
Human circulatory system, showing some of the major blood vessels. Arteries are color-coded red; veins are blue.



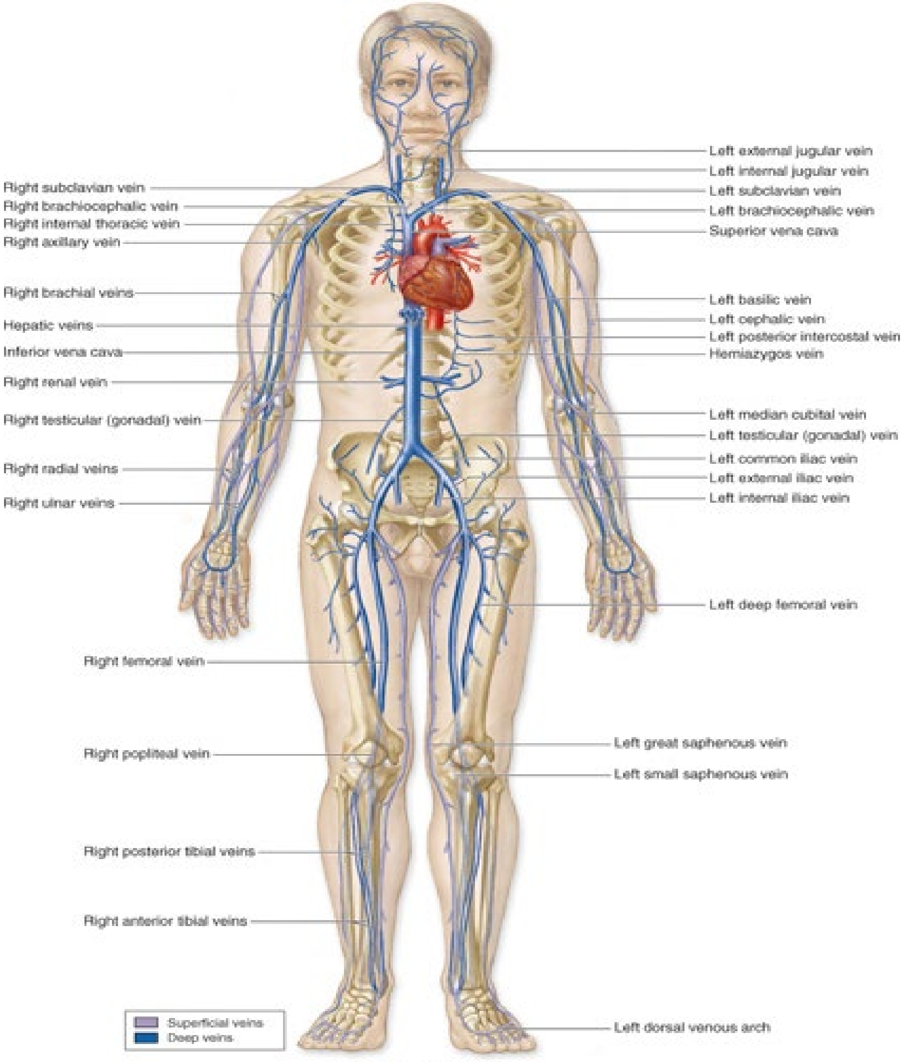


VASC



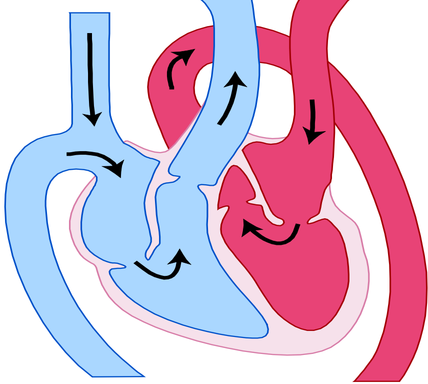


(a) Arteries, anterior view



(b) Veins, anterior view

The Heart



Pathway of blood flow:

Inferior vena cava → RIGHT ATRIUM ← Superior vena cava

RIGHT ATRIUM
↓
Tricuspid valve
↓
RIGHT VENTRICLE
↓
Pulmonary semilunar valve
↓
Pulmonary arteries
↓
Lungs
↓
Pulmonary veins
↓
LEFT ATRIUM
↓
Bicuspid valve
↓
LEFT VENTRICLE
↓
Aortic semilunar valve
↓
Aorta

Aorta → Arteries → Capillaries → Veins → Inferior vena cava

Deoxygenated

Oxygenated

Angiogenesis is the physiological process involving the growth of new blood vessels from pre-existing vessels

- **Angiogenesis takes place:**
  - As the number of vessels to a region increases
  - When existing vessels enlarge
  - When a heart vessel becomes partly occluded
  - Routinely in people in high altitudes, where oxygen content of the air is low
  - New tissue or extended tissue [abnormal as cancer]
  - wound healing and in granulation tissue

Vasculogenesis **is the de novo formation of blood vessels during embryogenesis.**

Hemangioblast angiogenic precursors develop and migrate to the sites of vascularization.

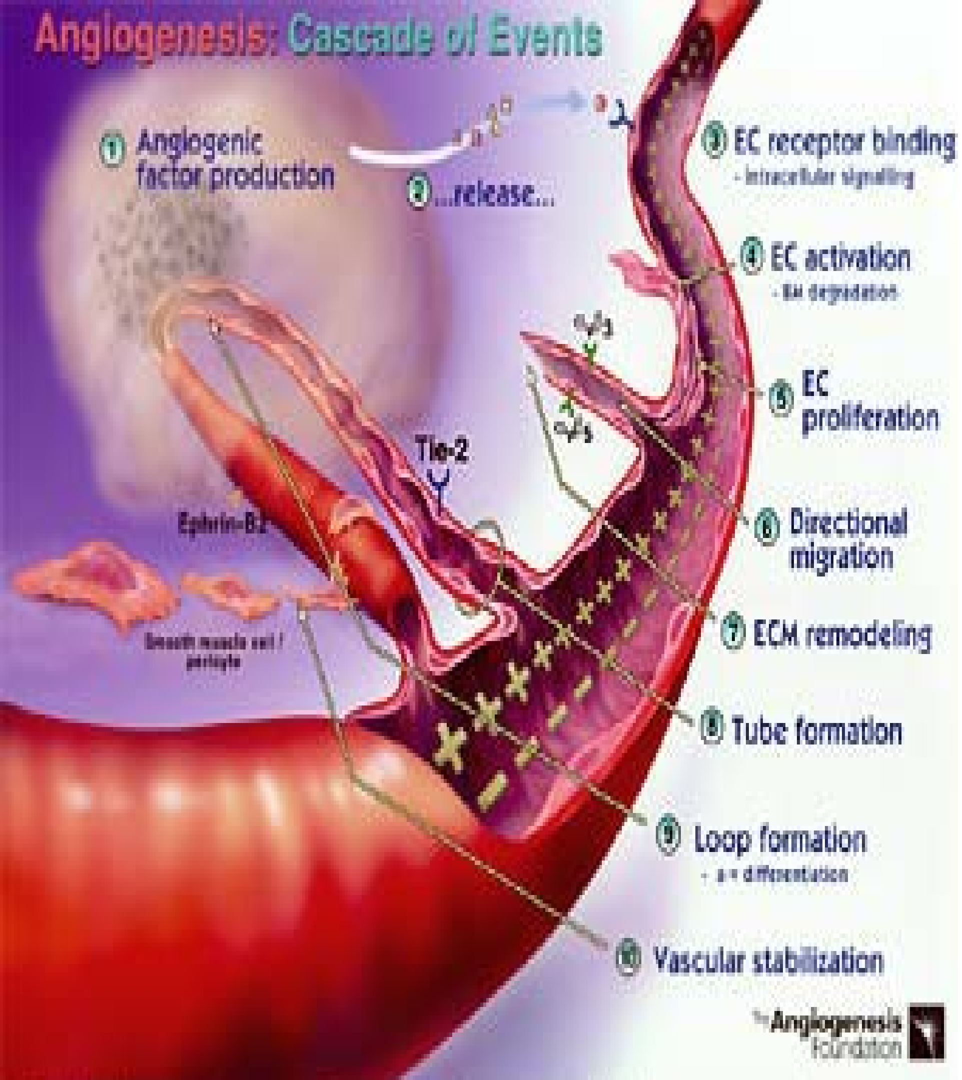
- **These differentiate into endothelial cells that associate to form a primitive vascular plexus;**
- **with time and the influence of local genetic, metabolic, and hemodynamic factors, this network of cells remodels (through pruning and/or vessel enlargement) into the definitive vascular system**

- **The various isoforms of vascular endothelial growth factor (VEGF) are the primary growth factors involved in this process.**
- **Subsequent stabilization of the endothelial tubes during development (and induction of endothelial cell quiescence) also critically requires the recruitment of pericytes and smooth muscle cells, a process that involves *angiopoietin 1* binding to endothelial cell *Tie2 receptors***

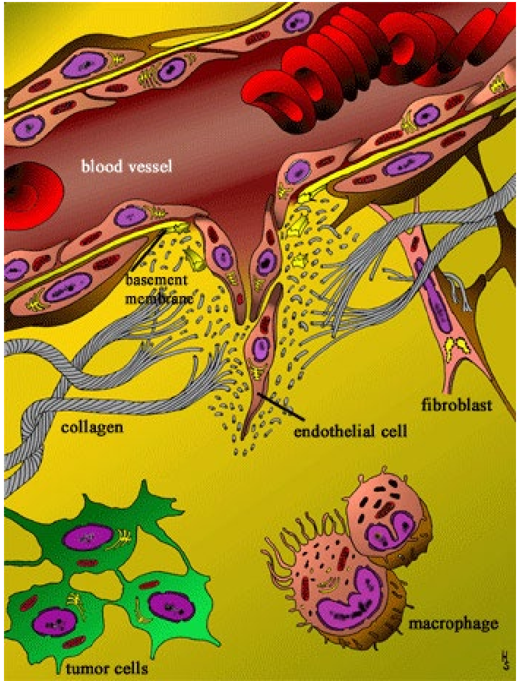
Arteriogenesis **refers to the remodeling of existing arteries in response to :**

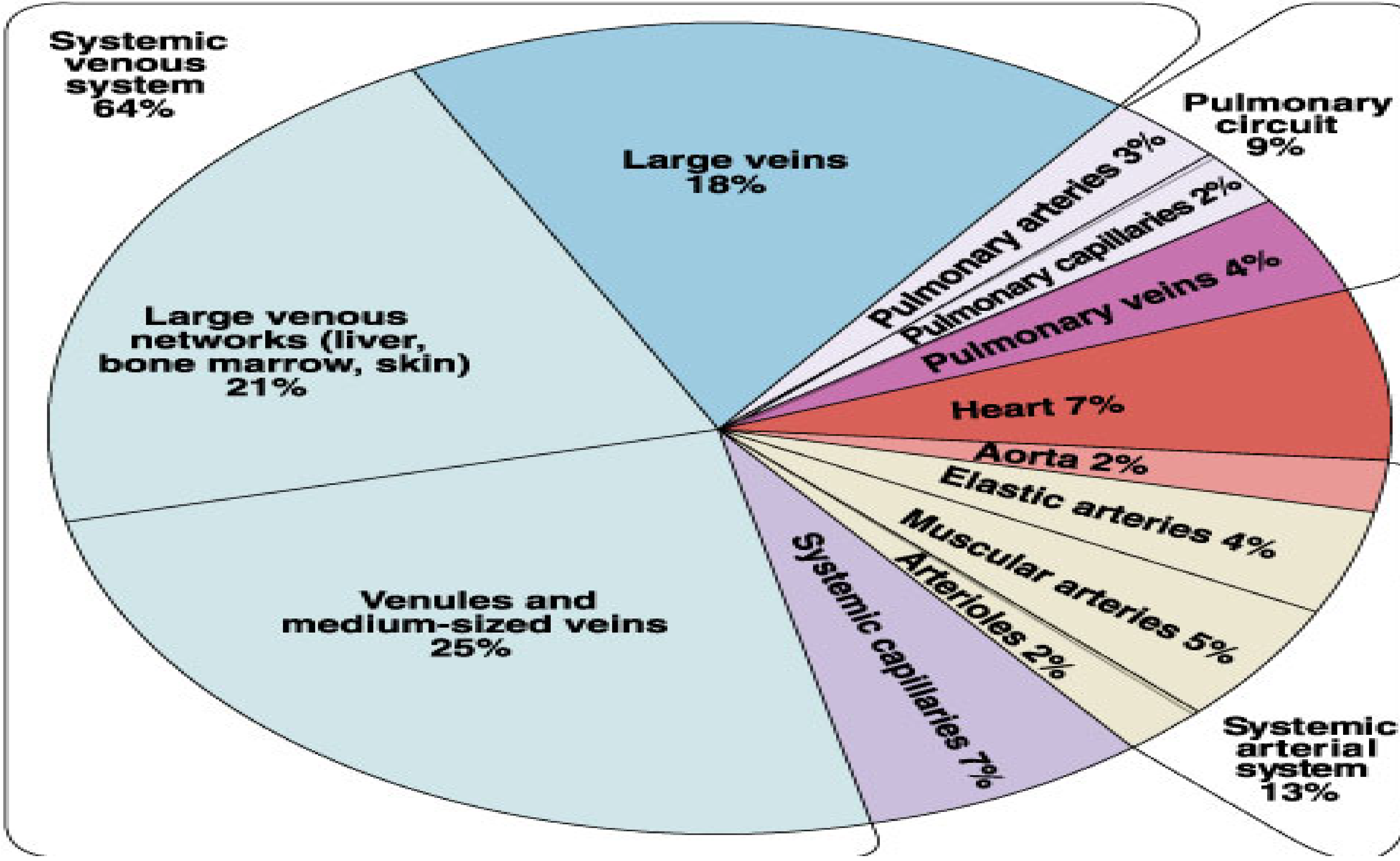
- **chronic changes in pressure or flow,**
- **results from an interplay of endothelial cell–and smooth muscle cell–derived factors**

Angiogenesis **(or *neovascularization*) constitutes the process of new vessel formation in the mature organism**

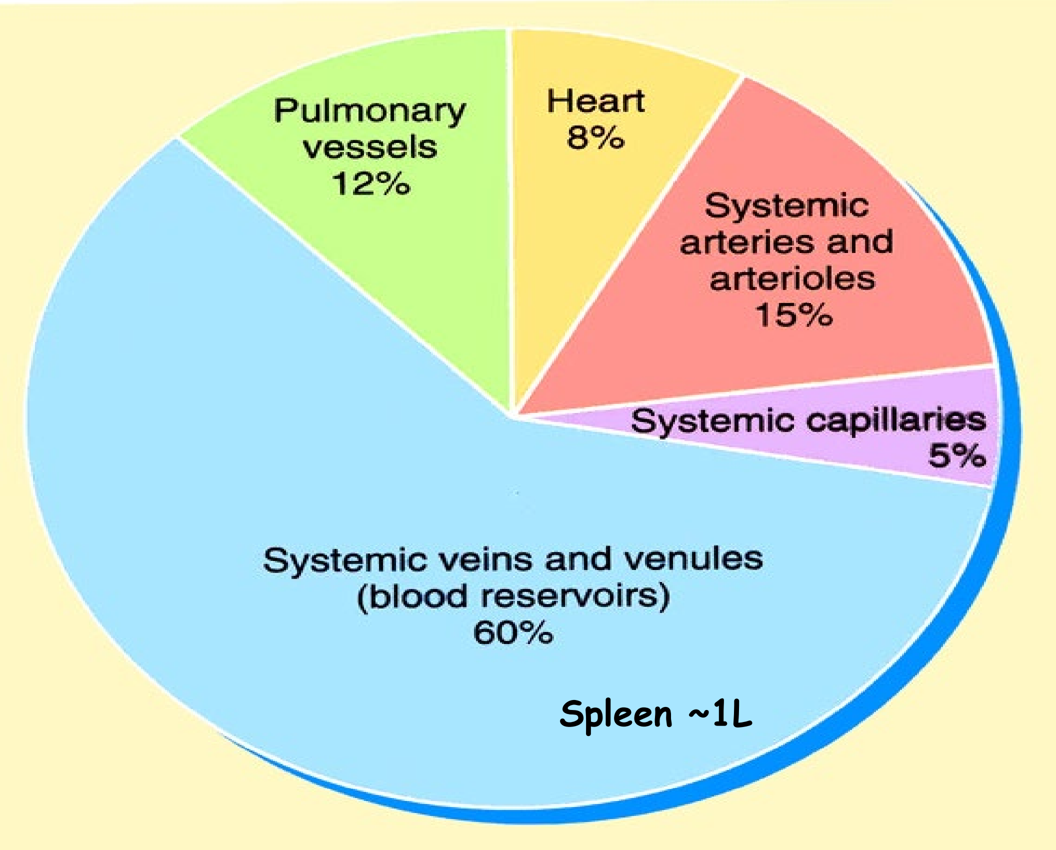


- The healthy body controls angiogenesis through a series of "on" and "off" switches:
- The main "on switches" are known as angiogenesis-stimulating growth factors
- The main "off switches" are known as angiogenesis inhibitors




Systemic venous system 64%
Large veins 18%
Large venous networks (liver, bone marrow, skin) 21%
Venules and medium-sized veins 25%
Pulmonary circuit 9%
Pulmonary arteries 3%
Pulmonary capillaries 2%
Pulmonary veins 4%
Heart 7%
Aorta 2%
Elastic arteries 4%
Muscular arteries 5%
Arterioles 2%
Systemic capillaries 7%
Systemic arterial system 13%

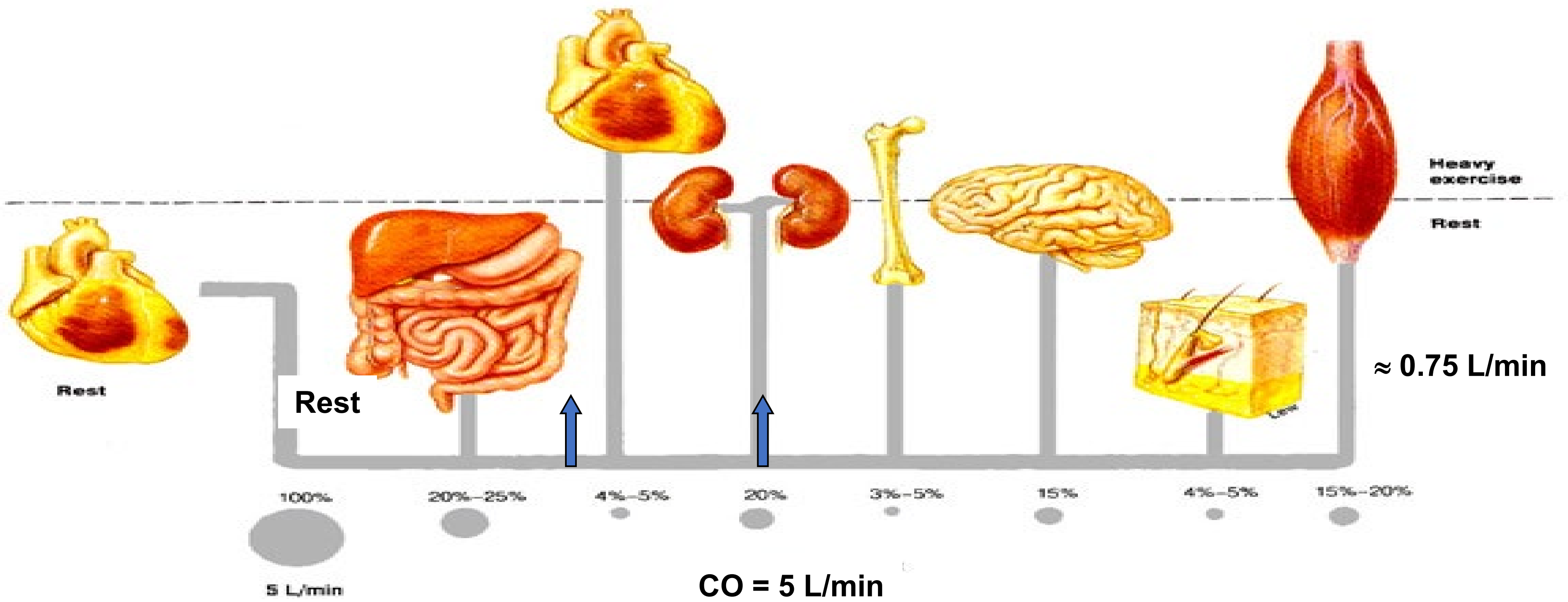
Vessel Structure/Function



Compare to Cardiac Output figures

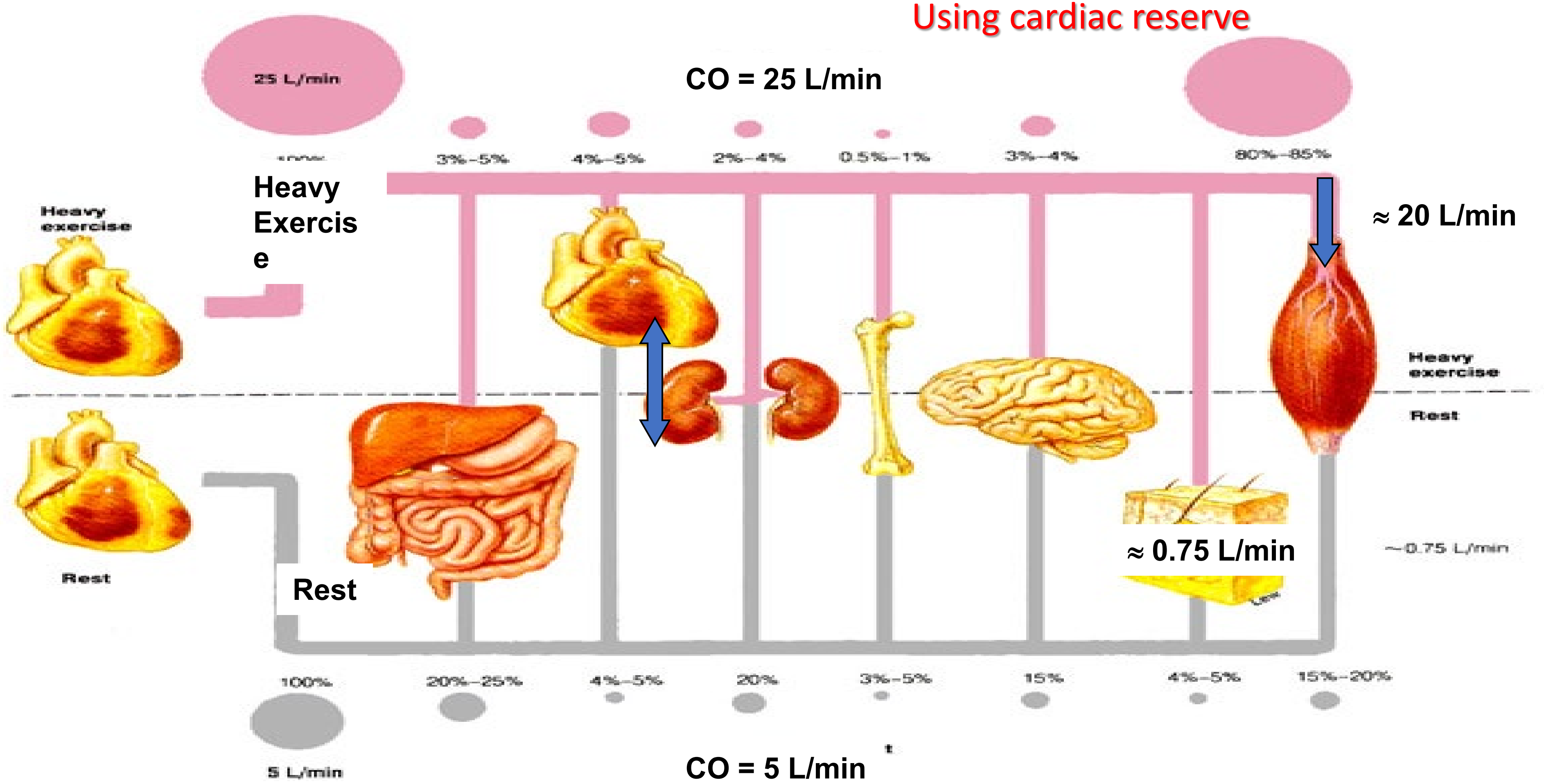
- **At rest**
  - 60% of **blood volume** is located in veins and venules
  - venous system serves as reservoirs for blood
  - particularly veins of the abdominal organs and the skin
- **ANS regulates volume distribution**
  - vasoconstriction
  - vasodilation
  - diverts blood to areas with increased metabolic needs

Blood Distribution at Rest



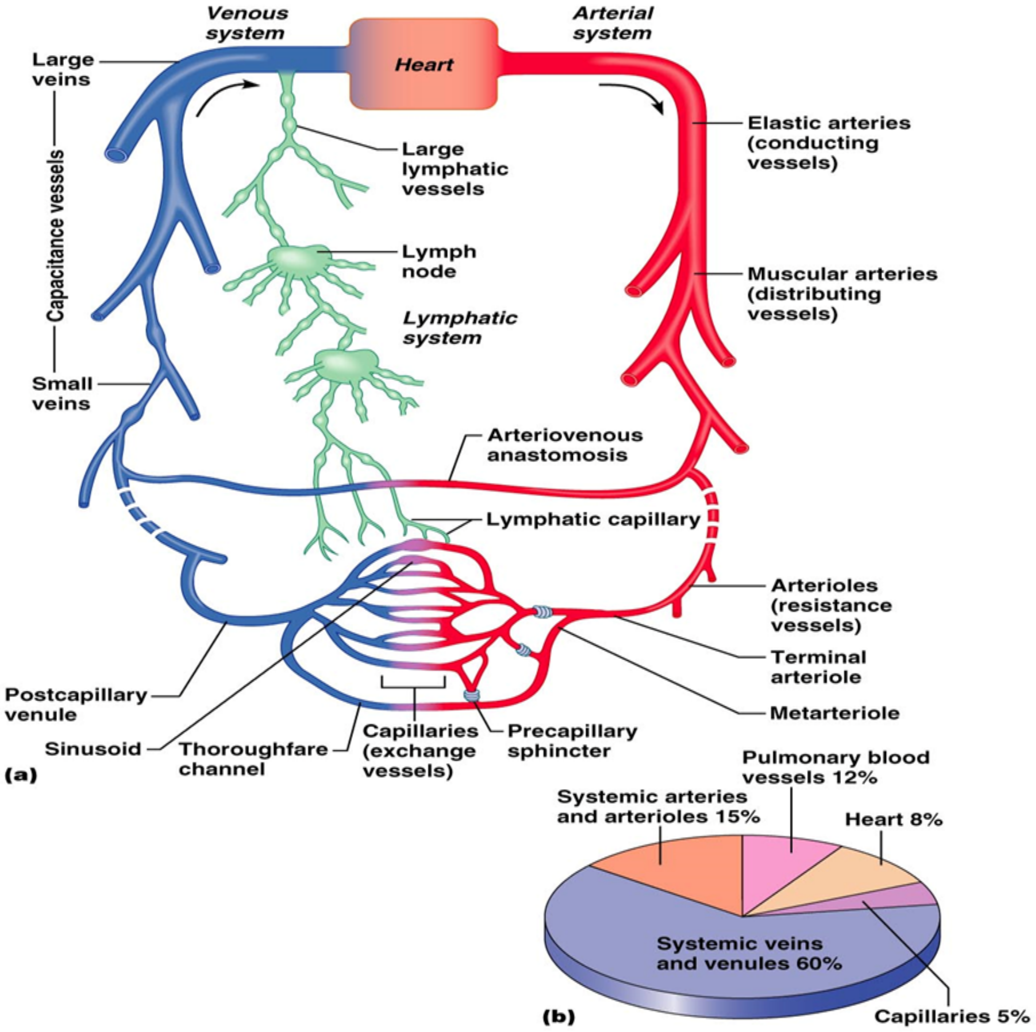
CO = 5 L/min

Blood Distribution -- Exercise

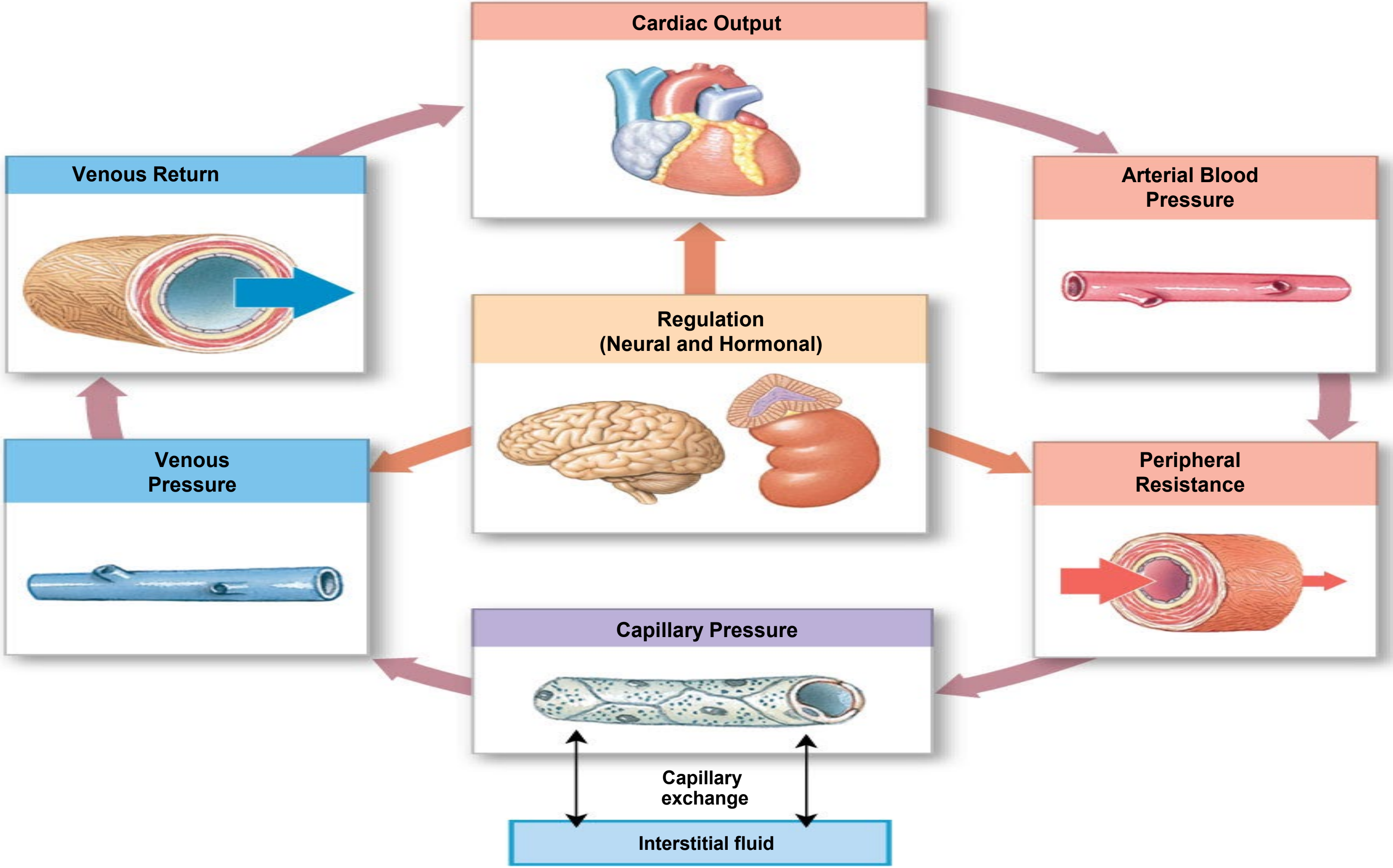


Blood Vessels

- **Blood is carried in a closed system of vessels that begins and ends at the heart**
- **Arteries carry blood away from the heart, veins carry blood toward the heart**
- **Capillaries contact tissue cells and directly serve cellular needs**

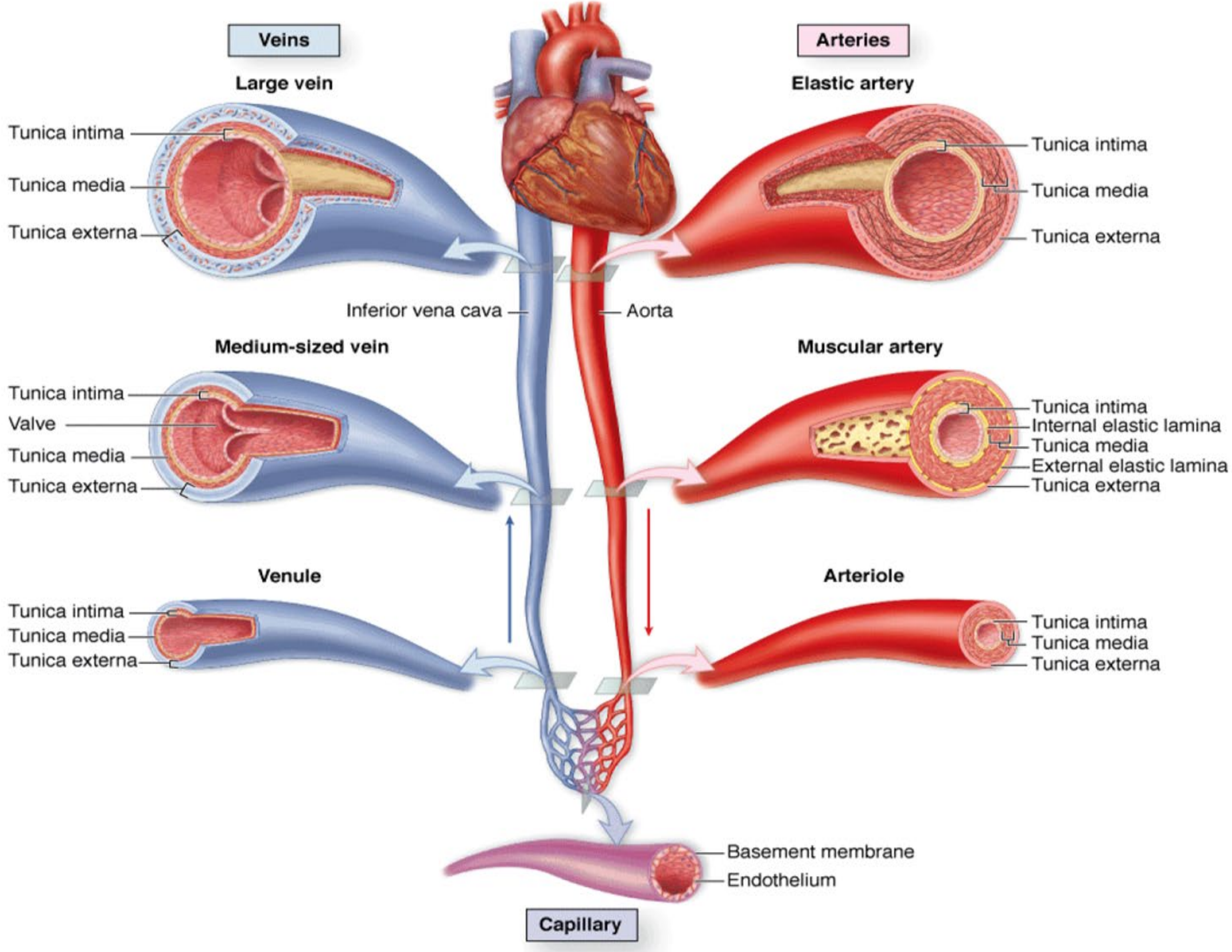


An Overview of Cardiovascular Physiology

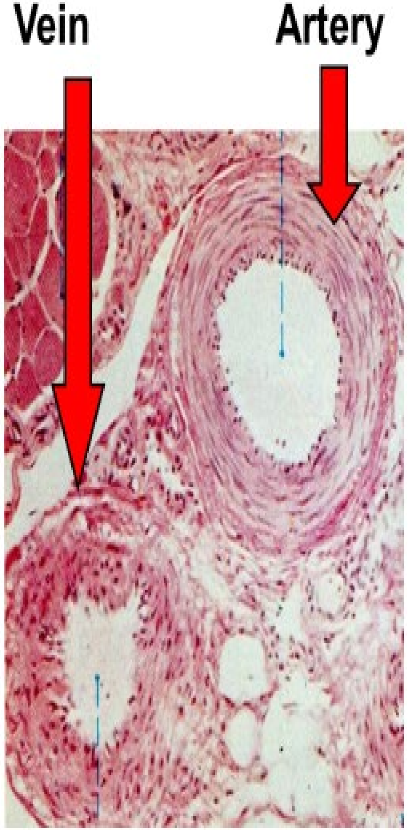


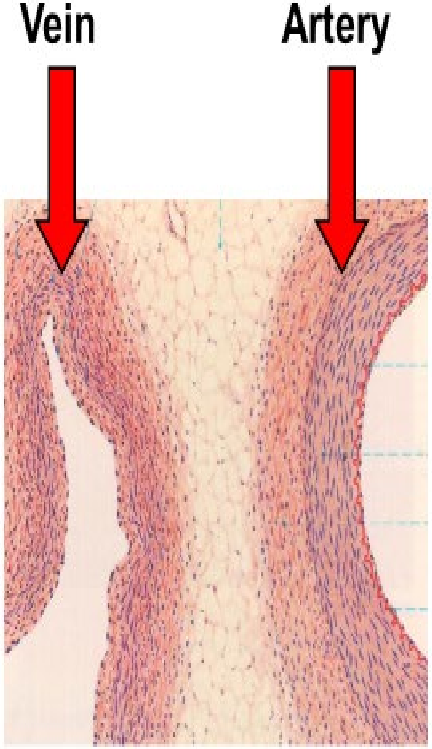
Type of blood vessels

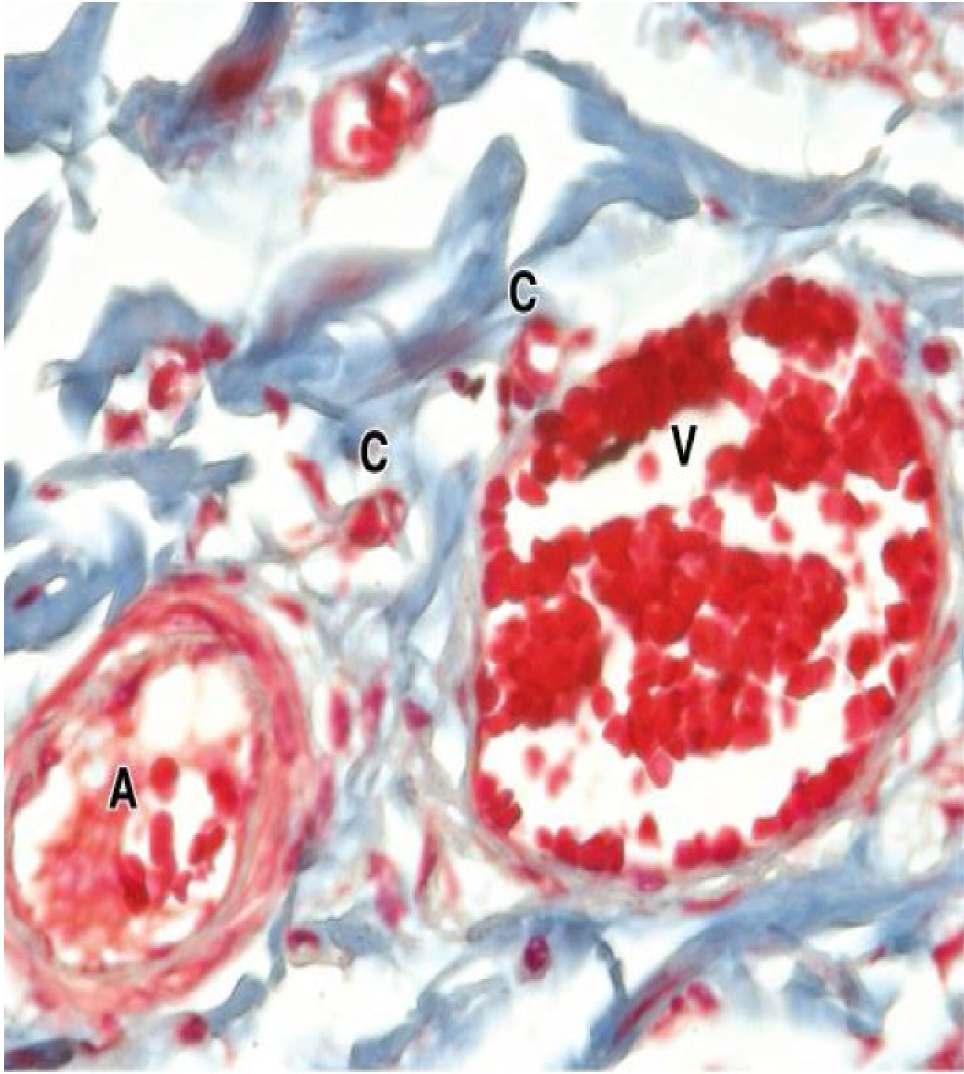
- **Arteries [small[arterioles], medium, large]**
- **Veins [small[veinules], medium, large]**
- **Capillaries**
- **Lymphatics**



Vessel Structure - Histology

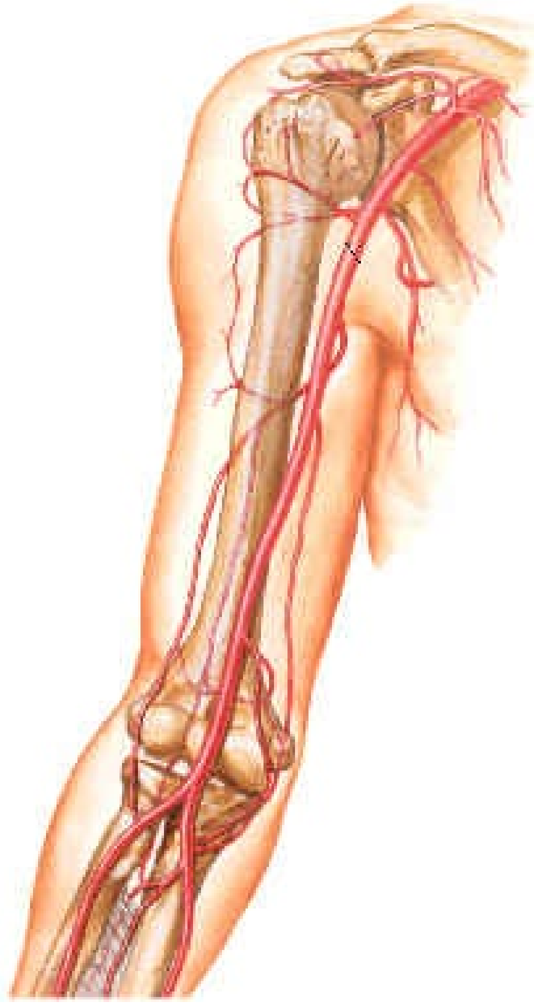






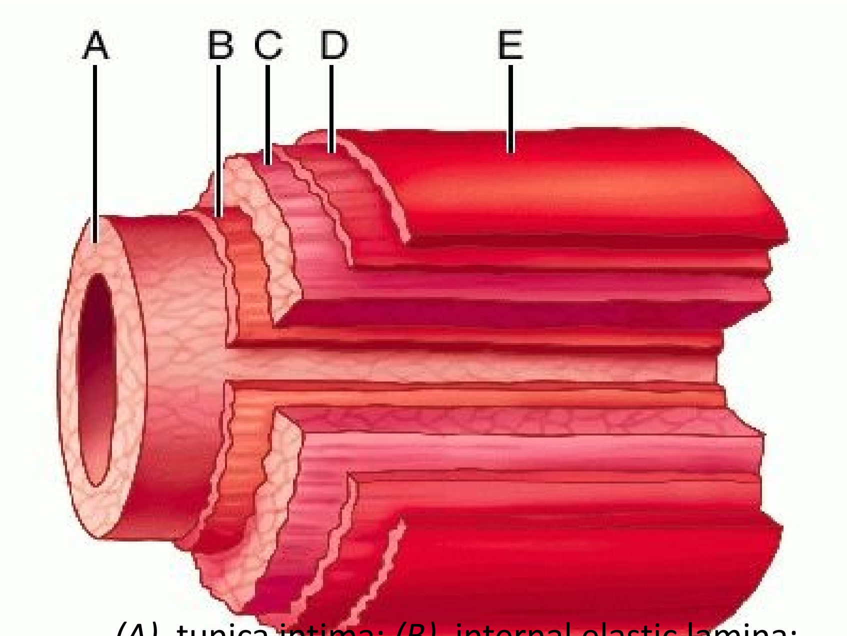
The Vascular Anastomosis

1. **Arterial anastomosis arterial arch:** - provide collateral supply to some organs and tissues, e.g., skeletal muscles
2. **Venous anastomosis venous arch** : - most common, e.g., deep and superficial veins in limbs and head
3. **Arteriovenous anastomosis : arteriolovenular anastomosis**
4. **Venous plexus**
5. **Collateral anastomosis collateral vessel collateral circulation**



Generalized Structure of Blood Vessels

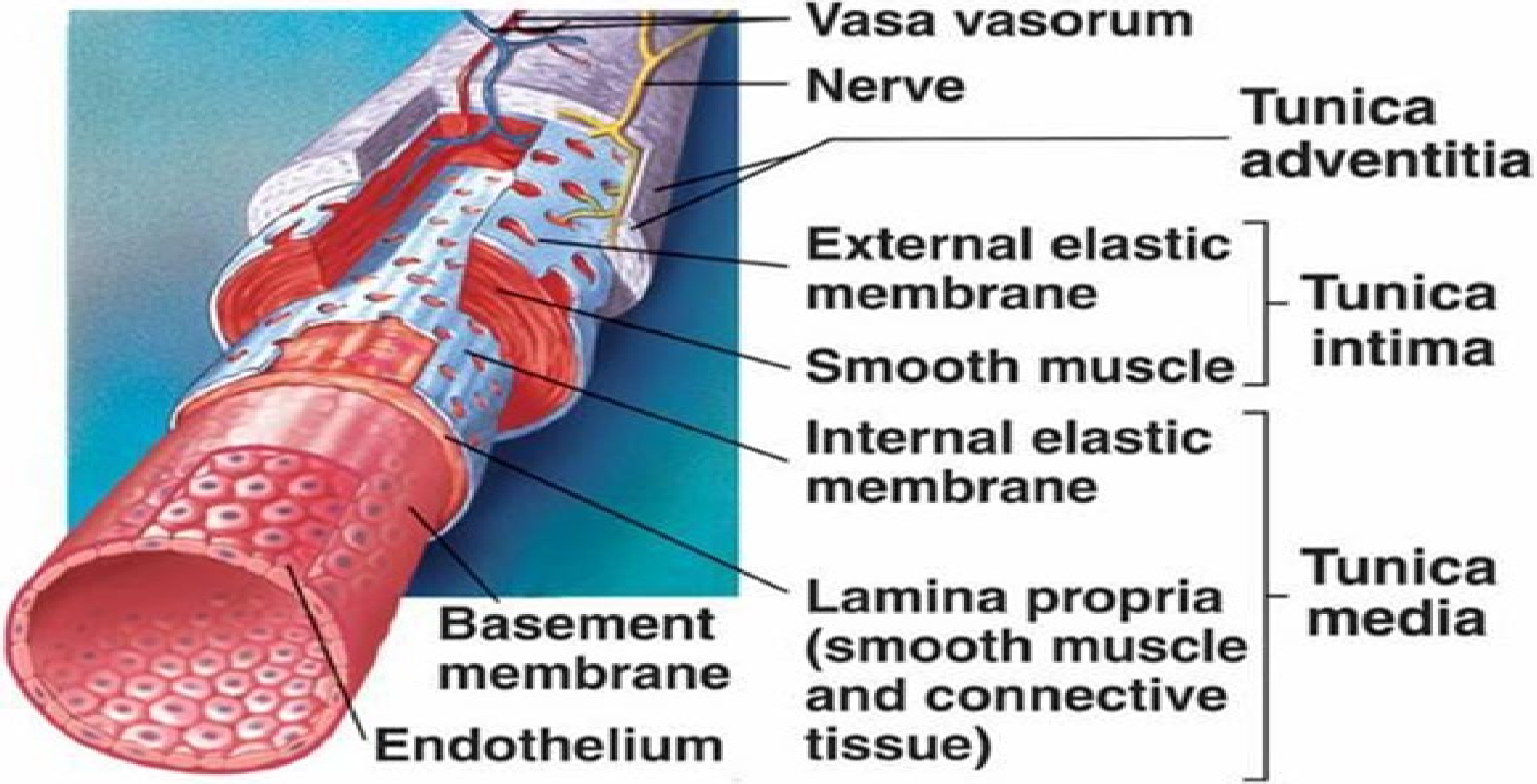
- **Arteries and veins are composed of three tunics –**
  - **tunica interna,**
  - **tunica media,**
  - **tunica externa**
- **<u>Lumen</u>** – central blood-containing space surrounded by tunics
- Capillaries are composed of endothelium with sparse basal lamina

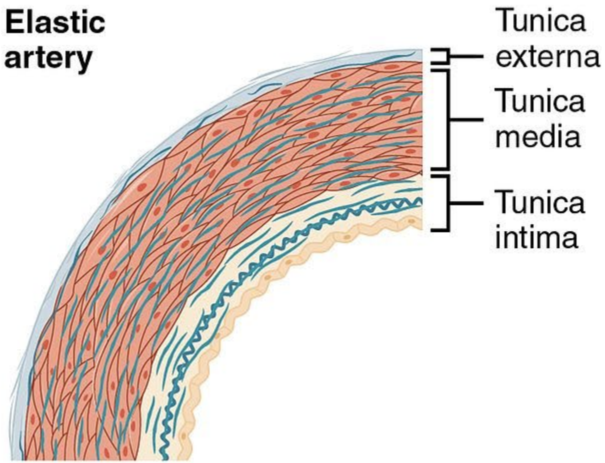


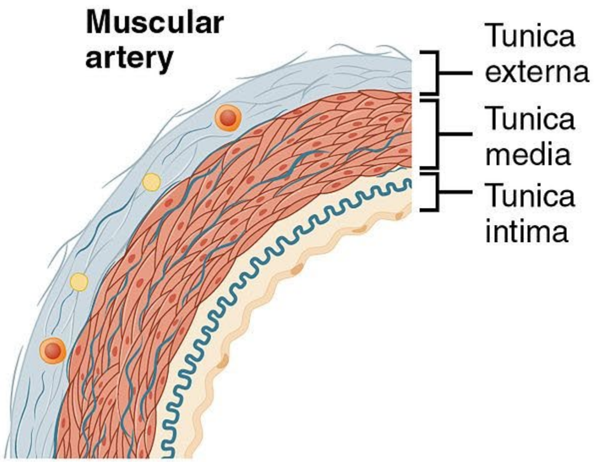
(A), tunica intima; *(B),* internal elastic lamina; *(C),* tunica media; *(D),* external elastic lamina; *(E),* tunica externa.

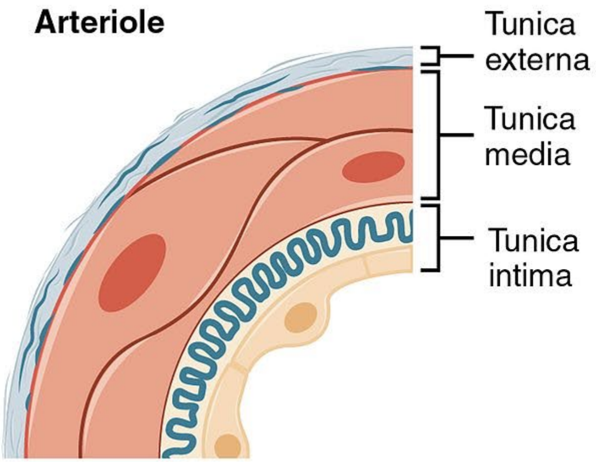
The arterial wall is composed of three main layers or tunics.

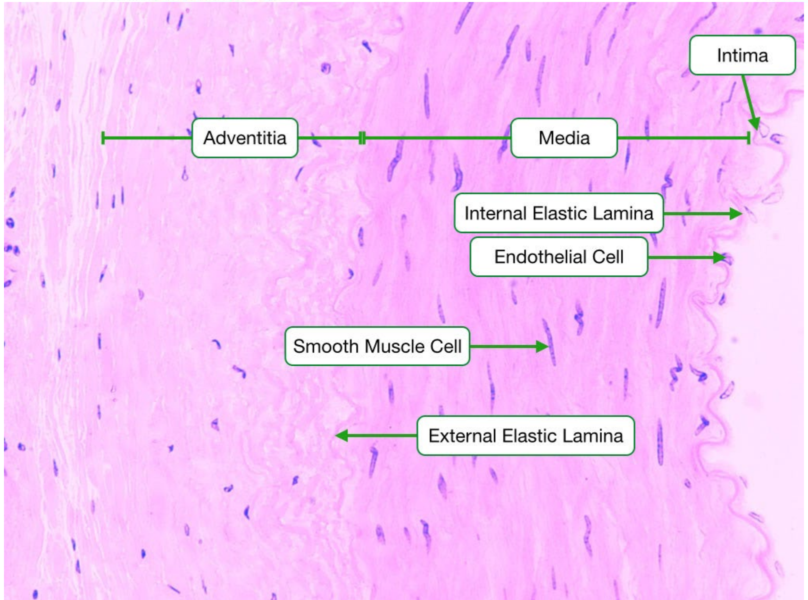
- ***Tunica intima*** (internal tunic) consisting of :
  - **endothelium** (single lining layer of endothelial cells) **sub-endothelial** connective tissue basement membrane **layer inner elastic limiting membrane** (elastic lamina, which after fixation appears undulating).
- ***Tunica media*** (middle tunic) consisting of :
  - **circular smooth muscle** (or spiral)
  - **concentric elastic lamina** (formed by the smooth muscle cells).
  - Smooth muscle and elastic fiber layer, regulated by sympathetic nervous system
  - Controls vasoconstriction/vasodilation of vessels
- ***Adventitia = tunica externa*** (outer layer) composed of :
  - Collagen fibers that protect and reinforce vessels
  - Larger vessels contain vasa vasorum
  - **connective tissue** surrounding the vessel **outer elastic limiting membrane** (on the border between the *Tunica media* and the *Adventitia* ***Vasa vasorum***.
  - These are small blood vessels supplying oxygen and nutrients to the wall of the artery.
  - The blood flow in the arterial lumen is too great for exchange of oxygen or nutrients.


Vasa vasorum
Nerve
Tunica adventitia
External elastic membrane
Smooth muscle
Tunica intima
Internal elastic membrane
Lamina propria (smooth muscle and connective tissue)
Tunica media
Basement membrane
Endothelium


Elastic artery
Tunica externa
Tunica media
Tunica intima

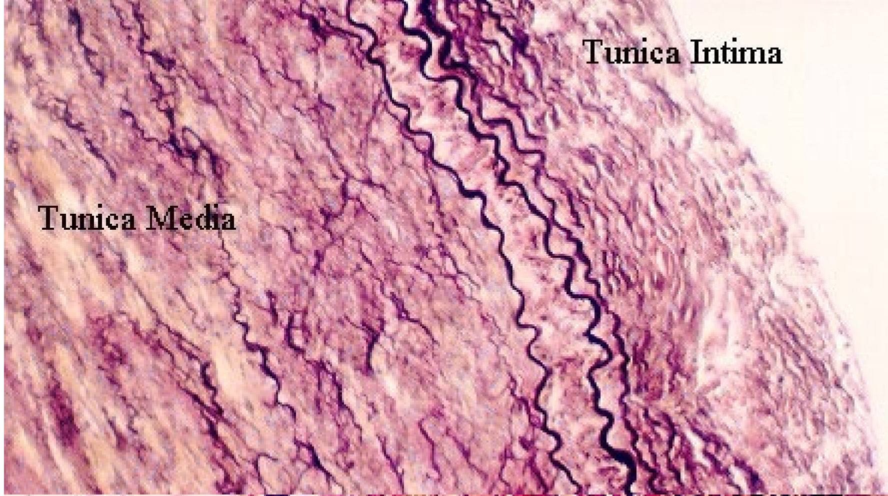

Muscular artery
Tunica externa
Tunica media
Tunica intima

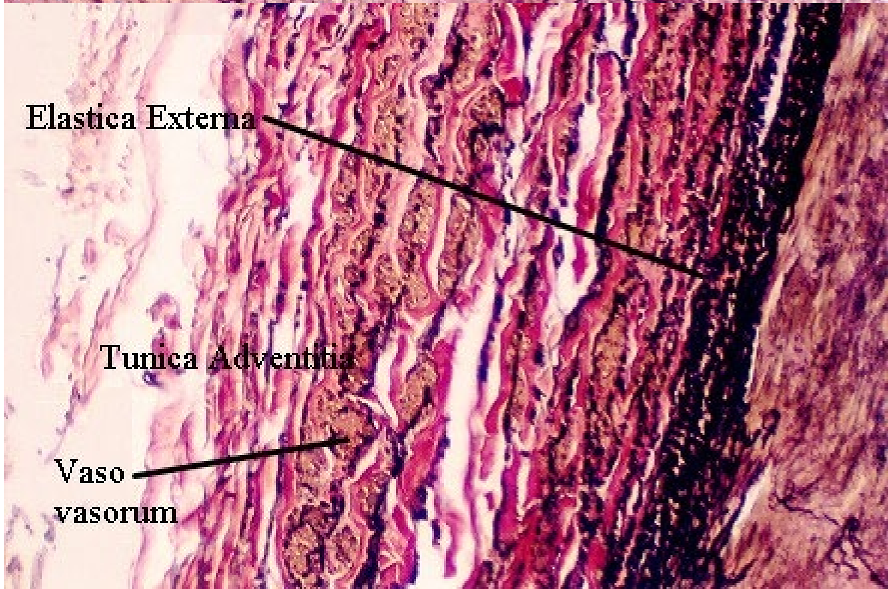

Arteriole
Tunica externa
Tunica media
Tunica intima

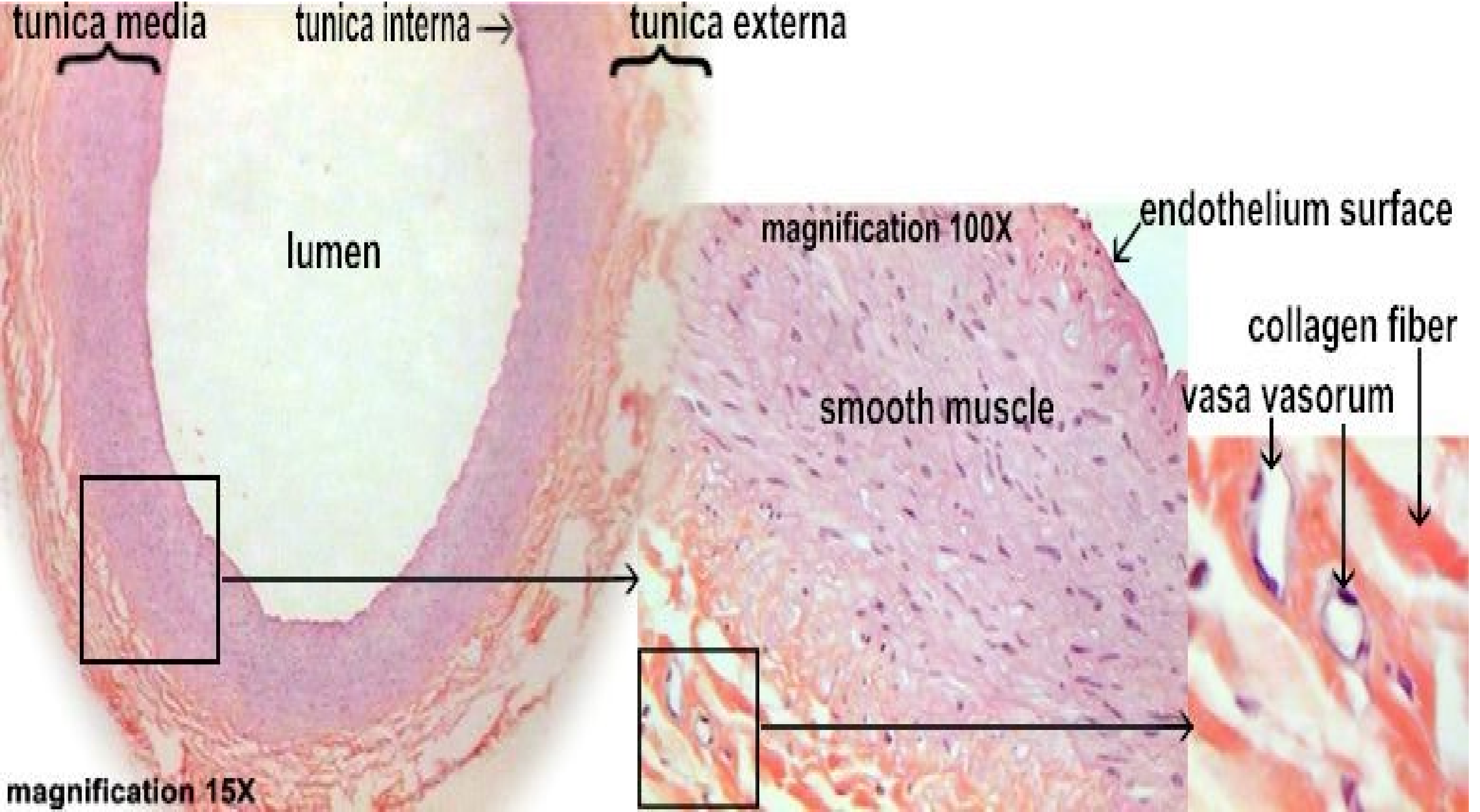

Intima
Adventitia
Media
Internal Elastic Lamina
Endothelial Cell
Smooth Muscle Cell
External Elastic Lamina

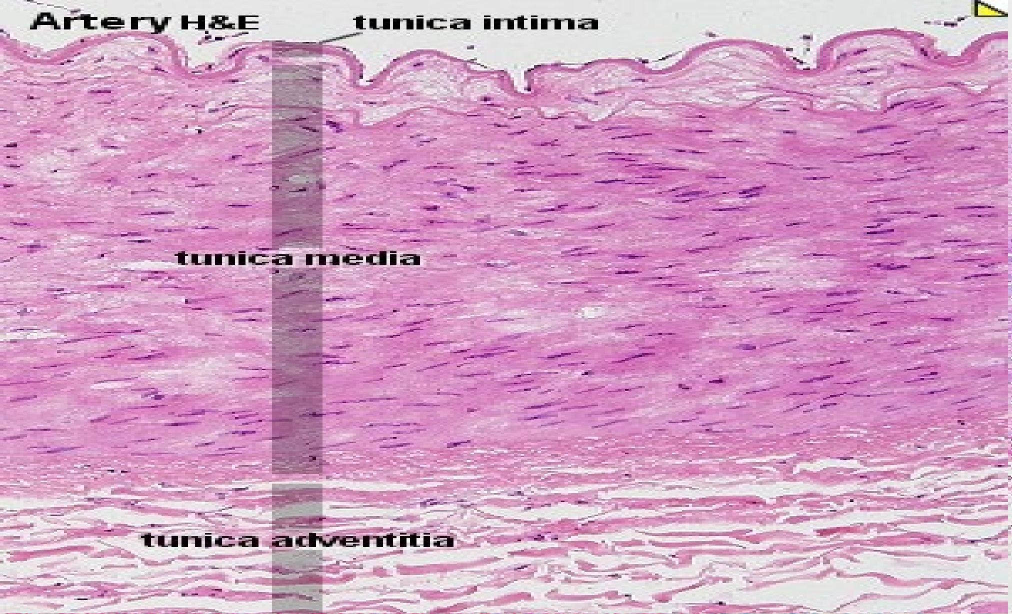
Elastic Artery

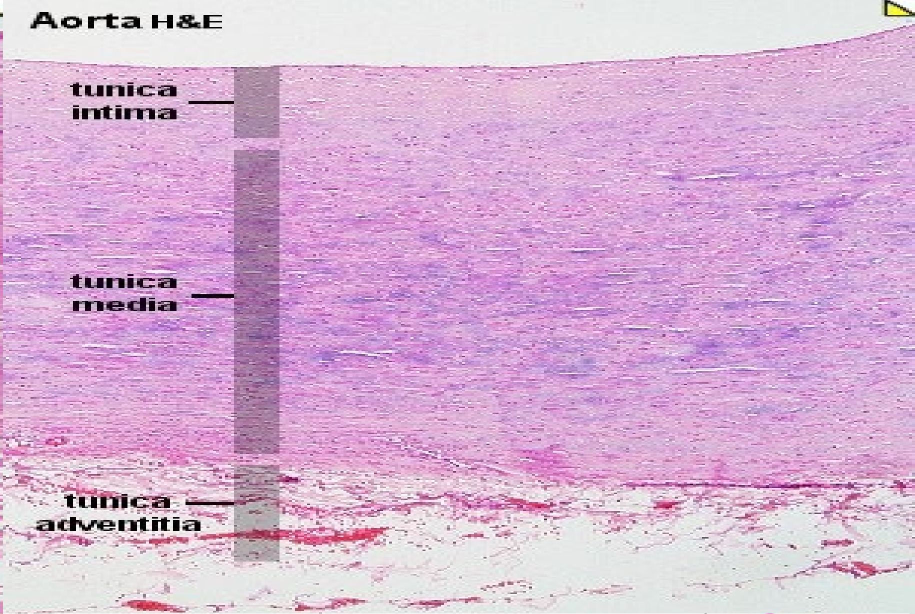
- The elastic artery is a specialized type of artery designed for distension and elasticity.
- The largest of these also have connective tissue underneath the endothelium.
- A good example of an elastic artery is the aorta.
- Thick-walled arteries near the heart; the aorta and its major branches
  - Large lumen allow low-resistance conduction of blood
  - Contain elastin in all three tunics
  - Withstand and smooth out large blood pressure fluctuations
  - Serve as pressure reservoirs

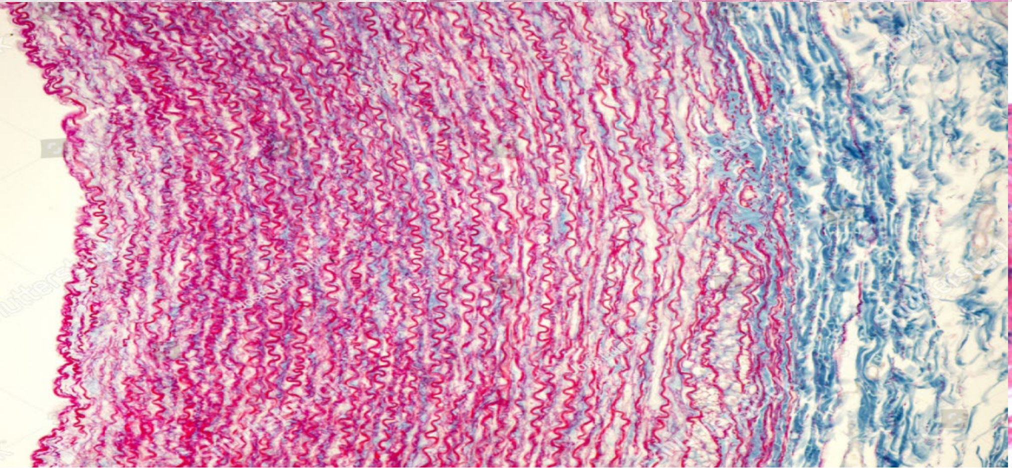





tunica media
tunica interna
tunica externa
lumen
magnification 15X
magnification 100X
endothelium surface
smooth muscle
collagen fiber
vasa vasorum







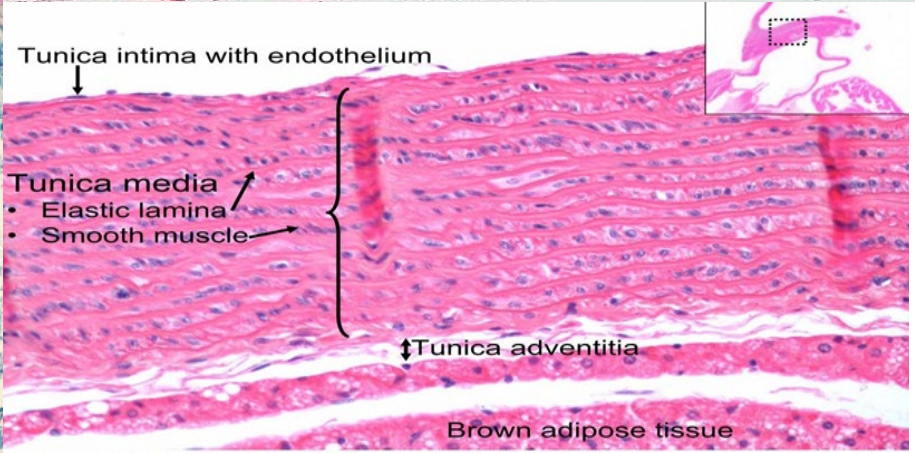
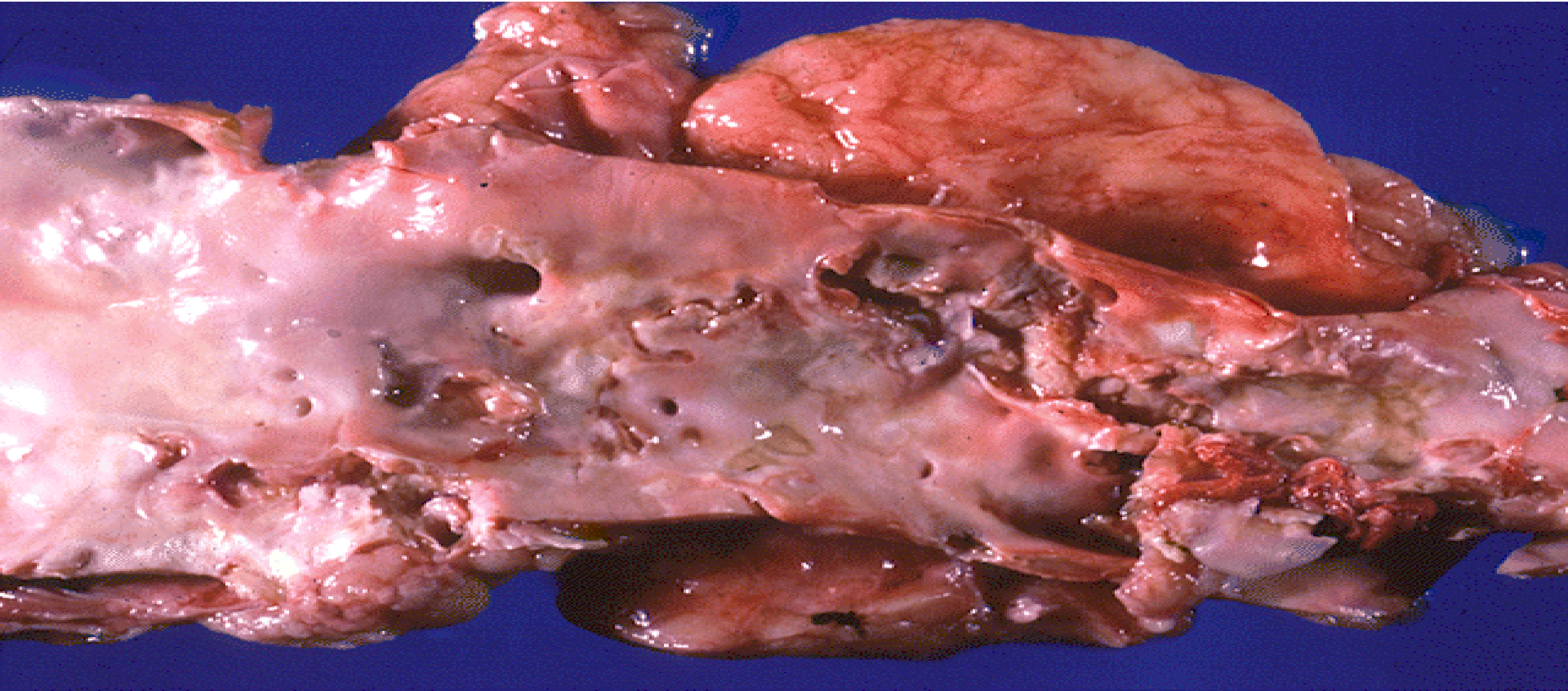


Fig.5 Aorta, large (elastic) artery, with numerous elastic membranes

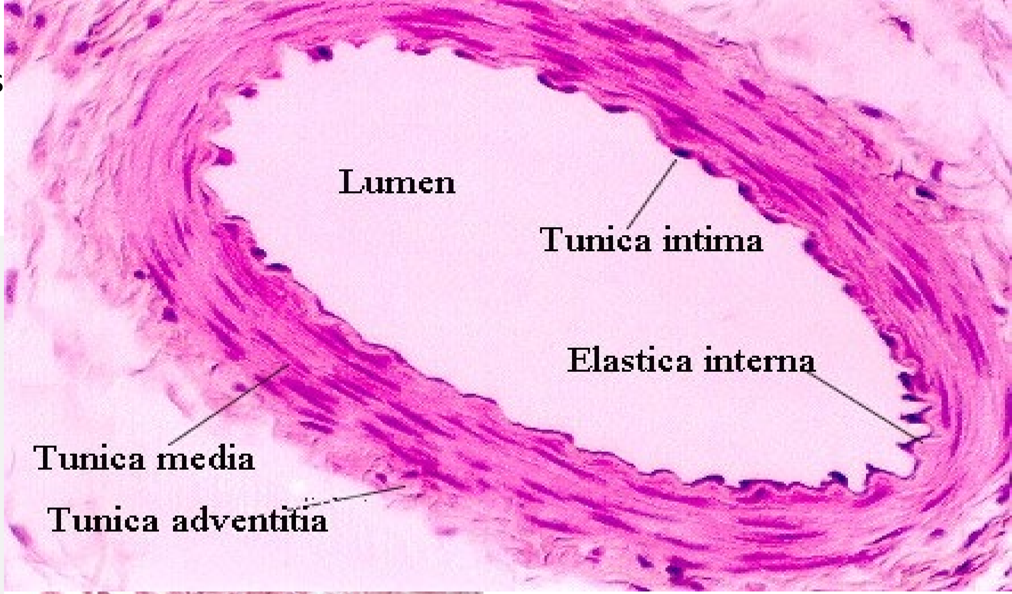
Atherosclerosis

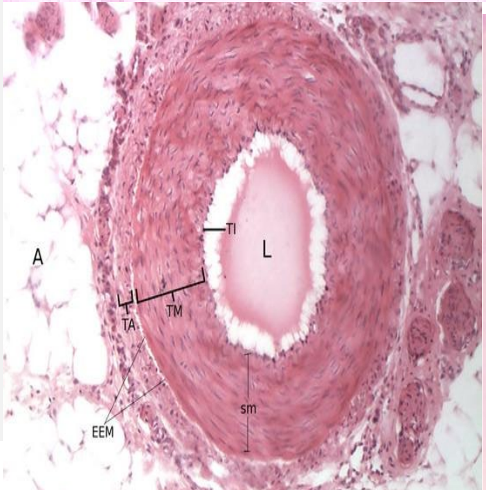


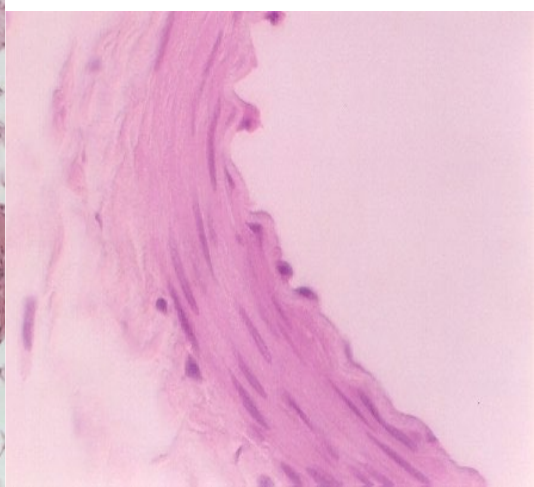
Muscular arteries –

- distal to elastic arteries; deliver blood to body organs
  - Have thick tunica media with more smooth muscle
  - Active in vasoconstriction

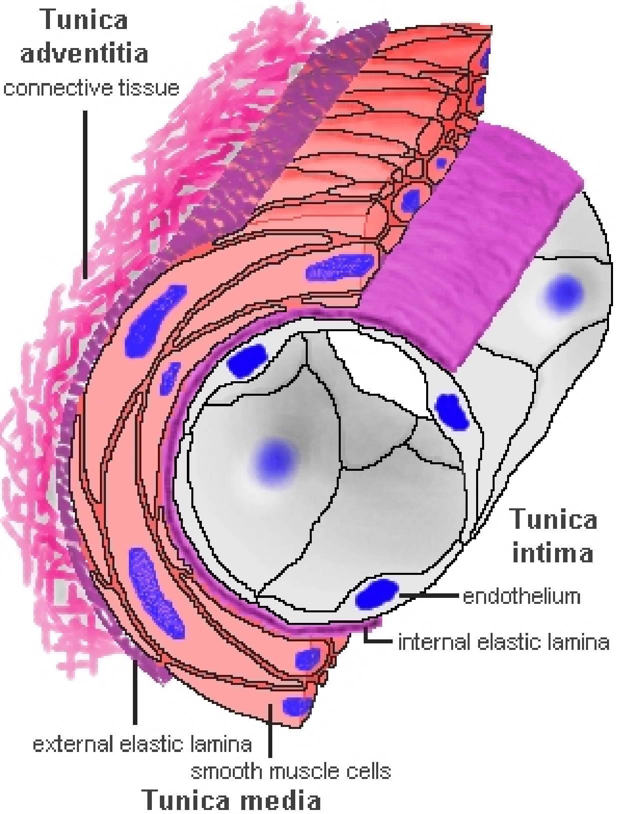
- Blood vessels contain each of the major tissue types: epithelia (called endothelia), connective tissue, muscle, and nerve fibers.
- The **Tunica intima** is a simple endothelial layer, made of **simple squamous cells.**
- Underneath is an internal elastic membrane, the **elastica interna.**
- Then, there is a smooth muscle layer, **the tunica media**.
- This is followed by a poorly defined outer elastic layer.
- Finally, the **Adventia is connective tissue (loose) that blends into the surrounding connective tissue.**

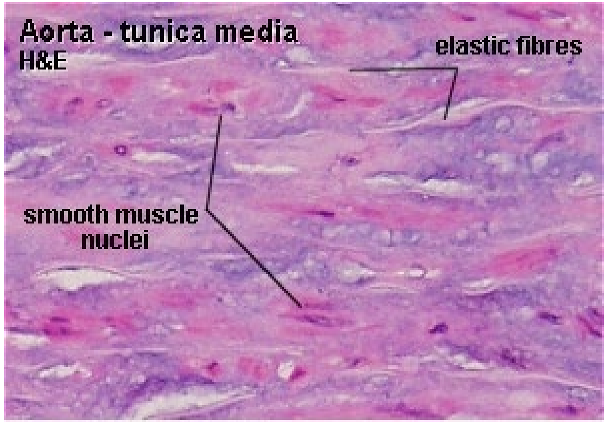


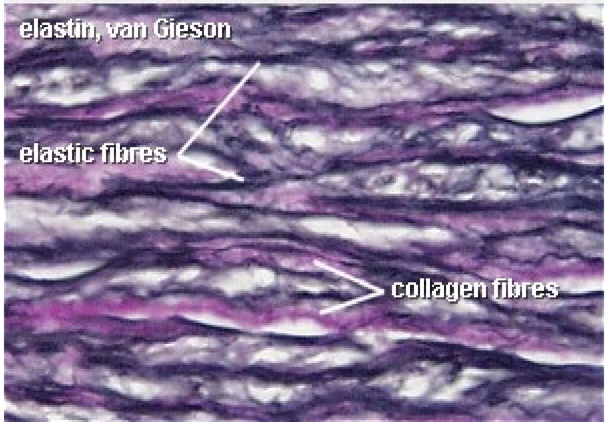


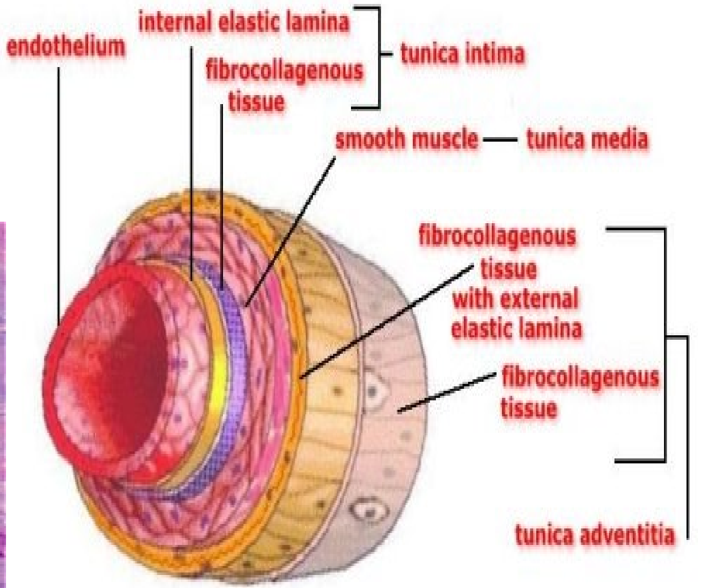


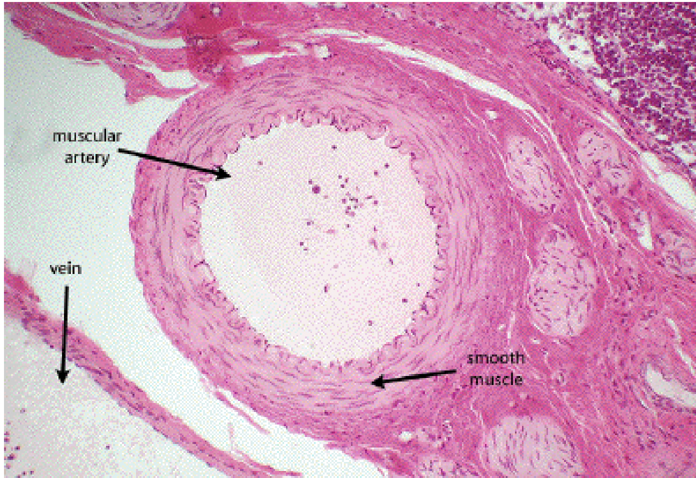
Muscular artery

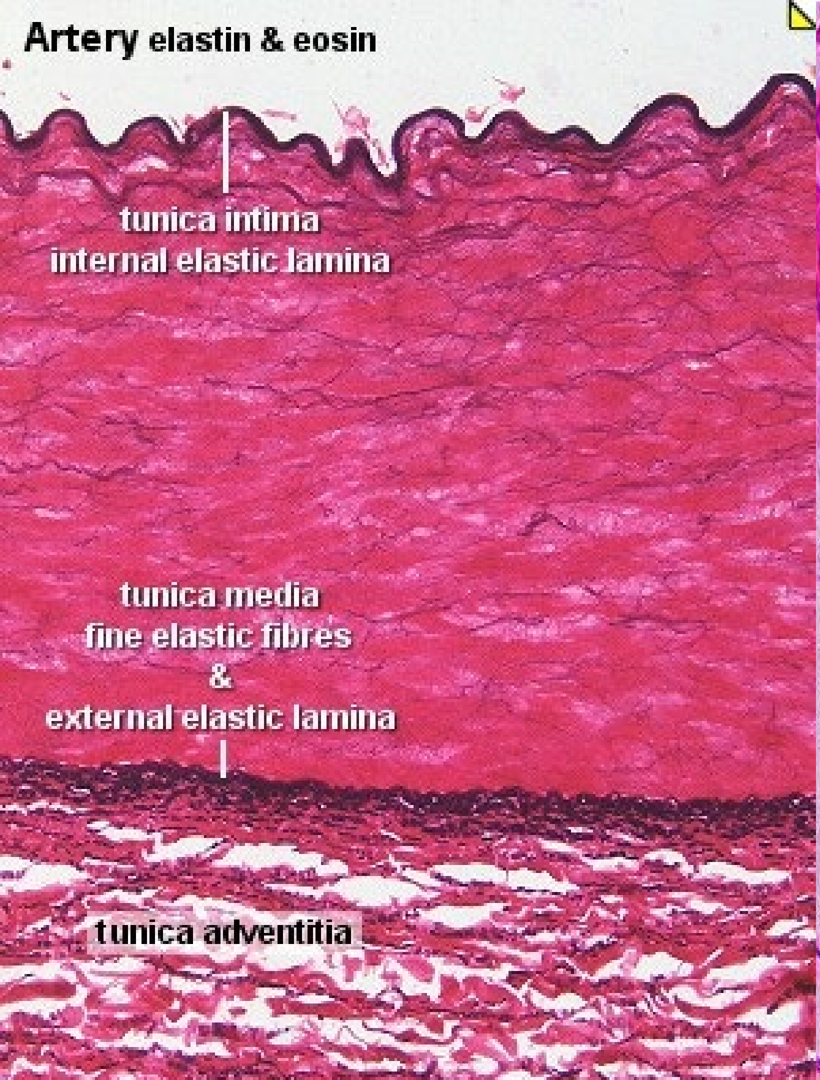


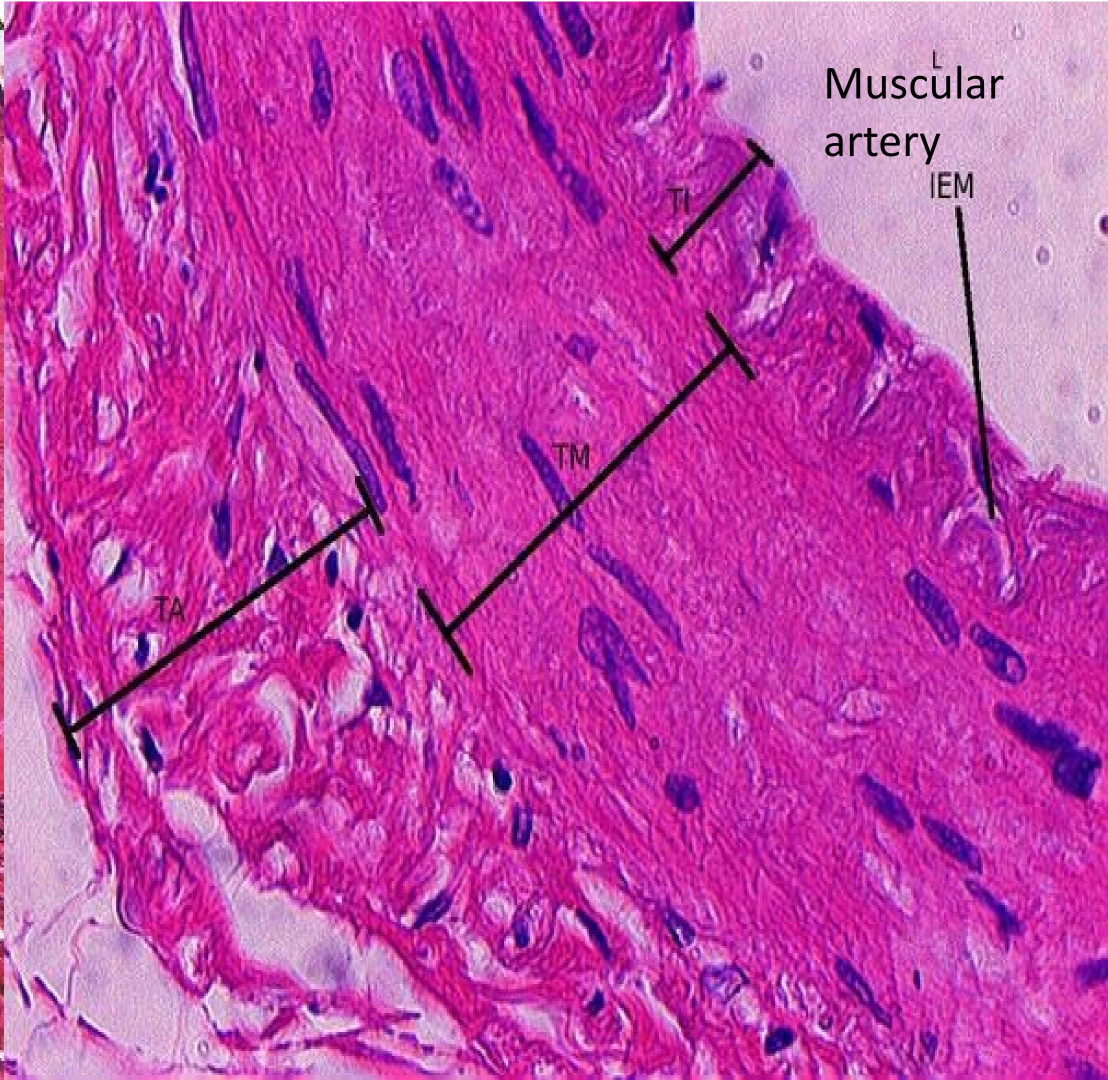






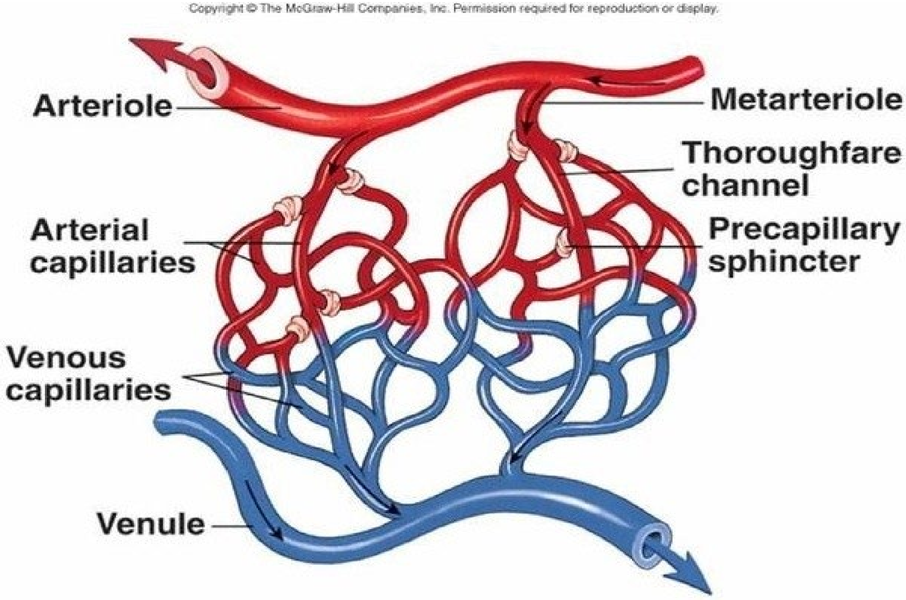


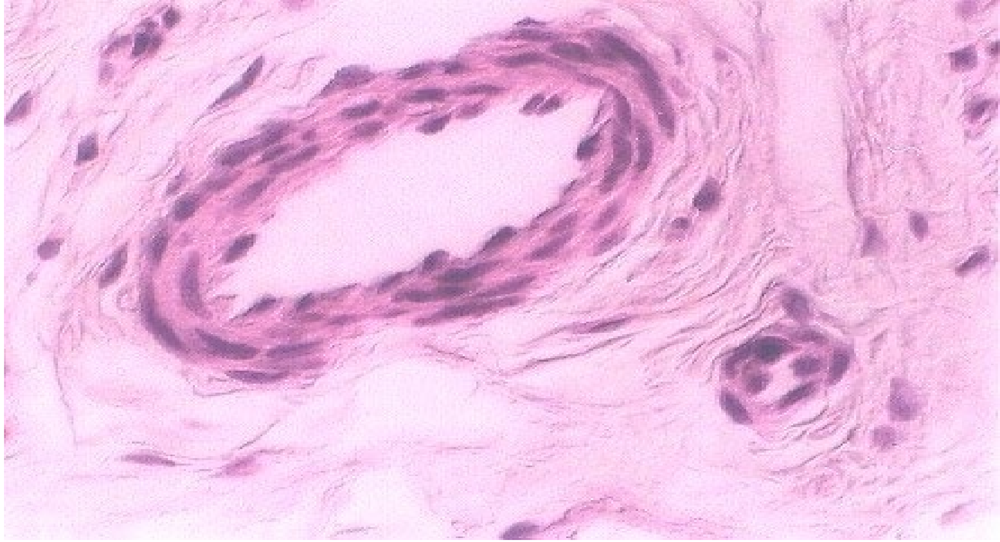

Artery elastin & eosin
tunica intima
internal elastic lamina
tunica media
fine elastic fibres
&
external elastic lamina
tunica adventitia

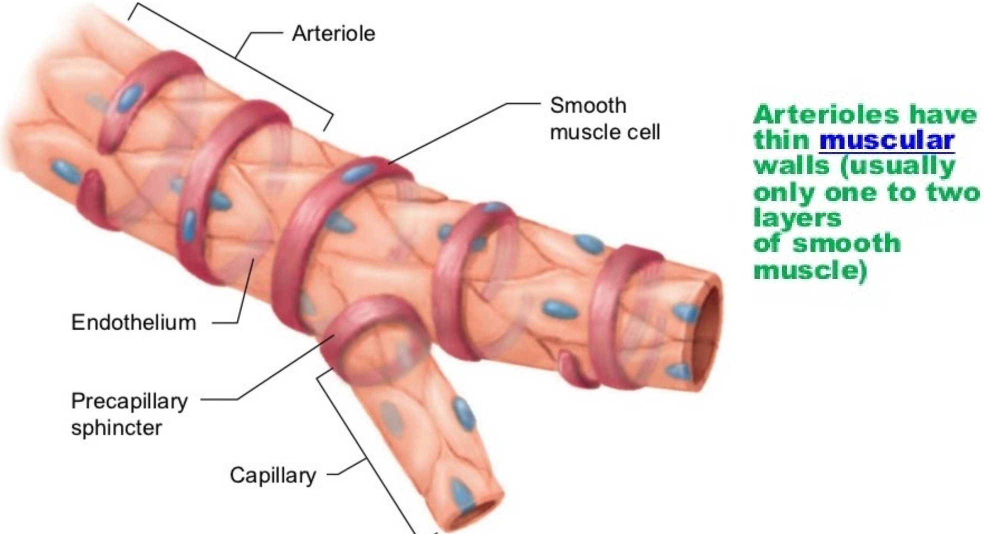

L
Muscular
artery
TI
IEM
TM
TA

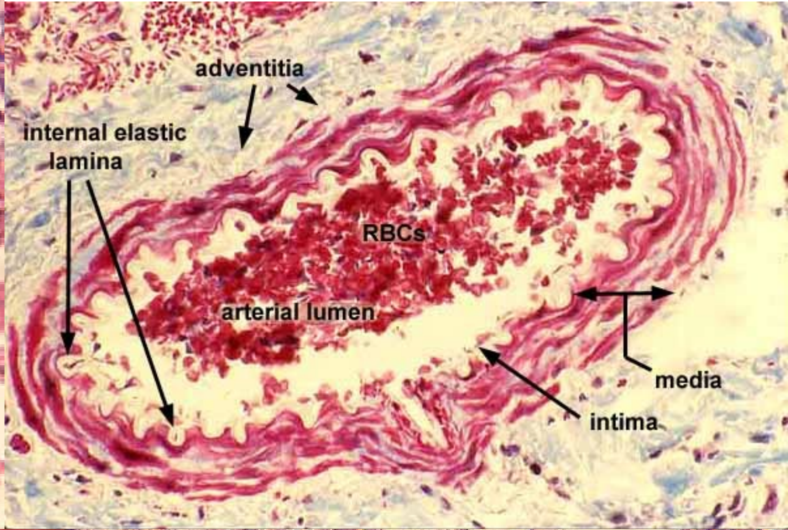
Arterioles

- Arterioles can be **differentiated from arteries** by the numbers of layers of smooth muscle.
- Usually there are **no more than 6 layers.**
- **The smaller of the two vessels is often called a "precapillary arteriole" because of the number of smooth muscle layers.**

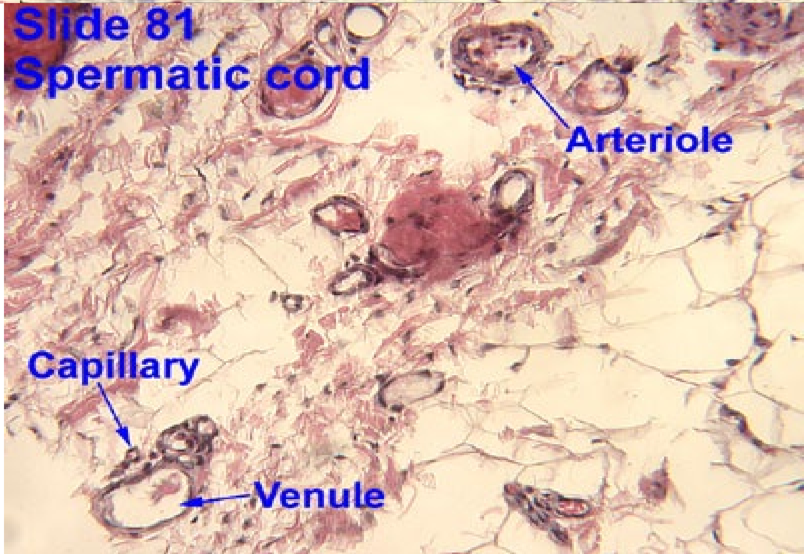


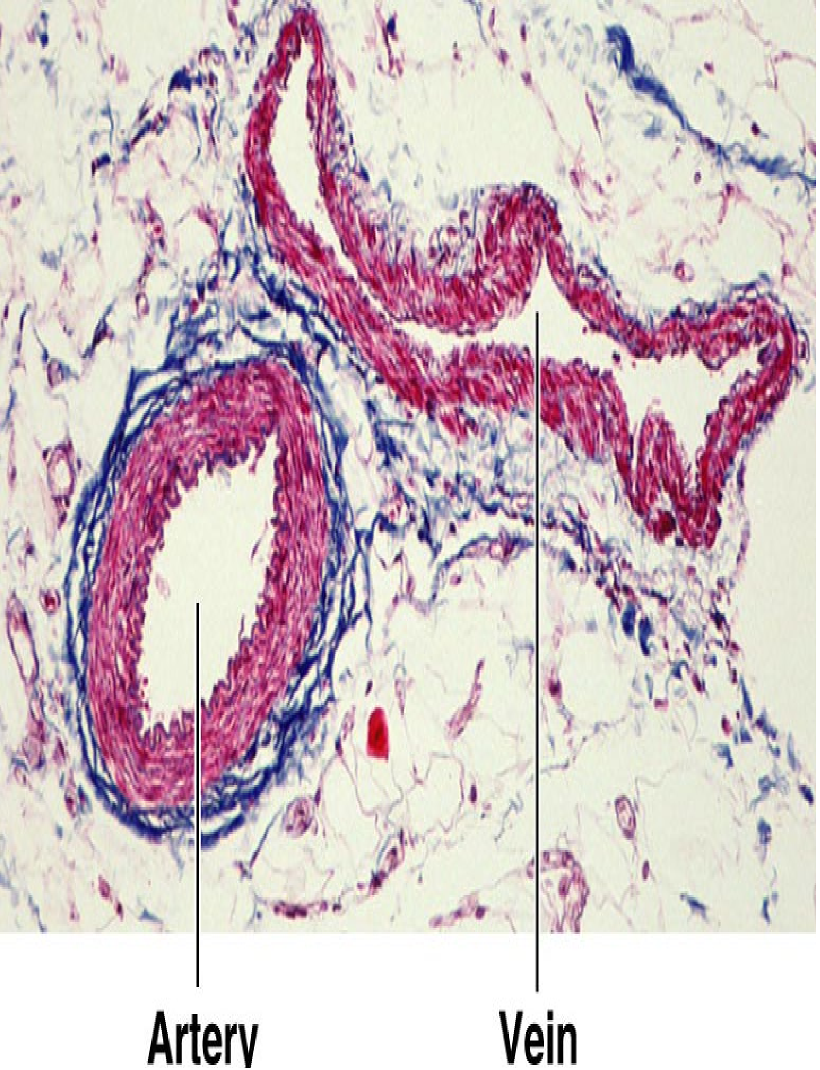






- Arterioles – smallest arteries; lead to capillary beds
  - Control flow into capillary beds via vasodilation and constriction



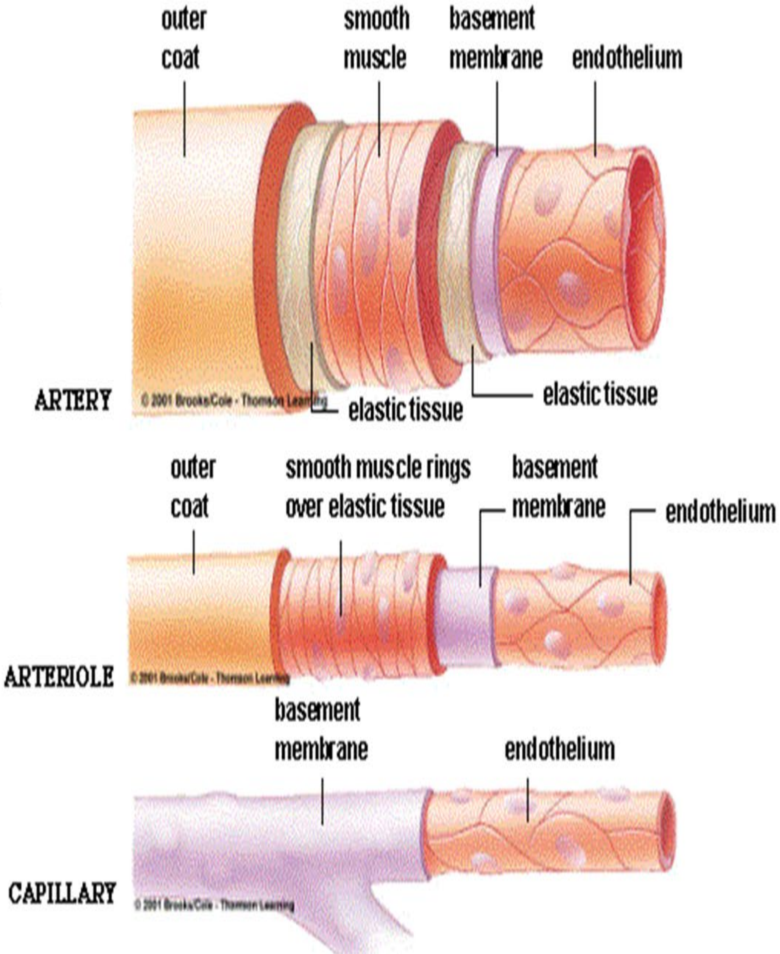


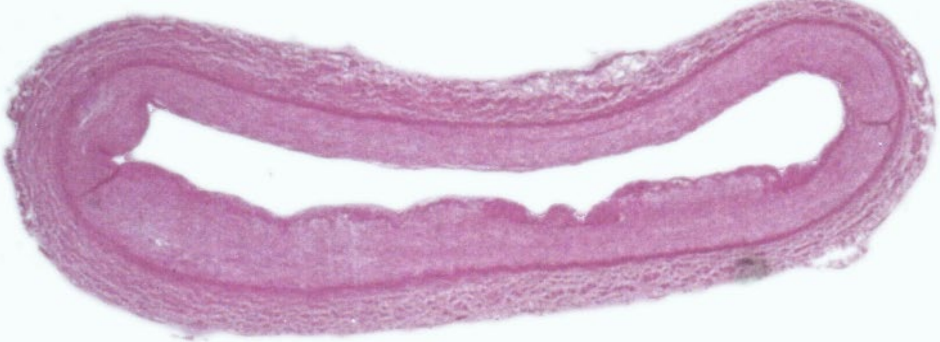
Blood Vessels

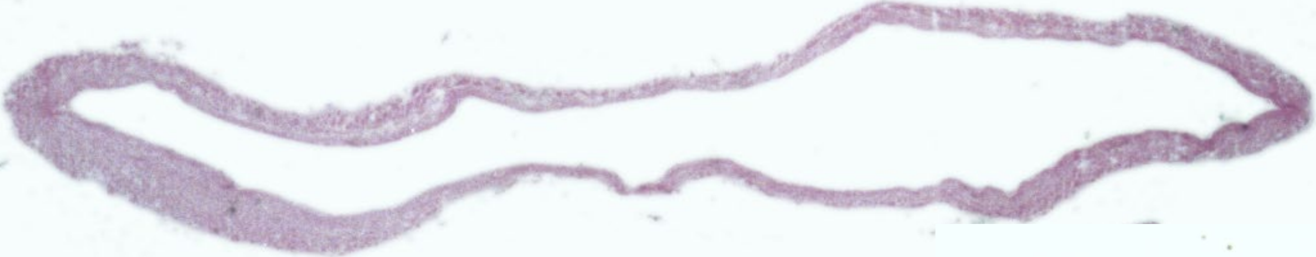
Arteries: main transporters of oxygenated blood

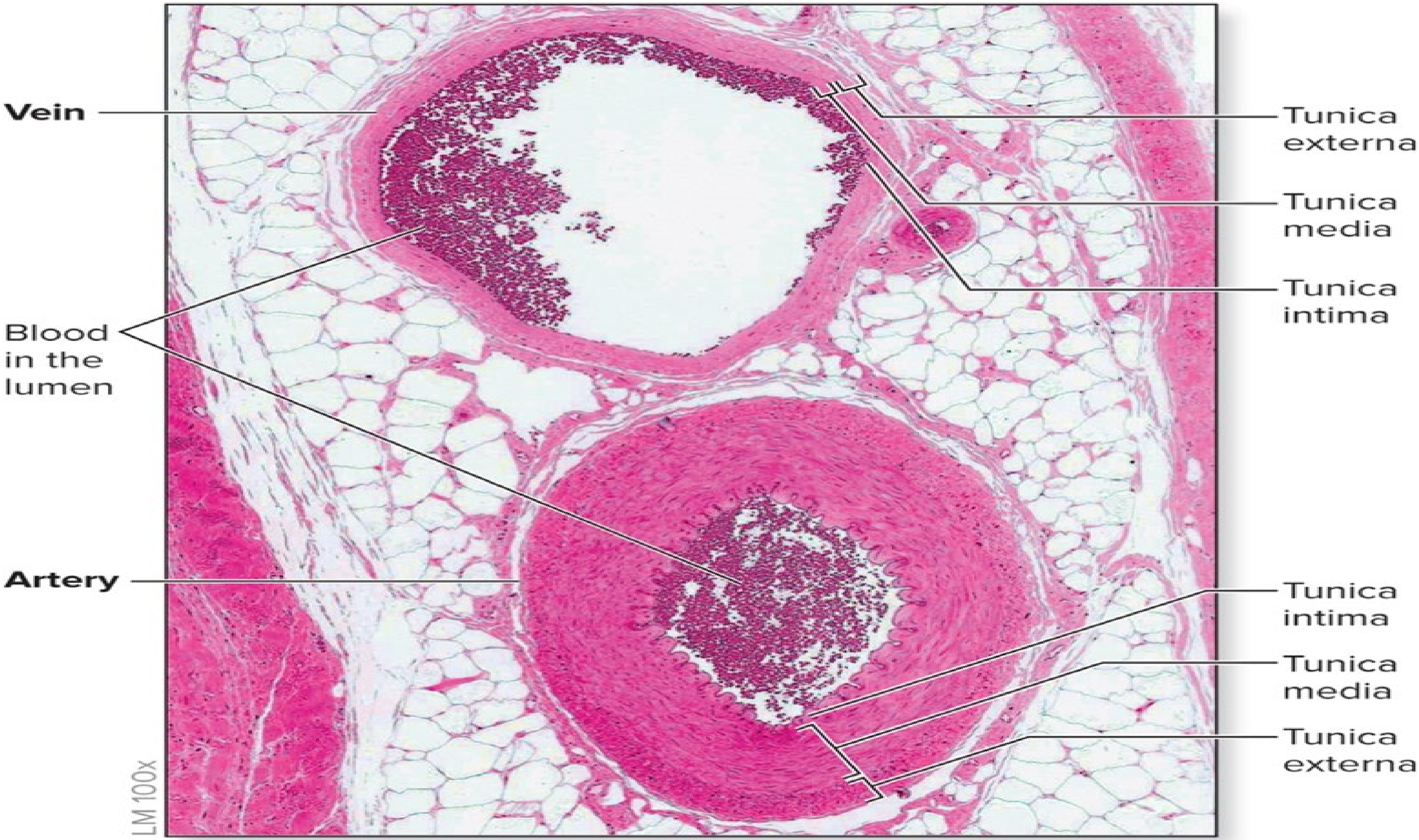
Arterioles: diameter is adjusted to regulate blood flow

Capillaries: diffusion occurs across thin walls









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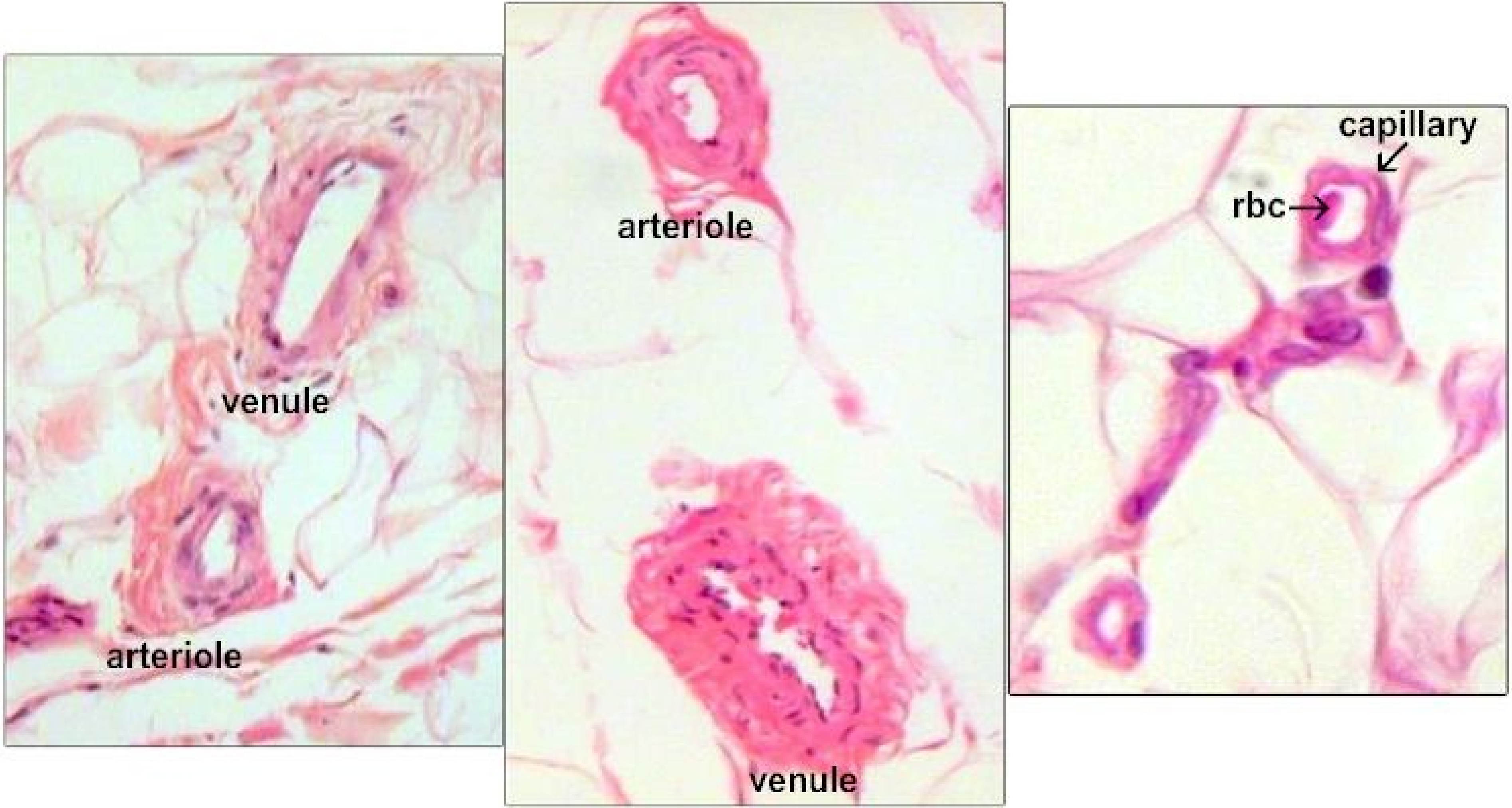
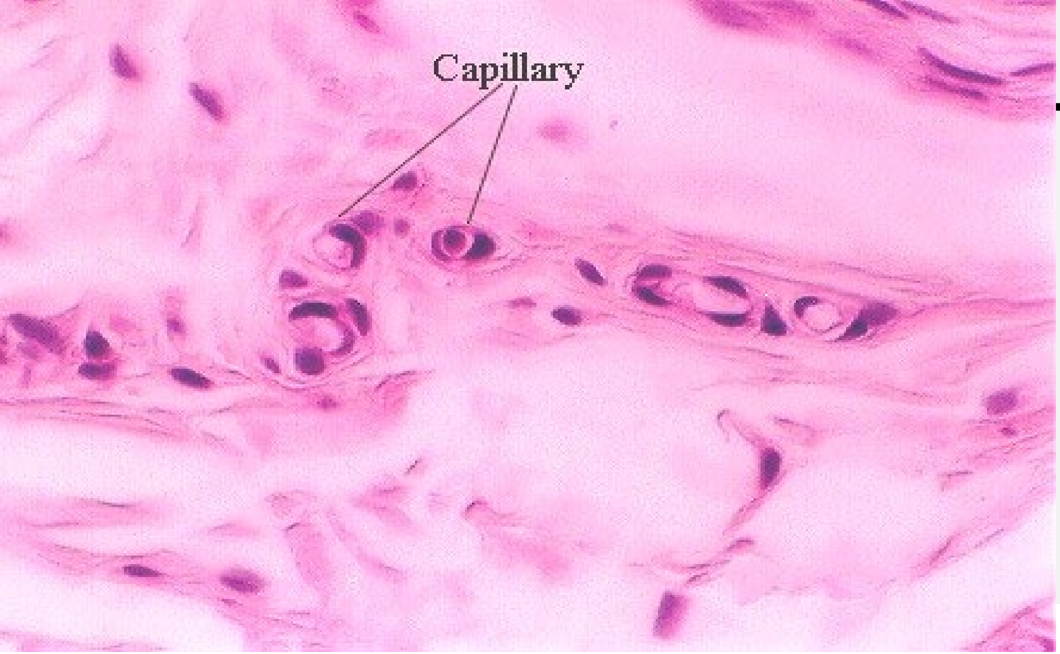

venule
arteriole
arteriole
venule
capillary
rbc

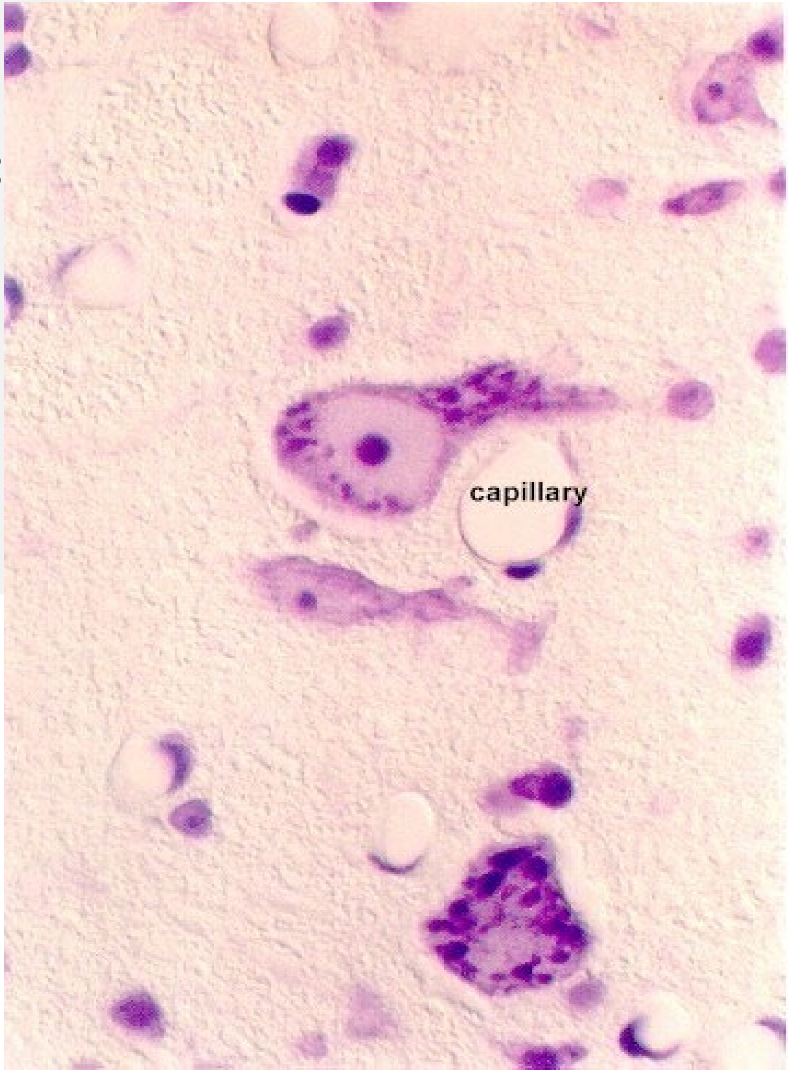
Table 20.1 Comparison of Companion Arteries and Veins

Characteristic	Artery	Vein
Lumen Diameter	Narrower than vein lumen	Wider than artery lumen
General Wall Thickness	Thicker than vein	Thinner than artery
Cross-Sectional Shape	Cross-sectional shape retained; even without blood in vessel	Cross-sectional shape tends to flatten out (collapse) without blood in vessel
Thickest Tunic	Tunica media	Tunica externa
Elastic and Collagen Fibers in Tunics	More than in vein	Less than in artery
Valves	None	Present in most veins
Blood Pressure Range	Higher than in veins (100 mm Hg in larger arteries to 40 mm Hg in smaller arterioles)	Lower than in arteries (20 mm Hg in venules to 0 mm Hg in the inferior vena cava)
Blood Flow	Transports blood away from heart to the body	Transports blood from the body toward the heart
Blood Oxygen Levels	Systemic arteries transport blood high in O_2 Pulmonary arteries transport blood low in O_2	Systemic veins transport blood low in O_2 Pulmonary veins transport blood high in O_2

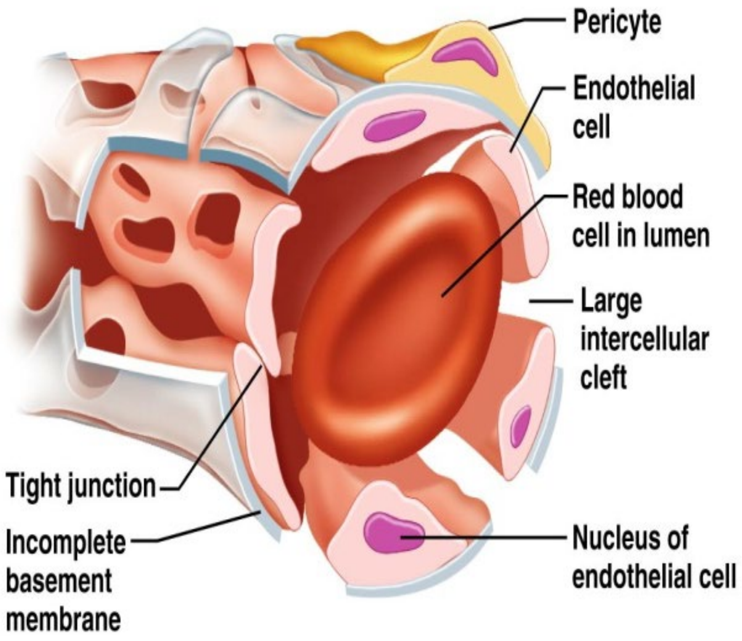
Capillaries



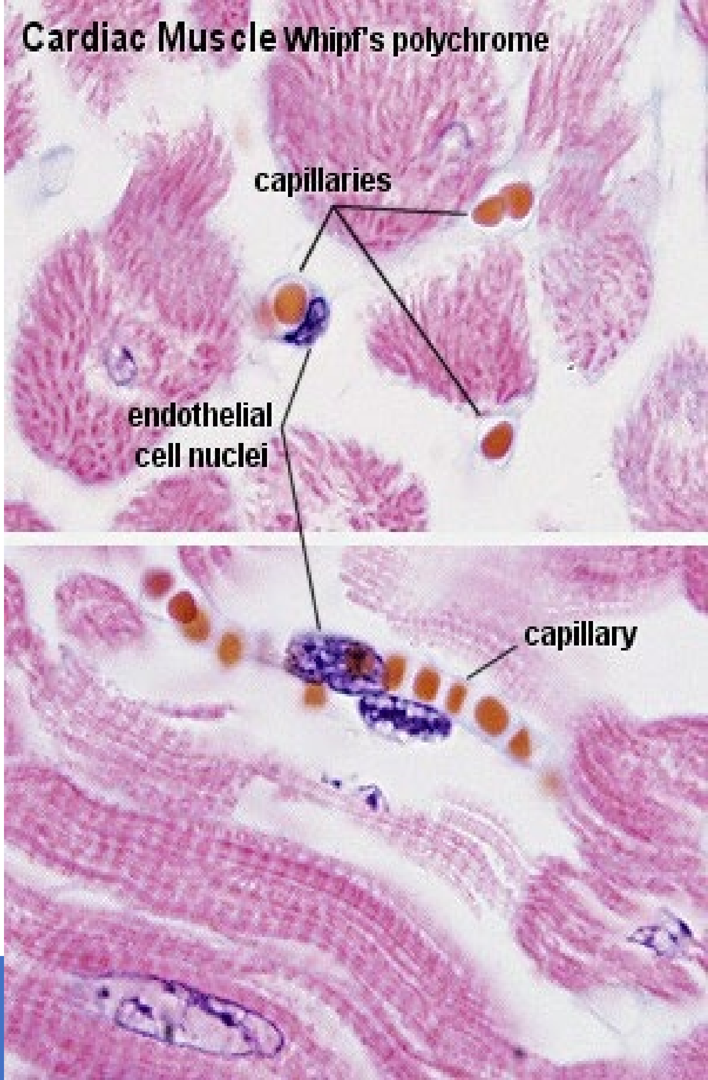
- Capillaries are tiny vessels lined by a single layer of endothelial cells.
- Capillary accomodates only one blood cell.



- Capillaries are the smallest blood vessels
  - Walls consisting of a thin tunica interna, one cell thick
  - Allow only a single RBC to pass at a time
  - **Pericyte**s on the outer surface stabilize their walls
- There are three structural types of capillaries: **continuous, fenestrated, and sinusoids**



Capillaries

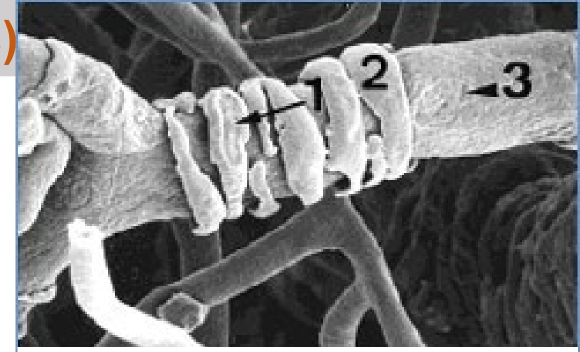


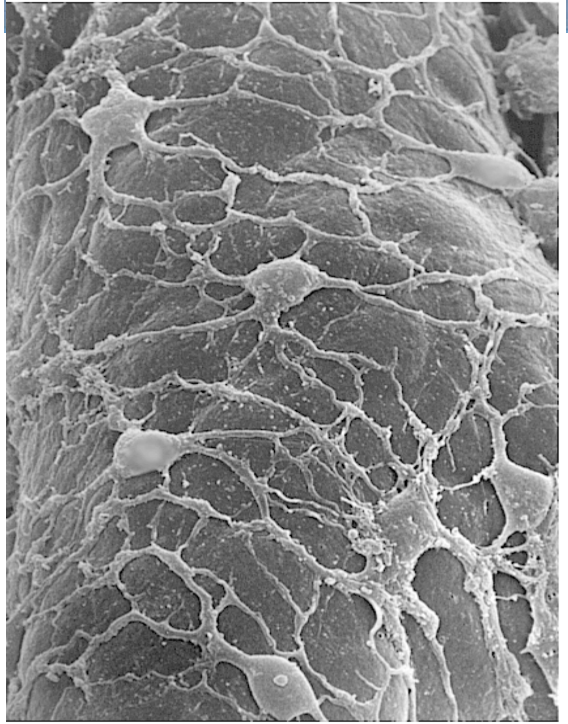
Pericytes (Perivascular cells)

- Many capillaries have inconspicuous, elongated cells, similar in appearance to embryonic mesenchymal cells, associated with them.
- These cells, known as **pericytes**, or **perivascular cells**, are quite difficult to see in most histological preparations.
- **These pericytes appear to have important roles in repair of blood vessels and connective tissue after injury**.
- They have the potential to develop into fibroblasts, smooth muscle cells and may even be phagocytic.

- Endothelial cells are known to produce a variety of local factors that are important in the functioning of the cardiovasystem. These include nitric oxide.

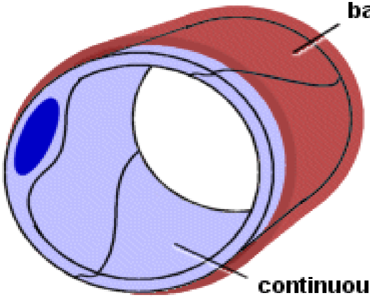
- it serves to **support these vessels**,
- it can differentiate into a **fibroblast, smooth muscle cell, or macrophage** if required.
- In order to migrate into the interstitium, the pericyte has to break the barrier, formed by the basement membrane, which can be accomplished by **fusion with the membrane**.
- **They are important in blood-brain barrier stability as well as angiogenesis**.
- They have been implicated in **blood flow regulation at the capillary level.**
- Their expression of smooth muscle actin (SMA) and desmin, two proteins found in smooth muscle cells, and their adherence to the endovascular cells makes them very strong candidates for **blood flow regulators in the microvasculature.**



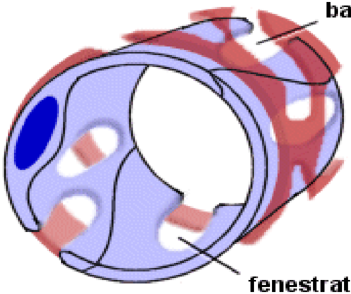


Blood Vessel Anatomy

Continuous Capillary



Discontinuous Capillary



Fenestrated Capillary

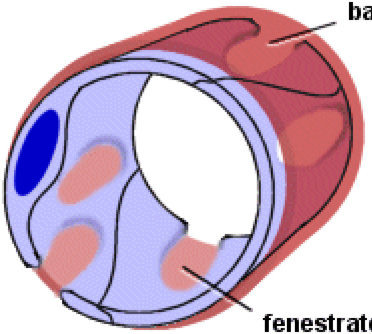
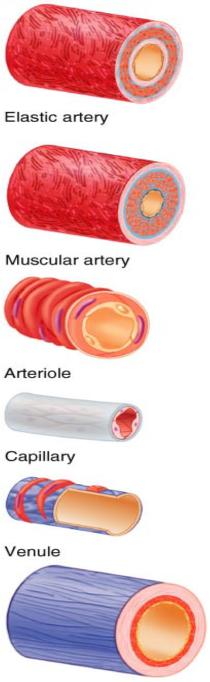
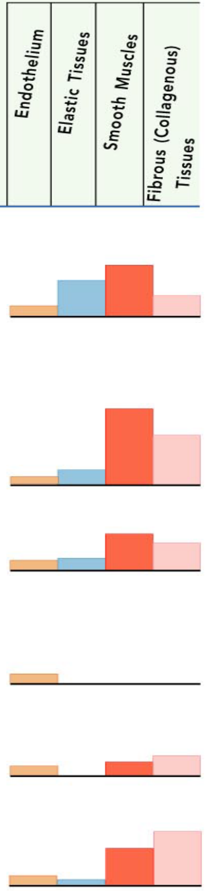


TABLE 19.1 Summary of Blood Vessel Anatomy



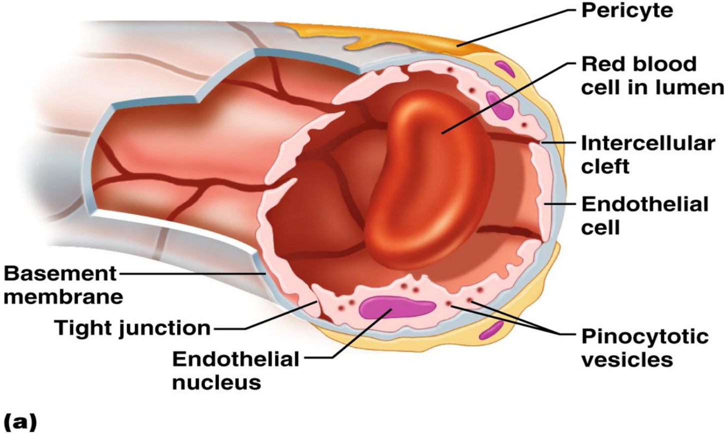


VESSEL TYPE/ ILLUSTRATION*	AVERAGE LUMEN DIAMETER (D) AND WALL THICKNESS (T)	RELATIVE TISSUE MAKEUP
Elastic artery	D : 1.5 cm T : 1.0 mm	
Muscular artery	D : 6.0 mm T : 1.0 mm	
Arteriole	D : 37.0 µm T : 6.0 µm	
Capillary	D : 9.0 µm T : 0.5 µm	
Venule	D : 20.0 µm T : 1.0 µm	
Vein	D : 5.0 mm T : 0.5 mm	

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

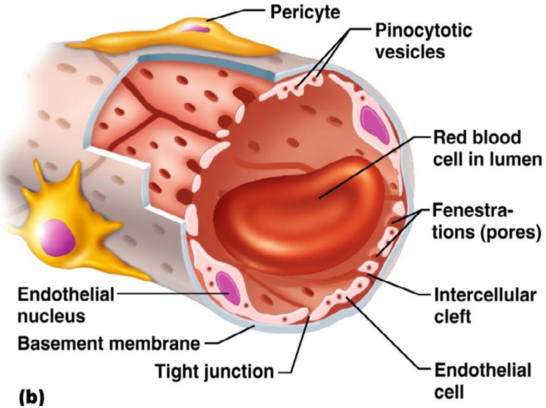
Continuous Capillaries

- Continuous capillaries are abundant in the skin and muscles
    - Endothelial cells provide an uninterrupted lining
    - Adjacent cells are connected with tight junctions
    - Intercellular clefts allow the passage of fluids
- Continuous capillaries of the brain:
    - Have tight junctions completely around the endothelium
    - Constitute the blood-brain barrier



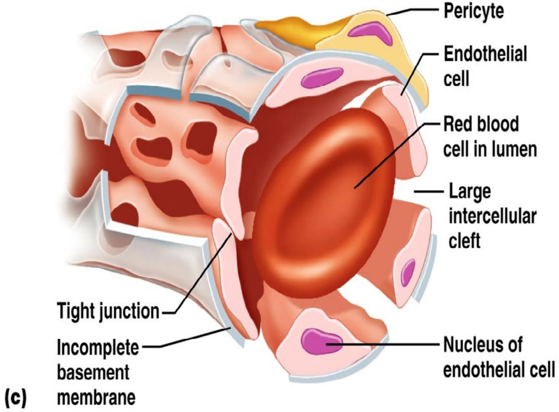
Fenestrated Capillaries

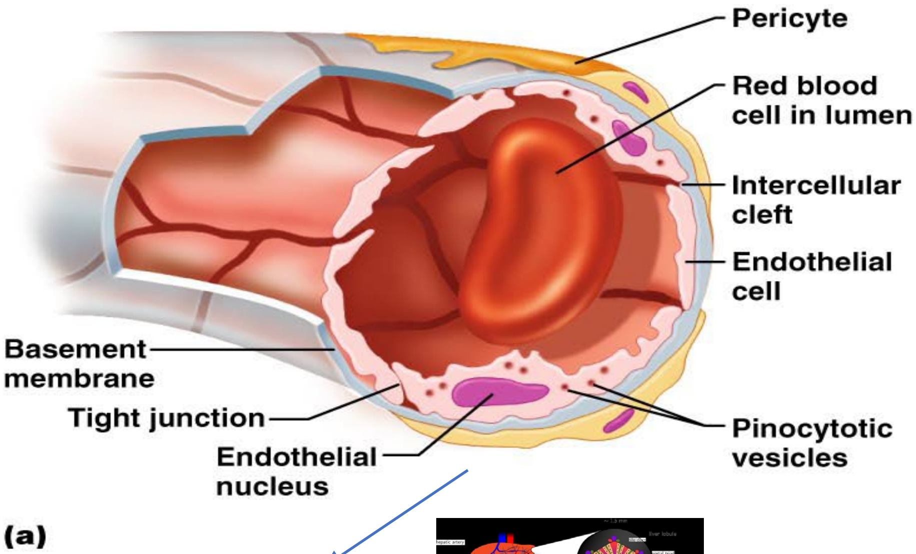
- Found wherever active capillary absorption or filtrate formation occurs (e.g., small intestines, endocrine glands, and kidneys)
- Characterized by:
    - An endothelium riddled with pores (fenestrations)
    - Greater permeability than other capillaries

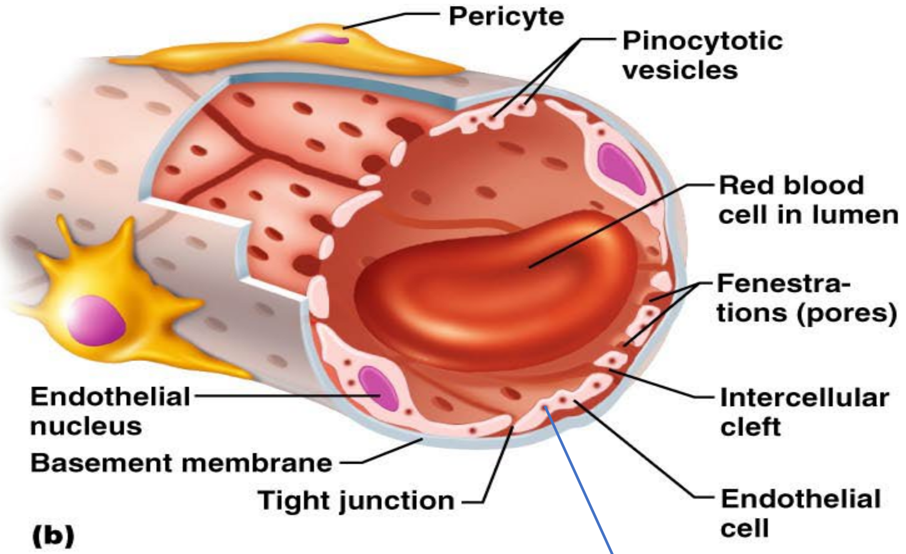


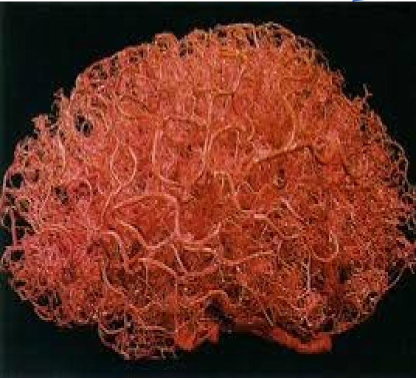
Sinusoids

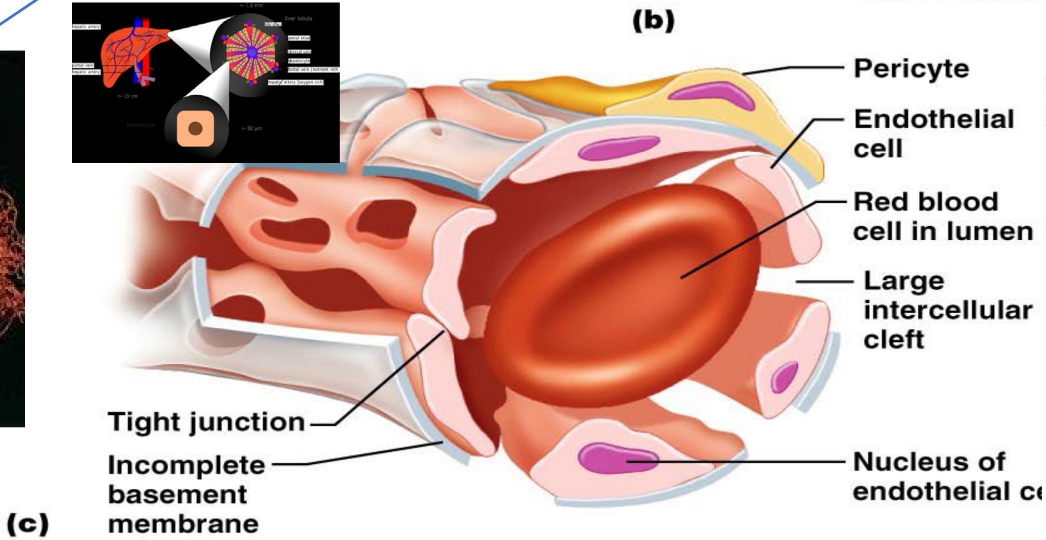
- Highly modified, leaky, fenestrated capillaries with large lumens
- Found in the liver, bone marrow, lymphoid tissue, and in some endocrine organs
- Allow large molecules (proteins and blood cells) to pass between the blood and surrounding tissues
- Blood flows sluggishly, allowing for modification in various ways




Pericyte
Red blood cell in lumen
Intercellular cleft
Endothelial cell
Basement membrane
Tight junction
Endothelial nucleus
Pinocytotic vesicles
(a)


Pericyte
Pinocytotic vesicles
Red blood cell in lumen
Fenestrations (pores)
Intercellular cleft
Endothelial cell
Endothelial nucleus
Basement membrane
Tight junction
(b)




Pericyte
Endothelial cell
Red blood cell in lumen
Large intercellular cleft
Tight junction
Incomplete basement membrane
Nucleus of endothelial ce
(c)

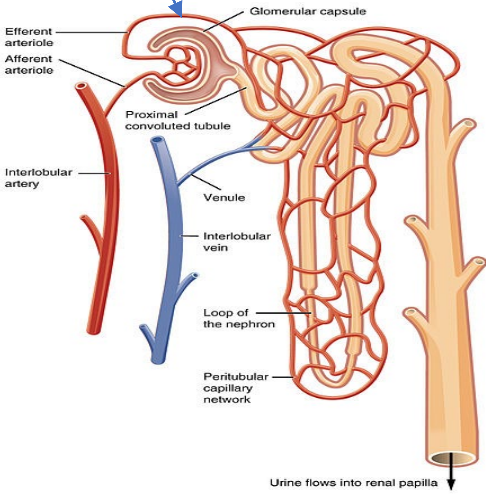
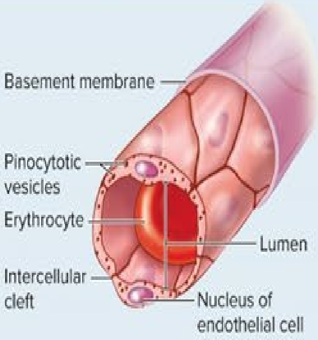
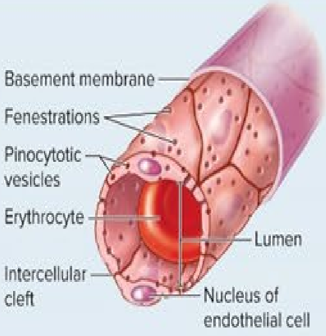
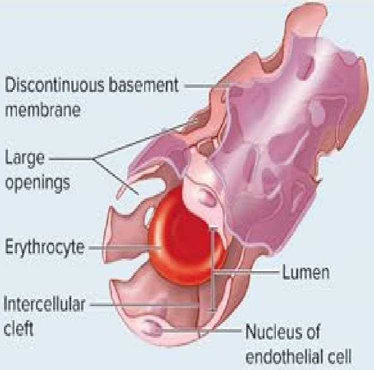
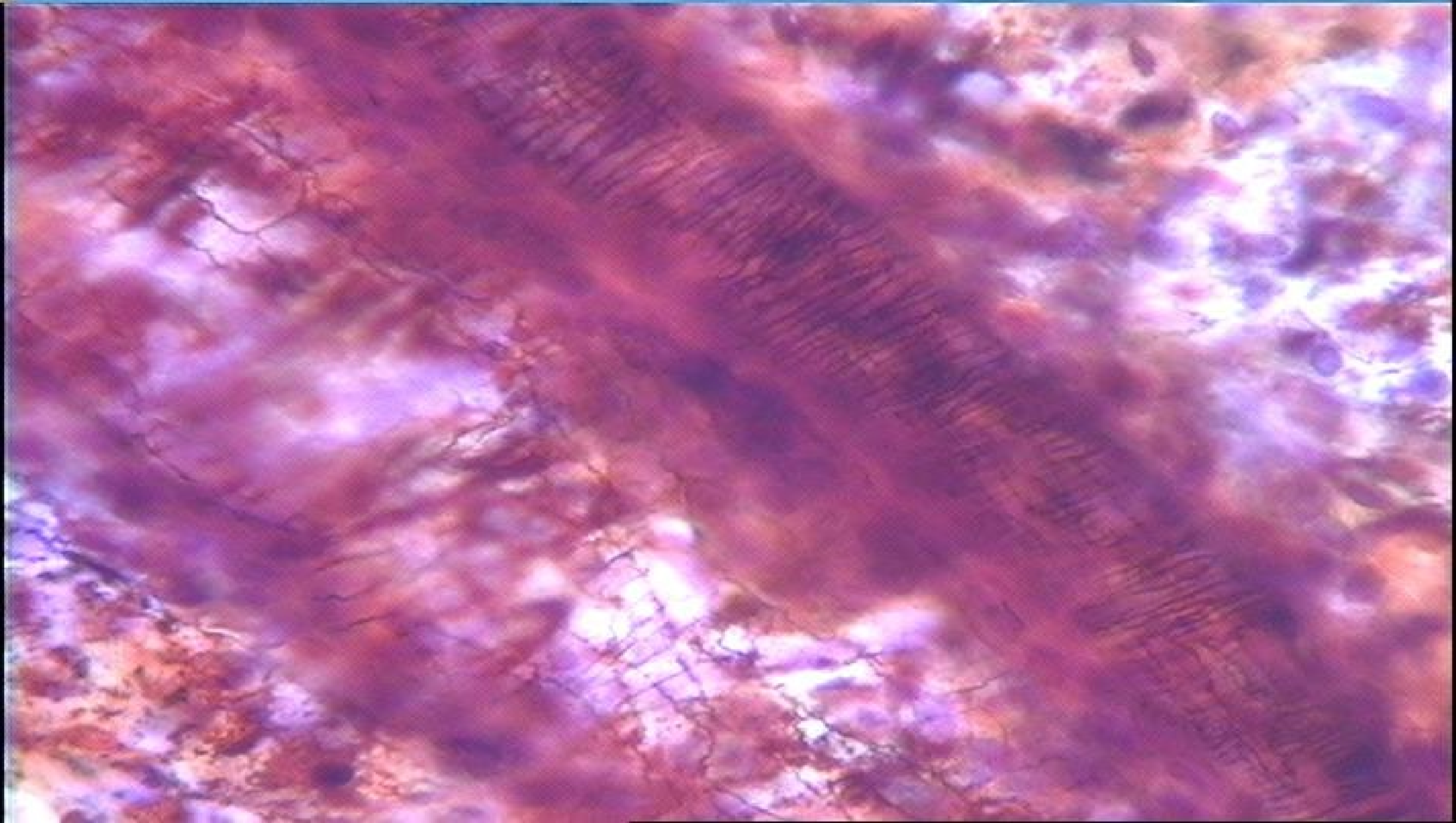
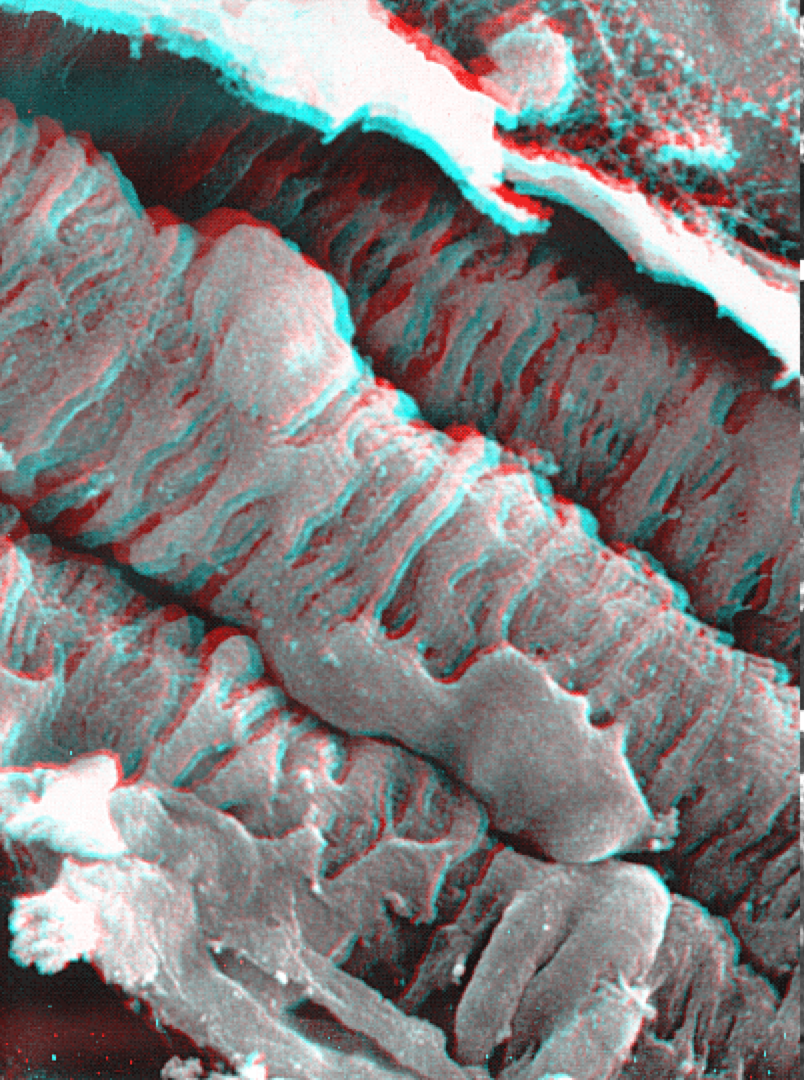
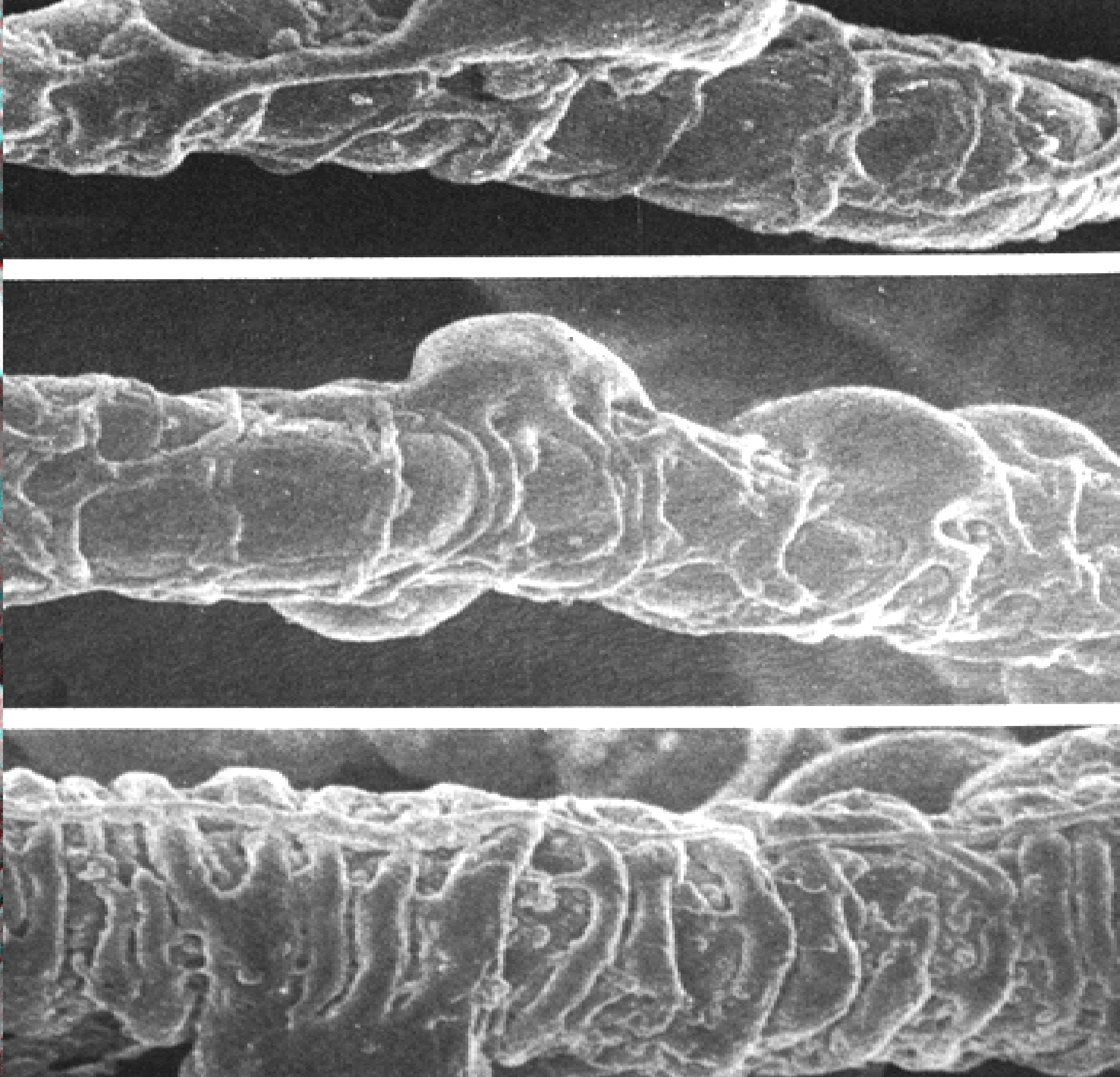

Glomerular capsule
Efferent arteriole
Afferent arteriole
Proximal convoluted tubule
Interlobular artery
Venule
Interlobular vein
Loop of the nephron
Peritubular capillary network
Urine flows into renal papilla

Table 20.2 Types of Capillaries

Characteristics	(a) Continuous Capillary	(b) Fenestrated Capillary	(c) Sinusoid
Structure			
Description	Lining of endothelial cells is complete around lumen; basement membrane is complete; intercellular clefts between endothelial cells	Same as continuous capillary, except also contains fenestrations	Lining of endothelial cells is incomplete around lumen; basement membrane is incomplete or absent
Materials That Pass Through Vessel Wall	Plasma and its contents (except most proteins); some leukocytes	Large amounts of materials are filtered, released, or absorbed; some smaller proteins	Large substances (formed elements, large plasma proteins) and plasma
Locations	Most capillaries (e.g., capillaries within muscles, skin, thymus, lungs, and central nervous system [CNS])	Small intestine; for absorbing nutrients Ciliary process; to produce aqueous humor in the eye Choroid plexus; to produce cerebrospinal fluid (CSF) in the brain Most endocrine glands; for release of hormones into the blood Kidneys; for filtering blood	Red bone marrow; for formed elements to enter the blood Liver and spleen; for removal of old erythrocytes from the cardiovascular circulation Some endocrine glands (anterior pituitary, adrenal, and parathyroid); for release of hormones into the blood

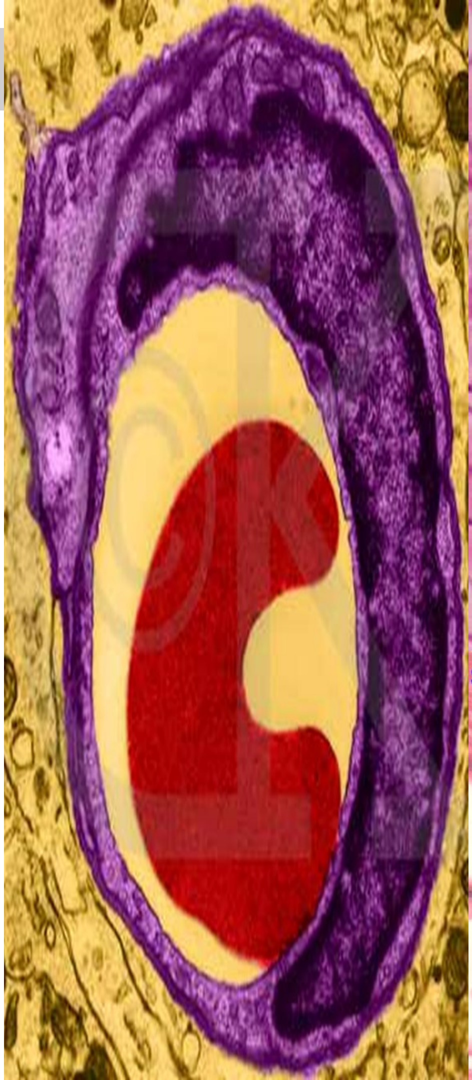


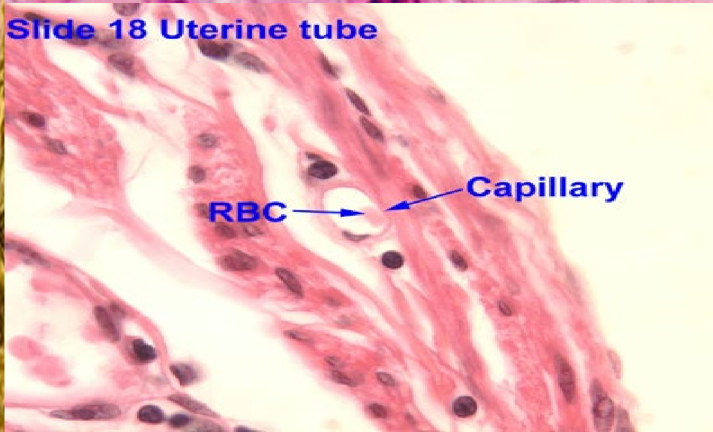


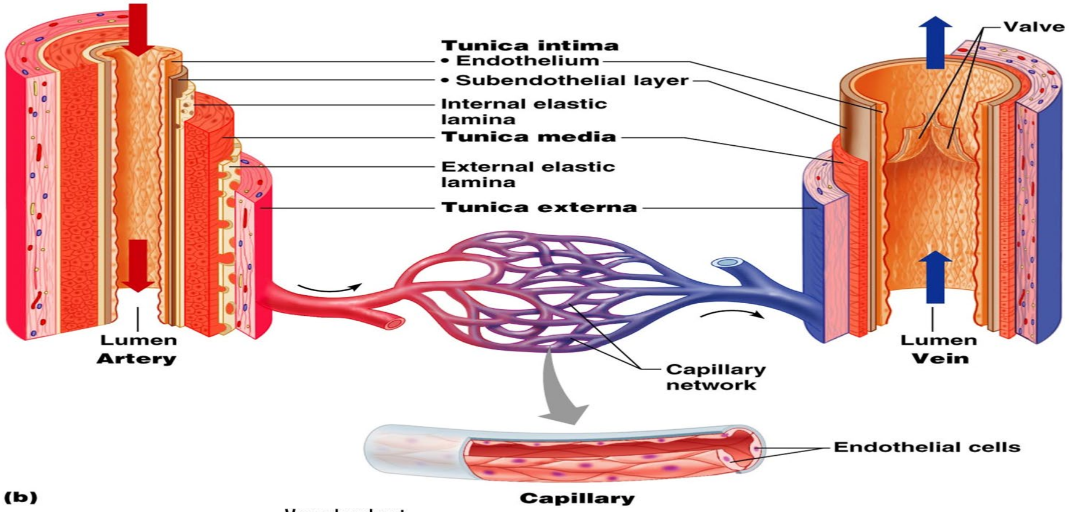


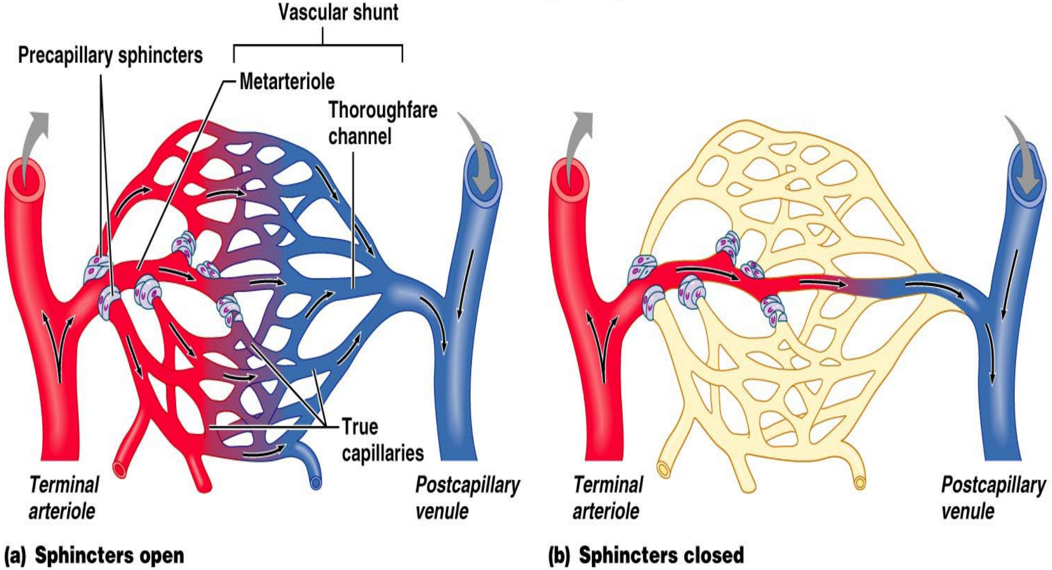
Capillary Beds

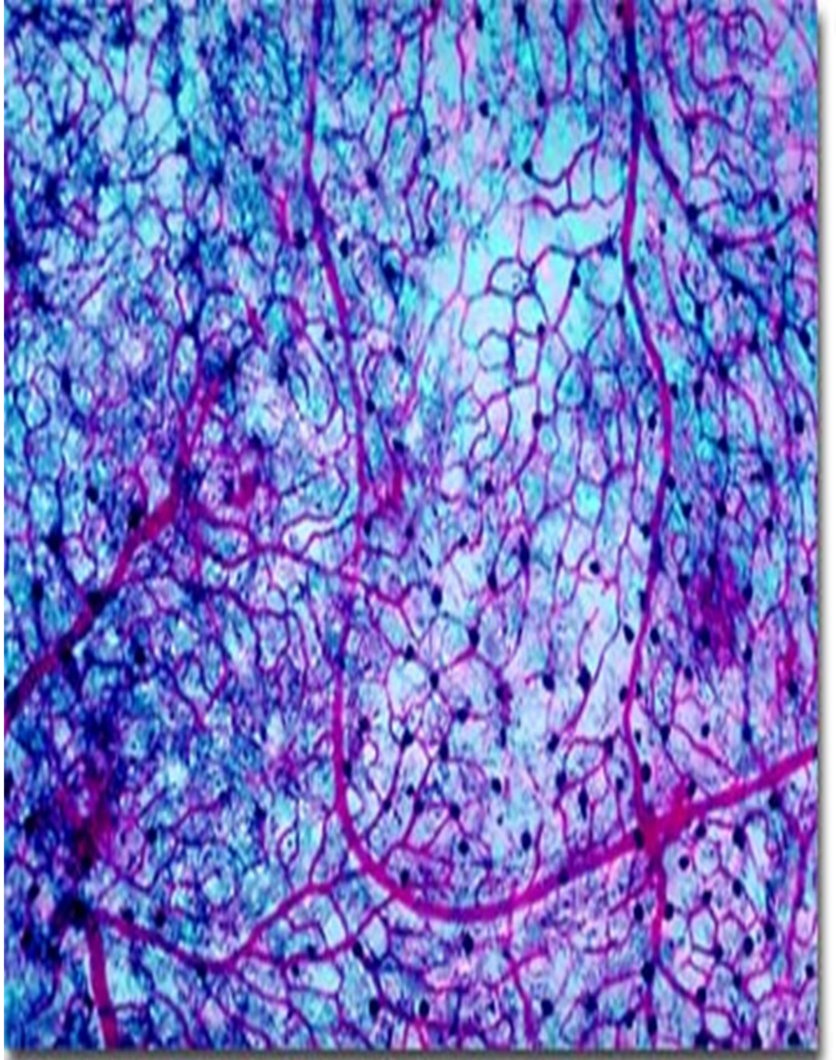
- A microcirculation of interwoven networks of capillaries, consisting of:
  - Vascular shunts – metarteriole–thoroughfare channel connecting an arteriole directly with a postcapillary venule
  - True capillaries – 10 to 100 per capillary bed, capillaries branch off the metarteriole and return to the thoroughfare channel at the distal end of the bed

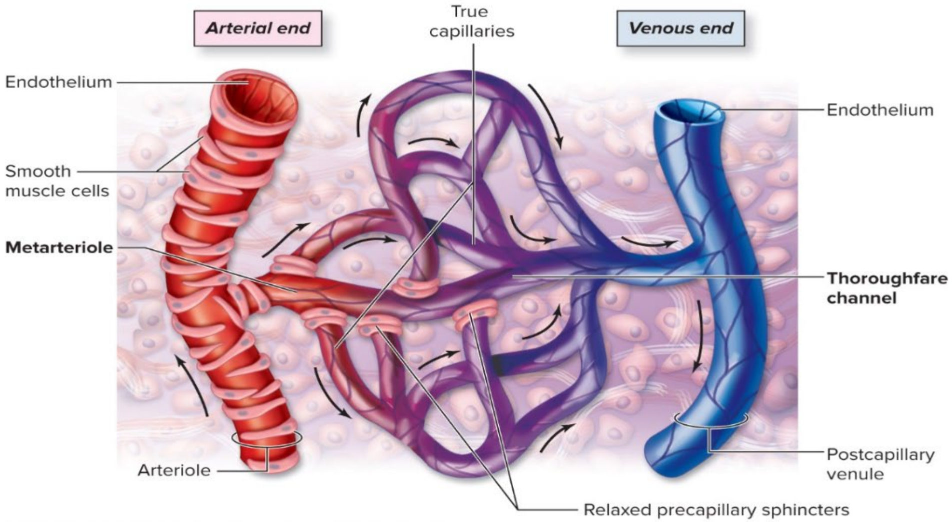




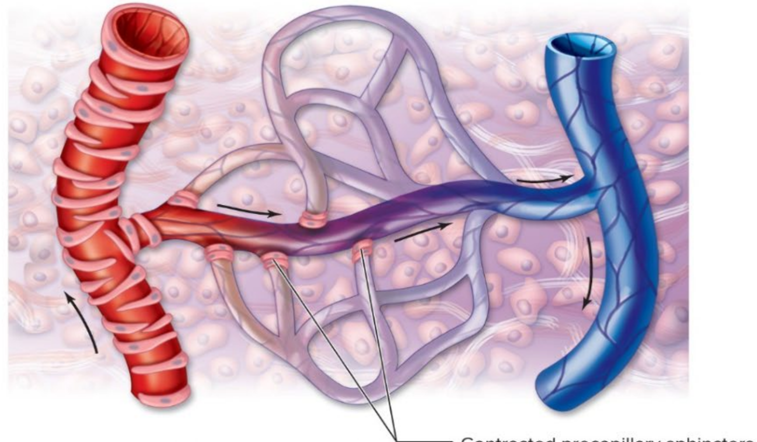

Tunica intima
• Endothelium
• Subendothelial layer
Internal elastic lamina
Tunica media
External elastic lamina
Tunica externa
Valve
Lumen
Artery
Lumen
Vein
Capillary network
Endothelial cells
Capillary
(b)


Vascular shunt
Precapillary sphincters
Metarteriole
Thoroughfare channel
True capillaries
Terminal arteriole
Postcapillary venule
Terminal arteriole
Postcapillary venule
(a) Sphincters open
(b) Sphincters closed

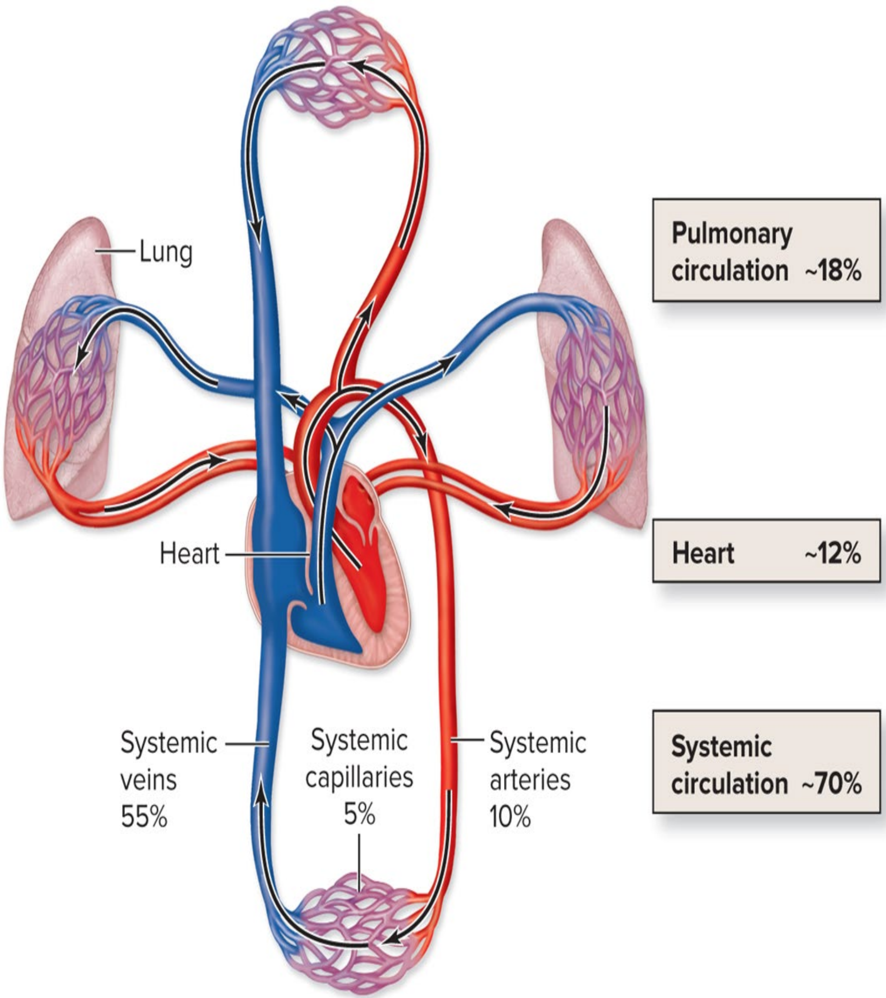


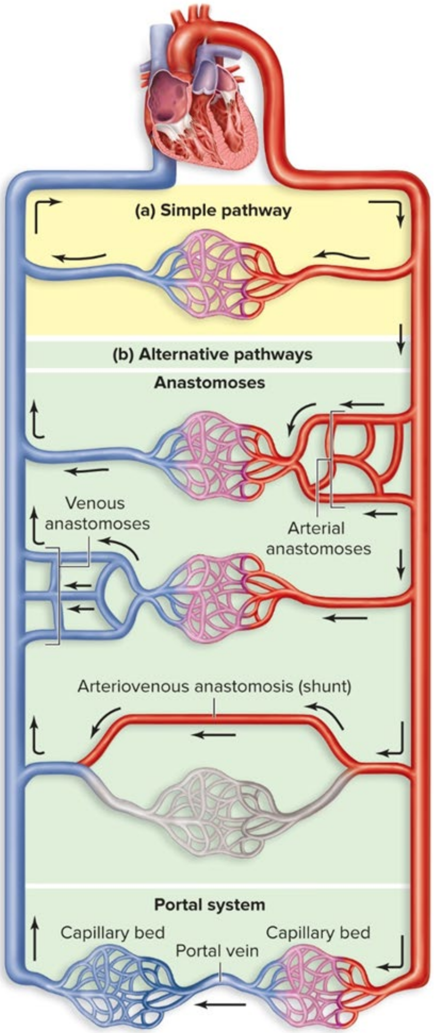


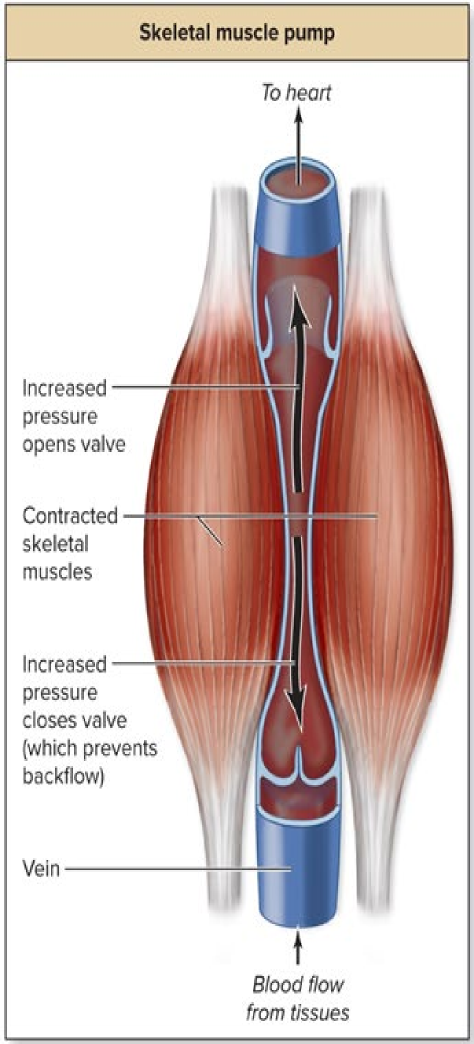
(a) Sphincters relaxed; capillary bed well perfused



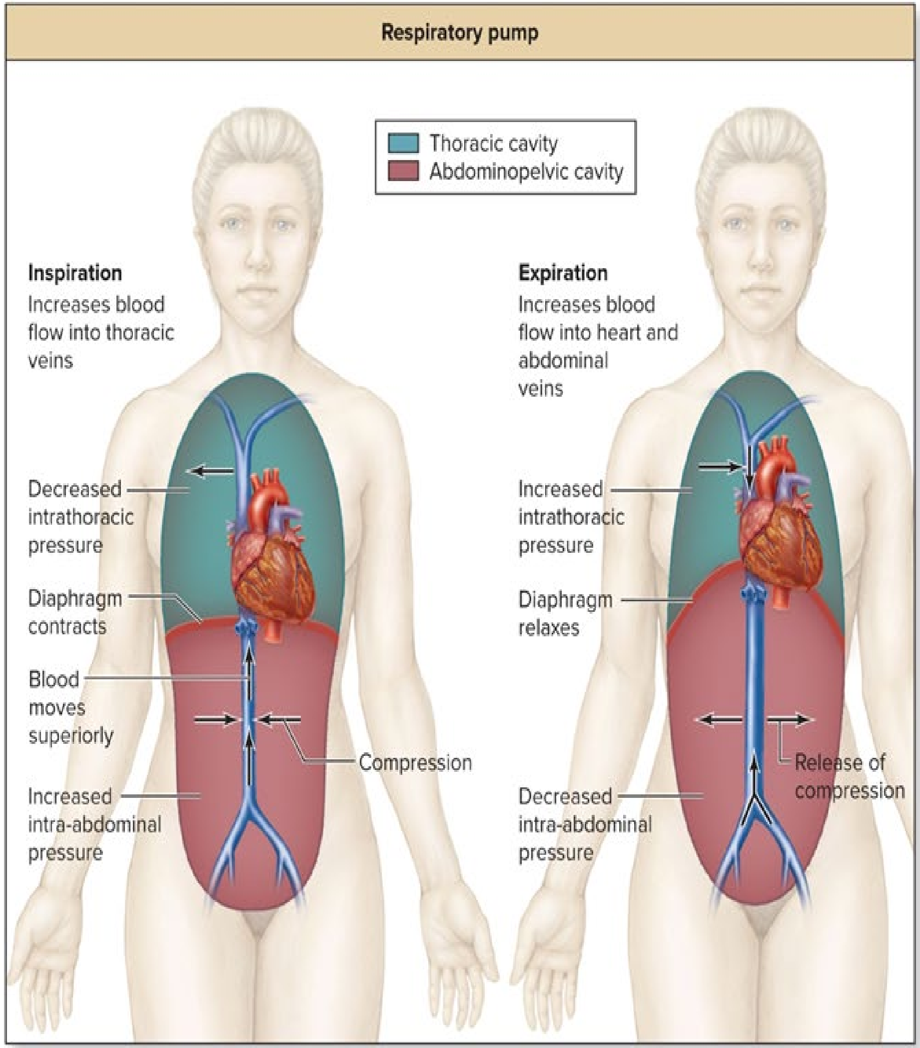
(b) Sphincters contracted; blood bypasses capillary bed




(a) Simple pathway
(b) Alternative pathways
Anastomoses
Venous anastomoses
Arterial anastomoses
Arteriovenous anastomosis (shunt)
Portal system
Capillary bed
Portal vein
Capillary bed


Skeletal muscle pump
To heart
Increased pressure opens valve
Contracted skeletal muscles
Increased pressure closes valve (which prevents backflow)
Vein
Blood flow from tissues

(a)


Respiratory pump
Thoracic cavity
Abdominopelvic cavity
Inspiration
Increases blood flow into thoracic veins
Decreased intrathoracic pressure
Diaphragm contracts
Blood moves superiorly
Compression
Increased intra-abdominal pressure
Expiration
Increases blood flow into heart and abdominal veins
Increased intrathoracic pressure
Diaphragm relaxes
Release of compression
Decreased intra-abdominal pressure

(b)

Mechanisms of Capillary Exchange

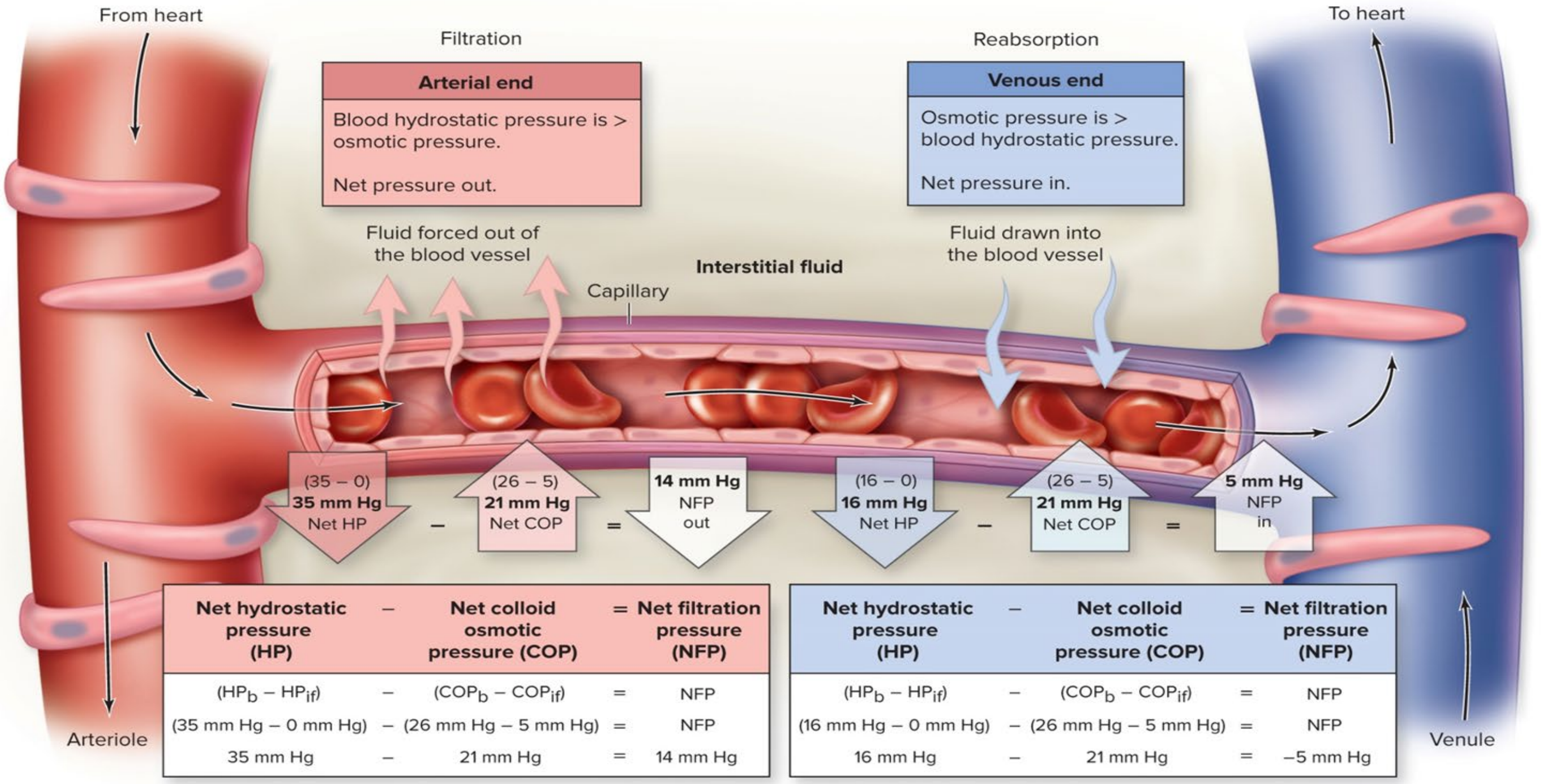
1.Diffusion:

1. **Simple Diffusion**: Movement of molecules from an area of higher concentration to an area of lower concentration directly through the capillary endothelial cell membranes.
2. **Facilitated Diffusion**: Movement of larger or polar molecules through specific transport proteins in the endothelial cell membranes.
3. **Factors Influencing Diffusion**:
   1. Concentration gradients: Substances move along their concentration gradients.
   2. Membrane permeability: The permeability of the endothelial cell membranes to specific substances.
   3. Surface area: The larger the surface area of the capillaries, the greater the rate of diffusion.

Filtration and Reabsorption:

- **Filtration**: Movement of fluid and small solutes from the capillaries into the interstitial fluid due to hydrostatic pressure.
- **Reabsorption**: Movement of fluid from the interstitial fluid back into the capillaries due to osmotic pressure, primarily driven by plasma proteins.
- **Forces Involved (Starling Forces)**:
  - Capillary hydrostatic pressure (CHP): The pressure exerted by blood against the capillary walls, pushing fluid out of the capillaries.
  - Interstitial fluid hydrostatic pressure (IFHP): The pressure exerted by the interstitial fluid, which can push fluid back into the capillaries.
  - Blood colloid osmotic pressure (BCOP): The osmotic pressure exerted by plasma proteins, drawing fluid into the capillaries.
  - Interstitial fluid osmotic pressure (IFOP): The osmotic pressure in the interstitial fluid, which can draw fluid out of the capillaries.

Capillary Exchange

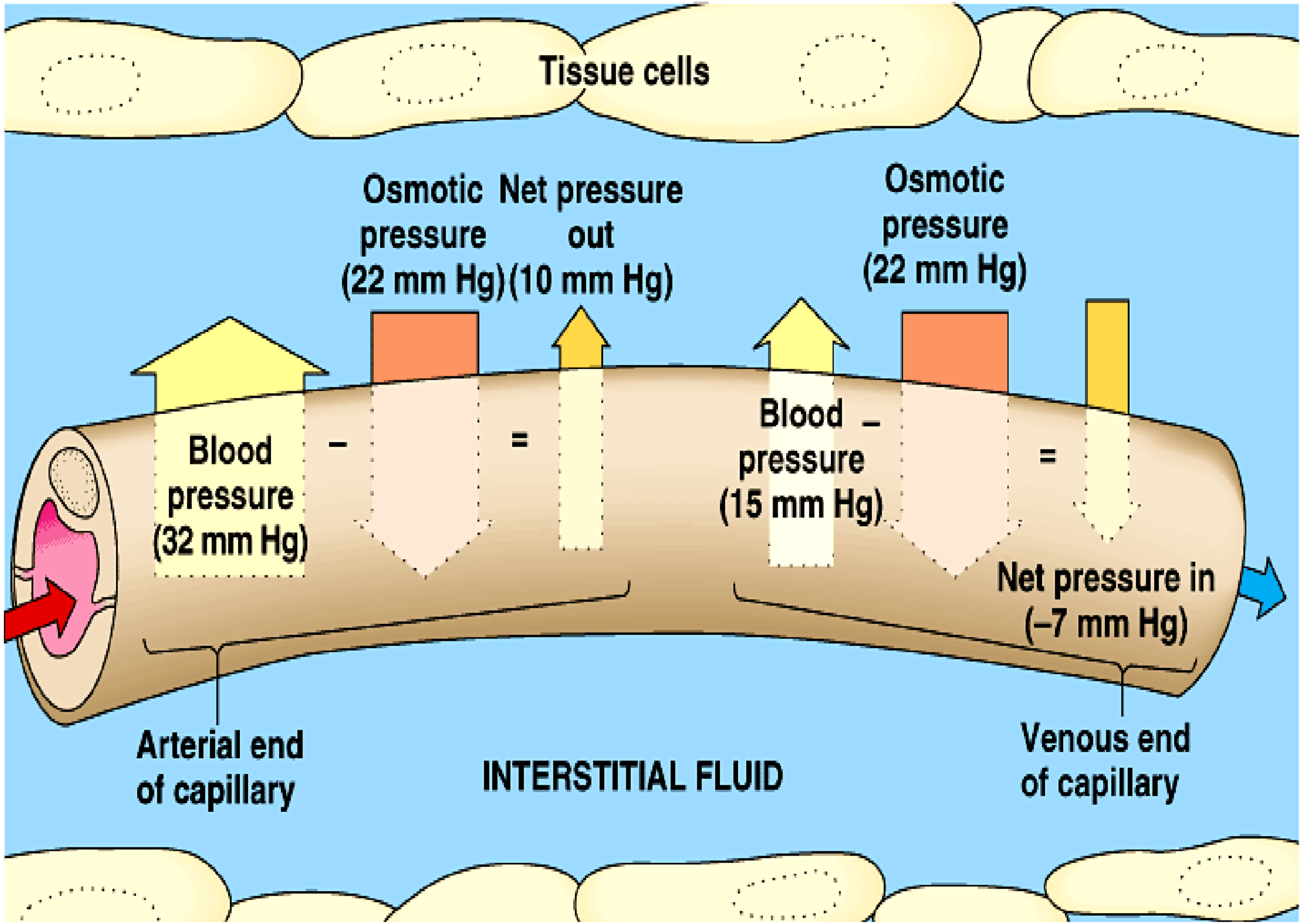


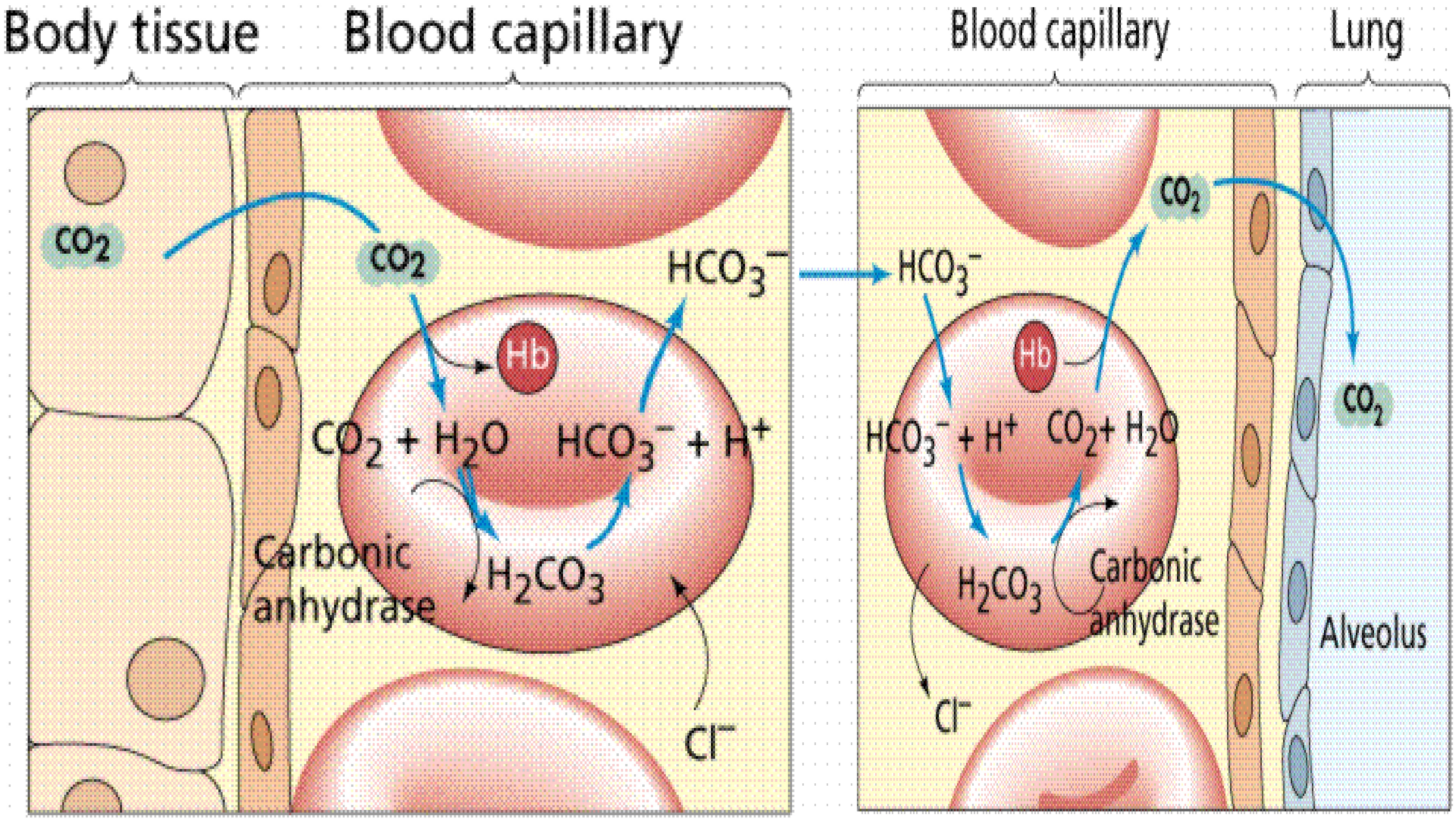
Transcytosis:
•Movement of larger molecules, such as proteins, across the endothelial cells via vesicles.
•Involves endocytosis (engulfing the molecule into the cell) on one side of the endothelial cell and exocytosis (releasing the molecule) on the other side.
•Important for the transport of substances that cannot pass through the endothelial cell membranes by diffusion or filtration.

Factors Affecting Capillary Exchange

1. **Hydrostatic Pressure**:
    1. **Capillary Hydrostatic Pressure (CHP)**: Promotes filtration by pushing fluid out of the capillaries.
    2. **Interstitial Fluid Hydrostatic Pressure (IFHP)**: Usually low, but can influence reabsorption if it rises.
2. **Osmotic Pressure**:
    1. **Blood Colloid Osmotic Pressure (BCOP)**: Promotes reabsorption by drawing fluid into the capillaries.
    2. **Interstitial Fluid Osmotic Pressure (IFOP)**: Usually low, but can affect filtration if it increases.
3. **Permeability of Capillary Walls**:
    1. The structure and integrity of the capillary endothelium determine the ease with which substances can pass through.
4. **Surface Area and Capillary Density**:
    1. Higher surface area and density enhance the efficiency of capillary exchange.

- **The movement of fluid between capillaries and the interstitial fluid.** Fluids flow out of a capillary at the upstream end near an arteriole and reenters a capillary downstream near a venule.
- The direction of fluid movement across the capillary wall at any point depends on the difference between two opposing forces: blood pressure and osmotic pressure.

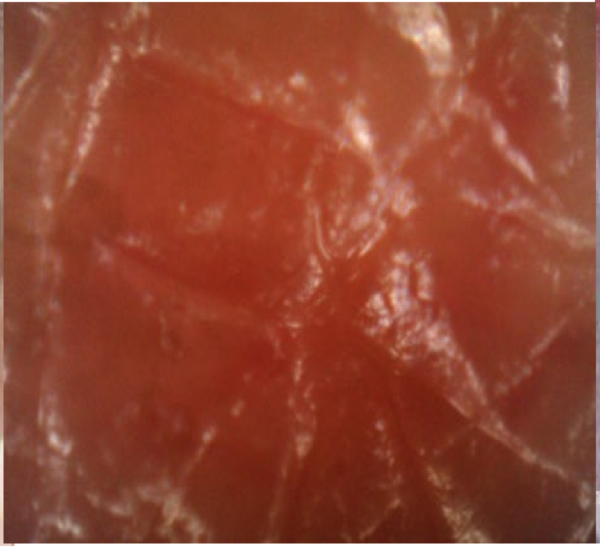




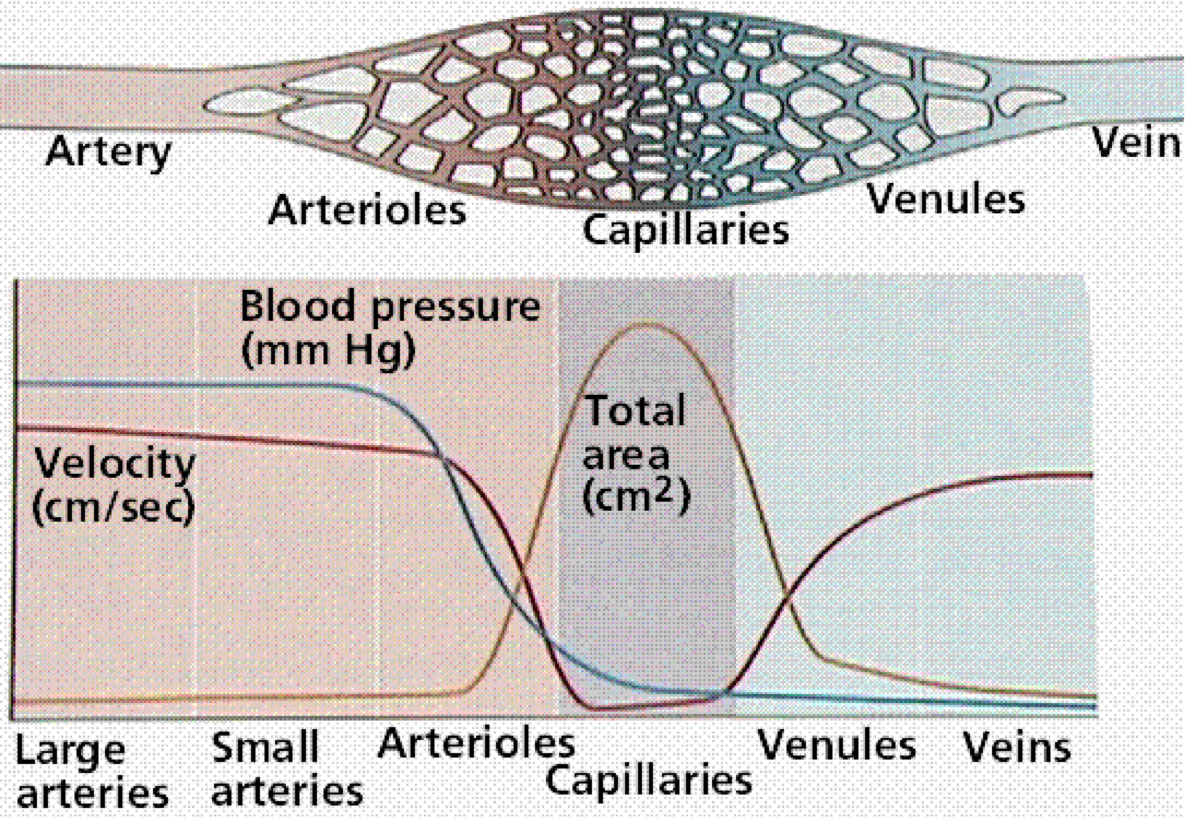
Body tissue
Blood capillary
Blood capillary
Lung
CO_2
CO_2
Hb
$CO_2 + H_2O$
$HCO_3^- + H^+$
HCO_3^-
Carbonic anhydrase
H_2CO_3
Cl^-
HCO_3^-
CO_2
Hb
$HCO_3^- + H^+$
$CO_2 + H_2O$
CO_2
H_2CO_3
Carbonic anhydrase
Alveolus
Cl^-

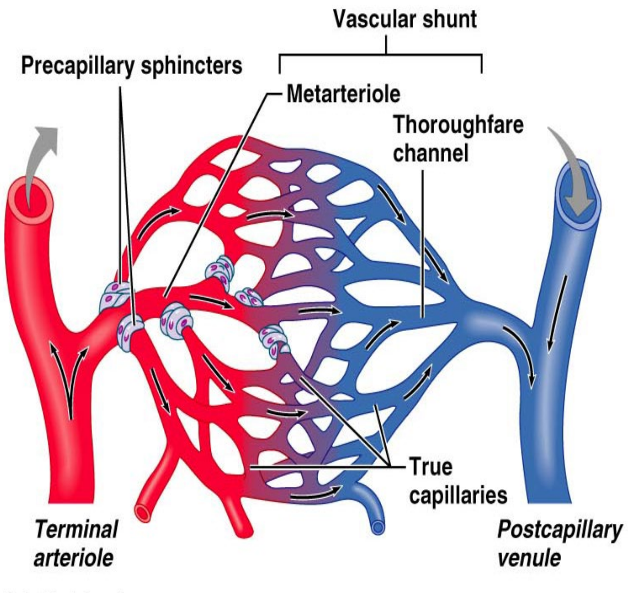
Blood Flow Through Capillary Beds

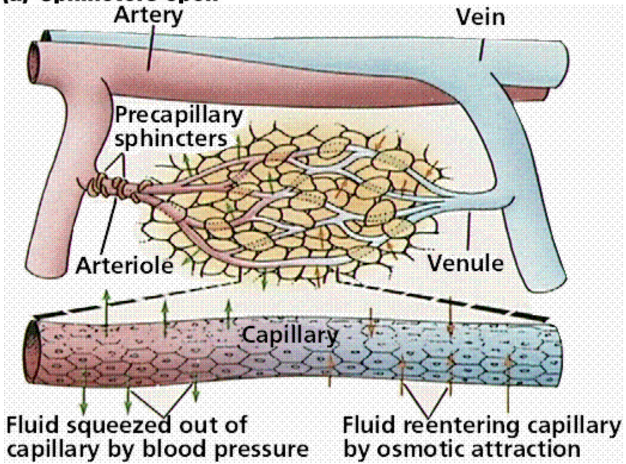
- **Precapillary sphincter**
  - Cuff of smooth muscle that surrounds each true capillary
  - Regulates blood flow into the capillary
- **Blood flow is regulated by vasomotor nerves and local chemical conditions**

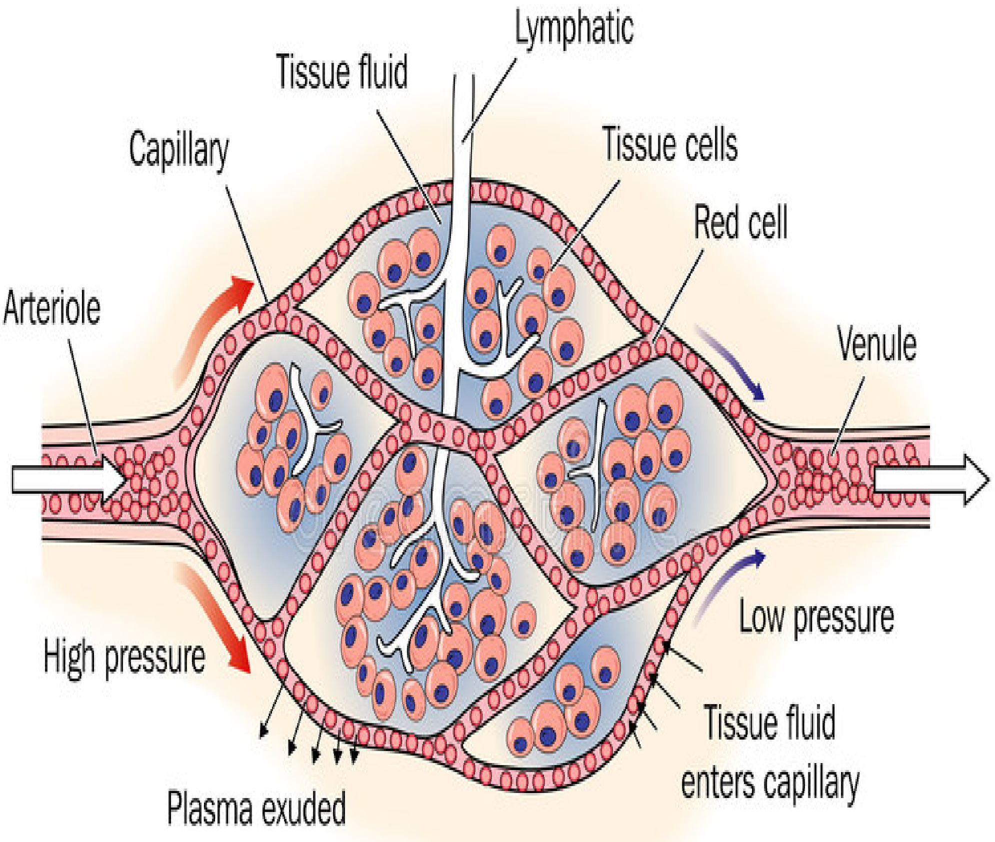


Capillary Beds

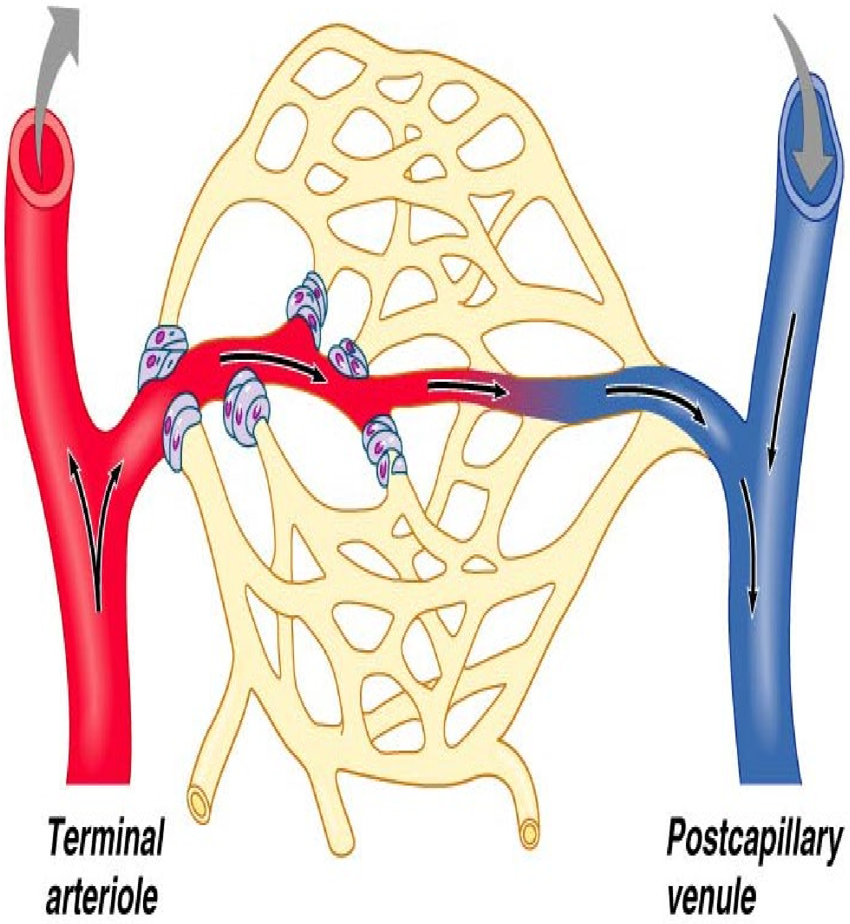




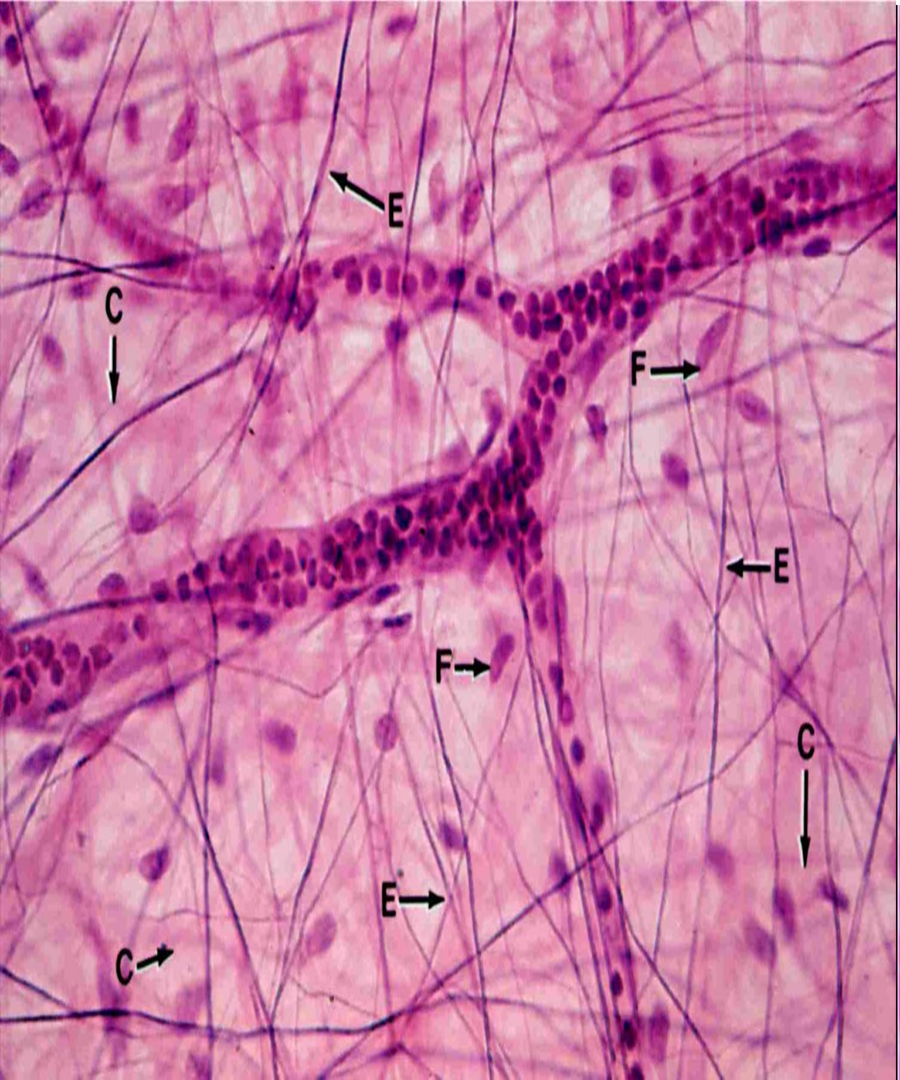




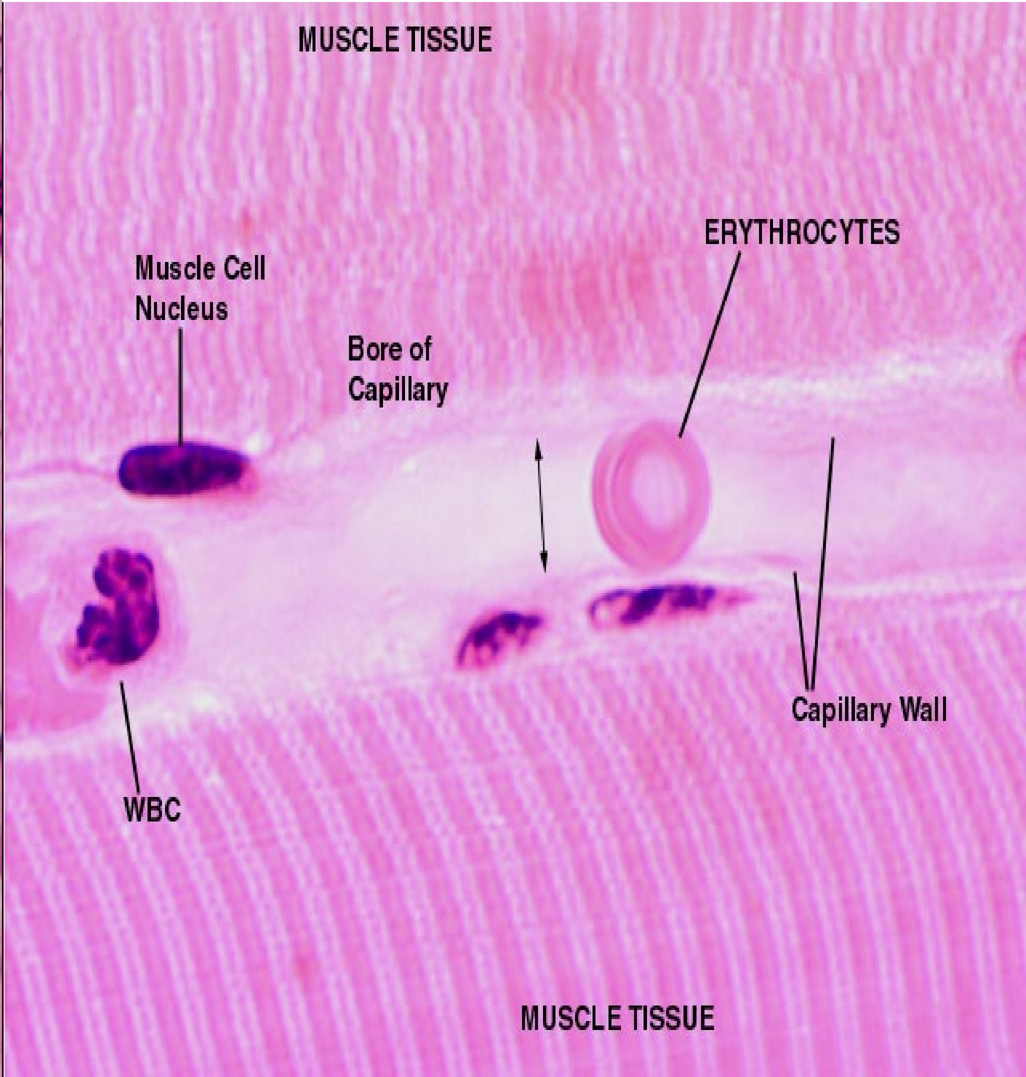
Capillary bed



(b) Sphincters closed



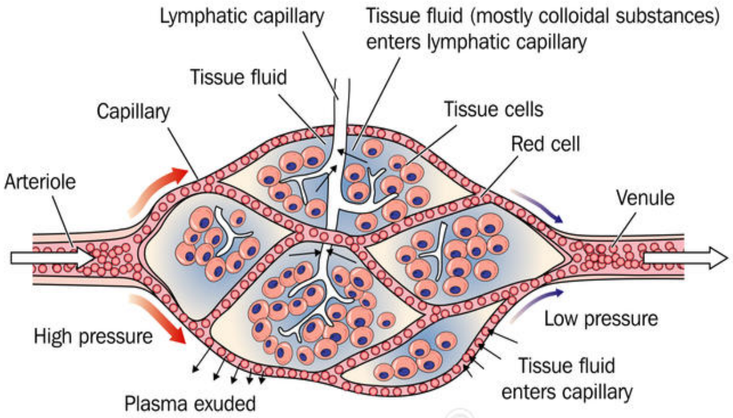
E
C
F
E
F
C
E
C



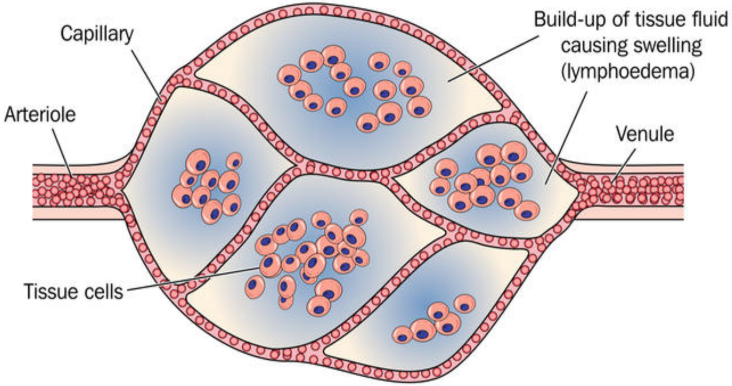
MUSCLE TISSUE
ERYTHROCYTES
Muscle Cell
Nucleus
Bore of
Capillary
Capillary Wall
WBC
MUSCLE TISSUE

Gas Exchange Between Alveoli and Capillaries

Capillary bed drainage by lymphatic capillary



Capillary bed following loss/disruption of local lymphatics



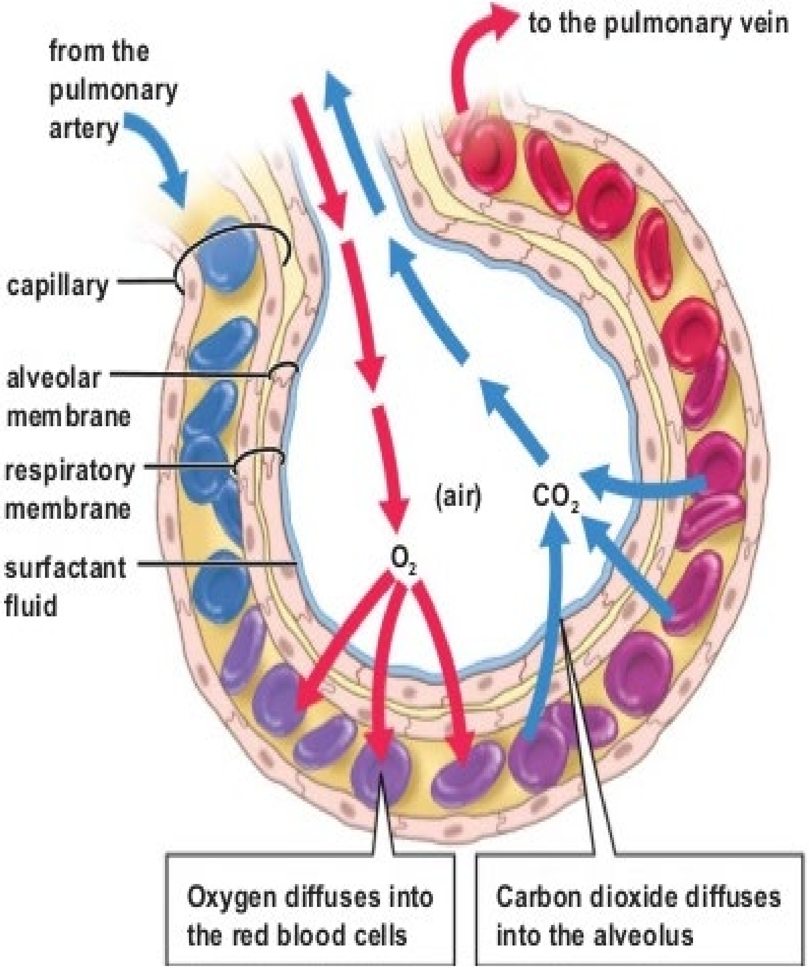


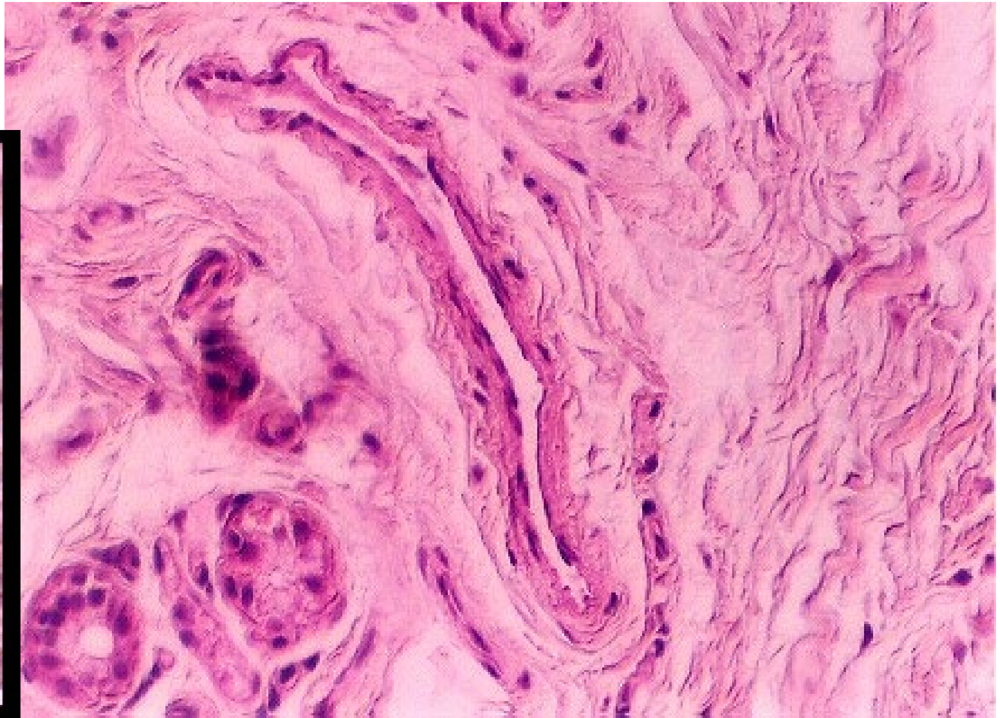
Fig.

VEINS

Venous System: Venules

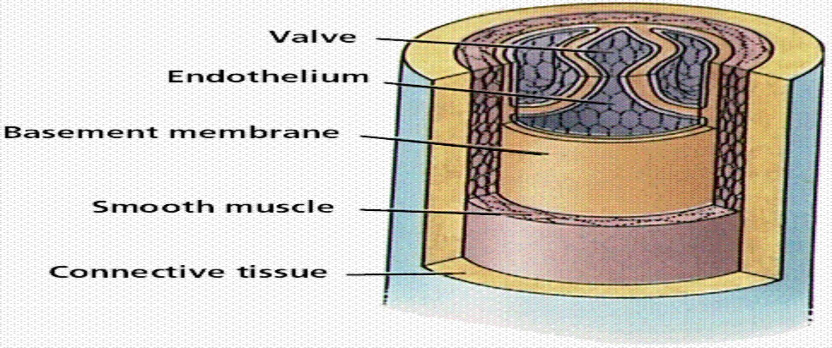
- Venules are formed when capillary beds unite
  - Allow fluids and WBCs to pass from the bloodstream to tissues
- Postcapillary venules – smallest venules, composed of endothelium and a few pericytes
- Large venules have one or two layers of smooth muscle (tunica media)

- Veins are distinguished by their thinner wall, valves, collapsed state.
- The tunica media does not look as well organized as that in the artery or arteriole.



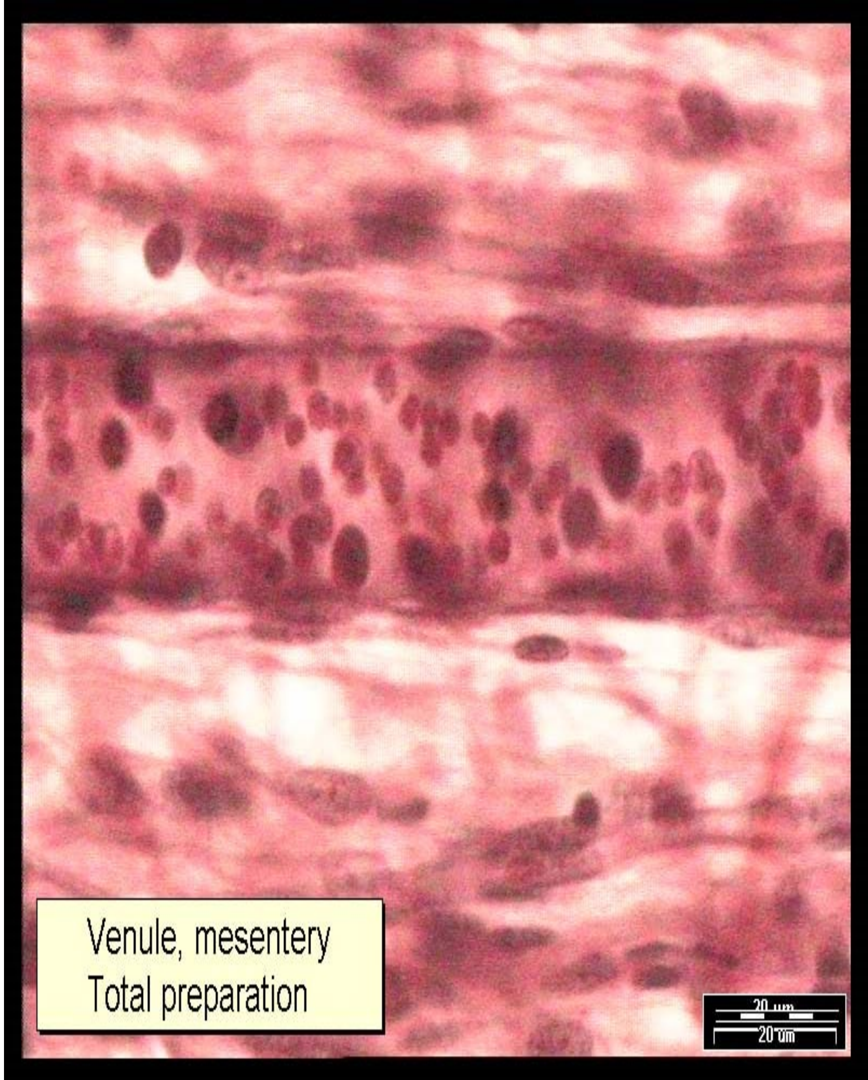
Venous System: Veins

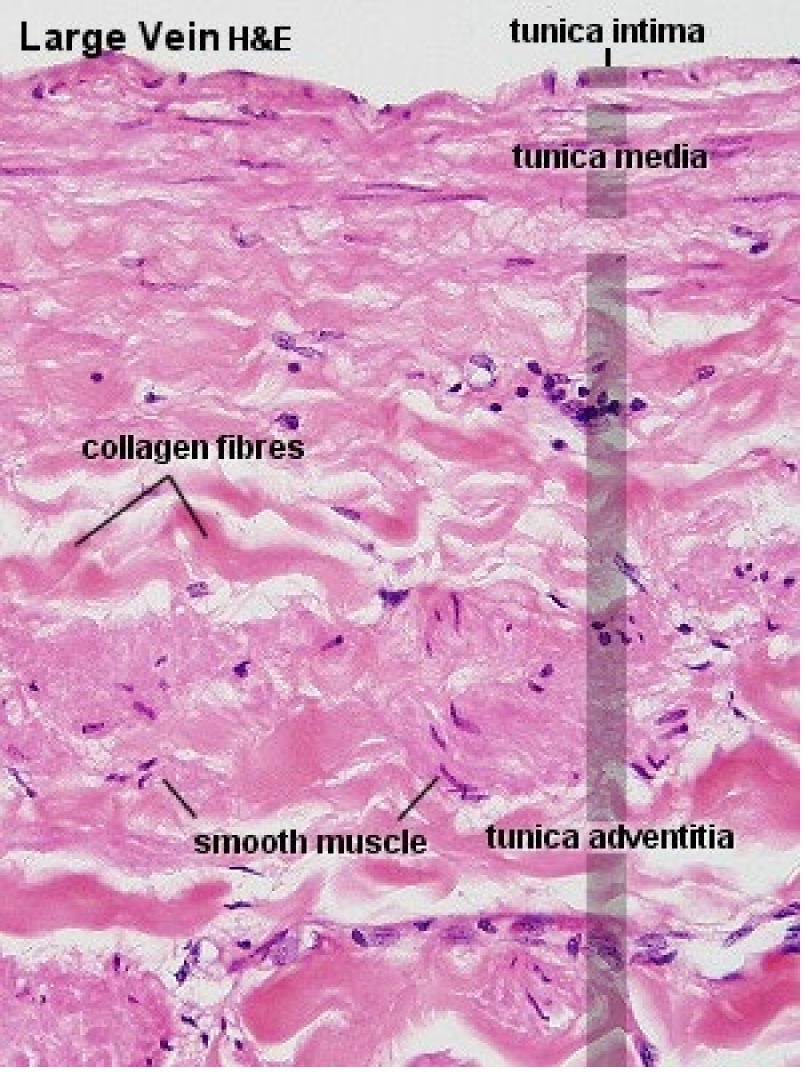
- Veins are:
  - Formed when venules converge
  - Composed of three tunics, with a thin tunica media and a thick tunica externa consisting of collagen fibers and elastic networks
  - **Capacitance vessels (blood reservoirs) that contain 65% of the blood supply**

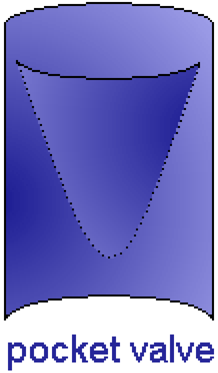


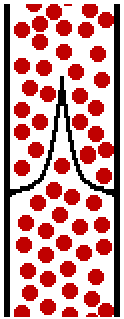
Venous System: Veins

- Veins have much lower blood pressure and thinner walls than arteries
- To **return blood to the heart**, veins have special adaptations
  - Large-diameter lumens, which offer little resistance to flow
  - Valves (resembling semilunar heart valves), which prevent backflow of blood
- **Venous sinuses** – specialized, flattened veins with extremely thin walls (e.g., **coronary sinus of the heart and dural sinuses of the brain)**



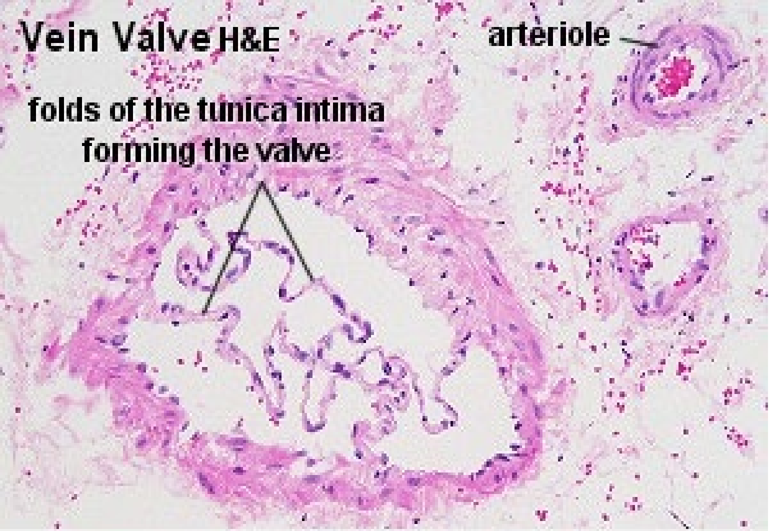


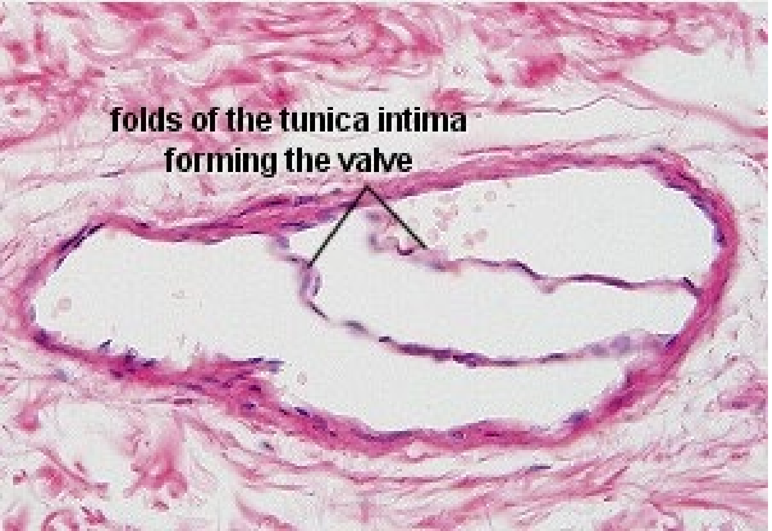


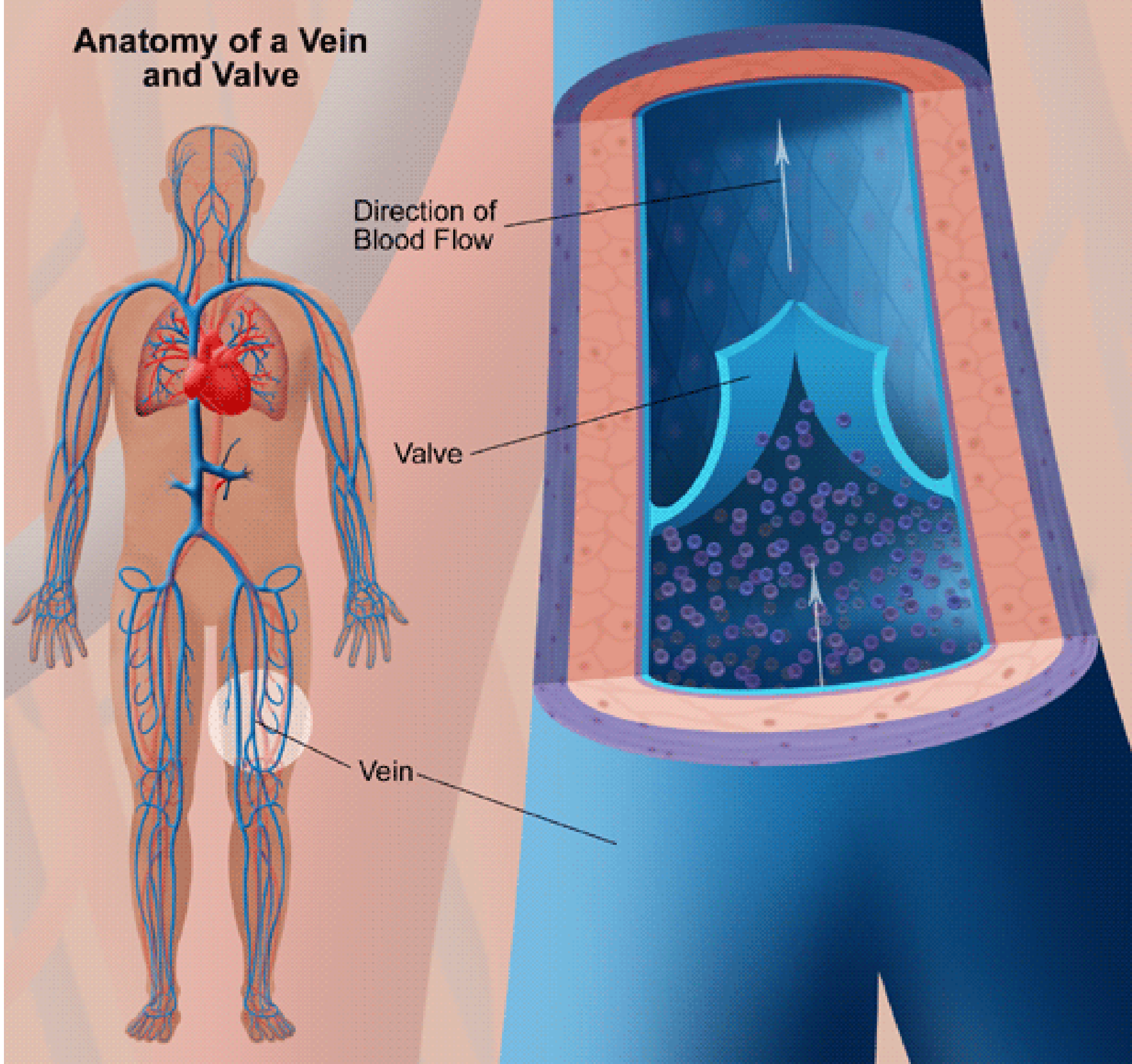


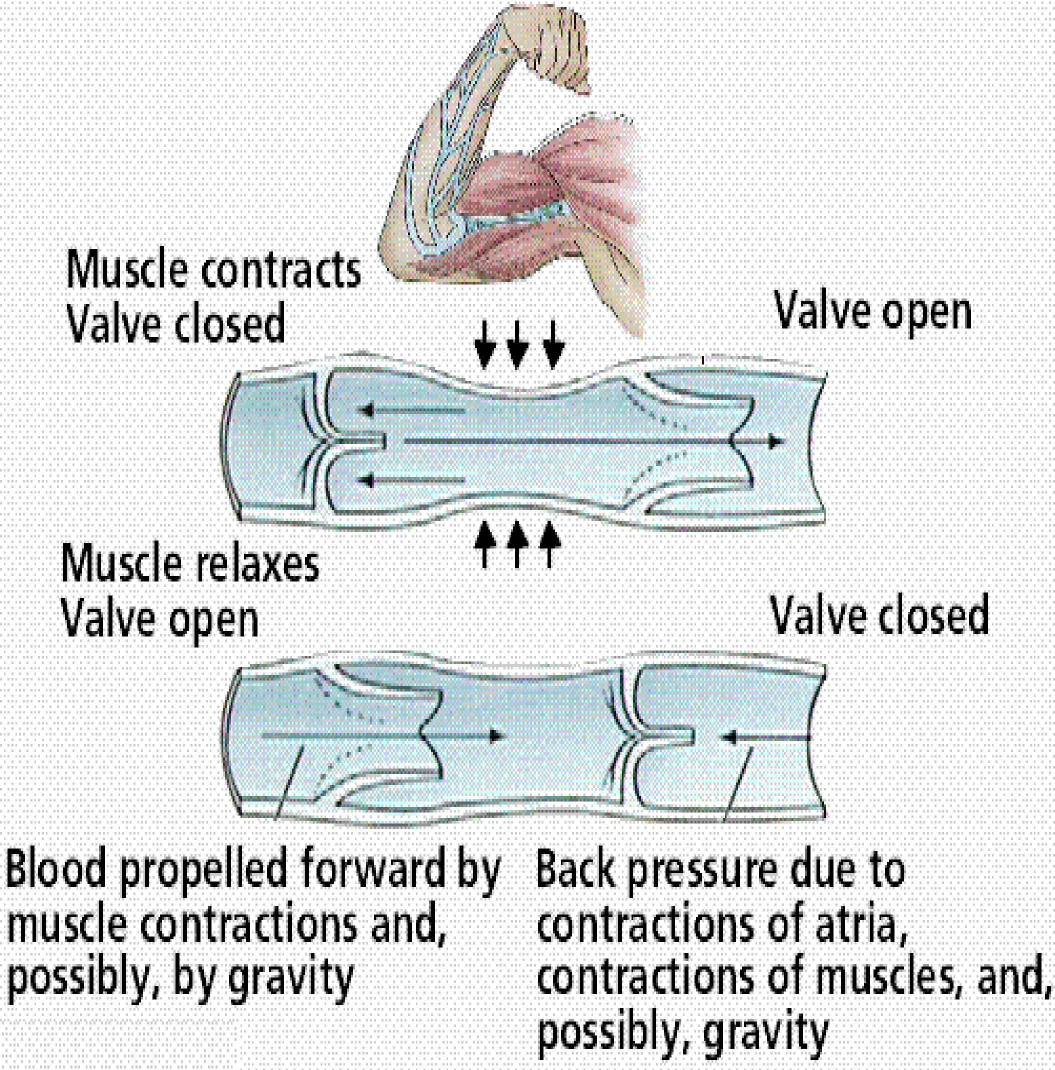
- The largest veins of the abdomen and thorax
- do contain some subendothelial connective tissue in the tunica intima, but both it and the tunica media are still comparatively thin.
- Collagen and elastic fibres are present in the tunica media. The tunica adventitia is very wide, and it usually contains bundles of longitudinal smooth muscle.
- The transition from the tunica adventitia to the surrounding connective tissue is gradual.
- Valves are absent.

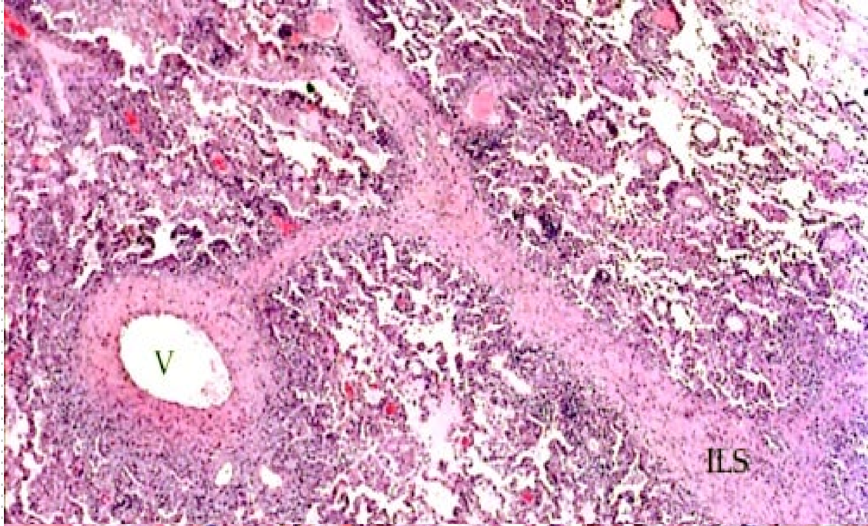
  Vasa vasorum are more frequent in the walls of large veins than in that of the corresponding arteries - probably because of the lower oxygen tension in the blood contained within them.

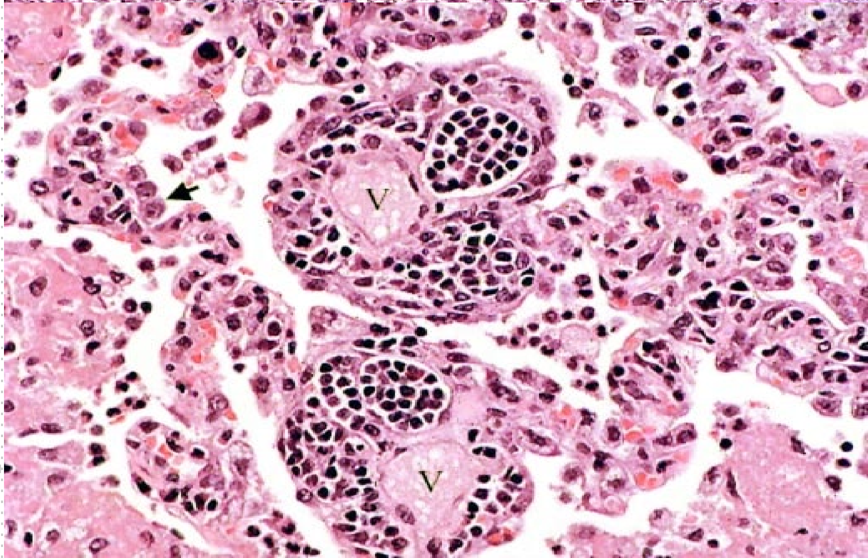

Vein Valve H&E
arteriole
folds of the tunica intima
forming the valve


folds of the tunica intima
forming the valve

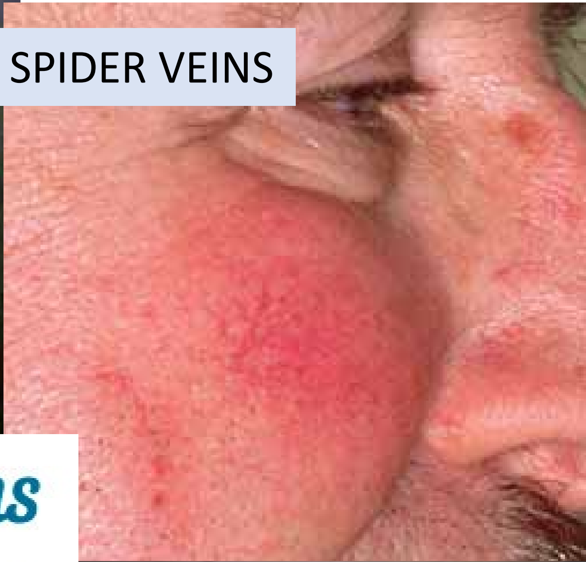

Anatomy of a Vein and Valve
Direction of Blood Flow
Valve
Vein


Muscle contracts
Valve closed
Valve open
Muscle relaxes
Valve open
Valve closed
Blood propelled forward by muscle contractions and, possibly, by gravity
Back pressure due to contractions of atria, contractions of muscles, and, possibly, gravity

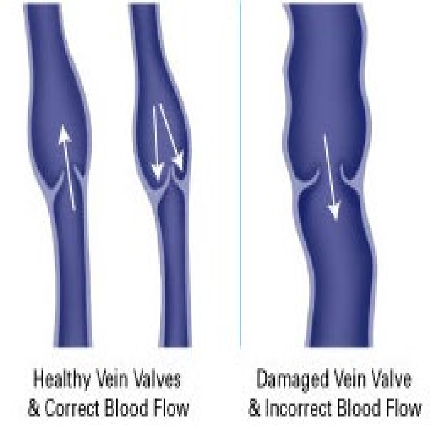

V
ILS

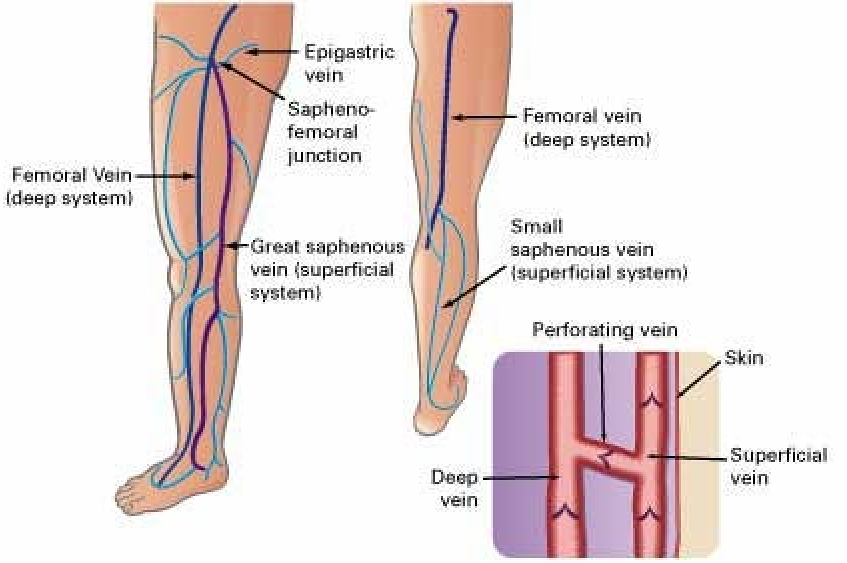

V
V

SPIDER VEINS



RETICULAR VEINS



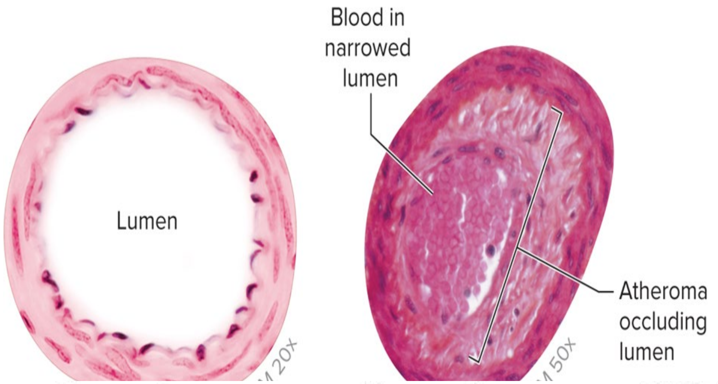


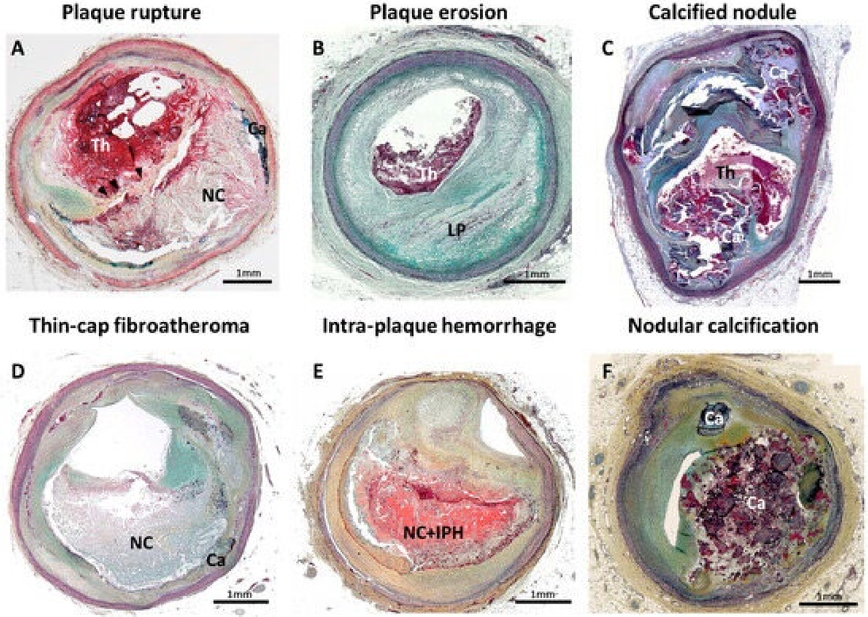
Perforating veins connect the deep system with the superficial system

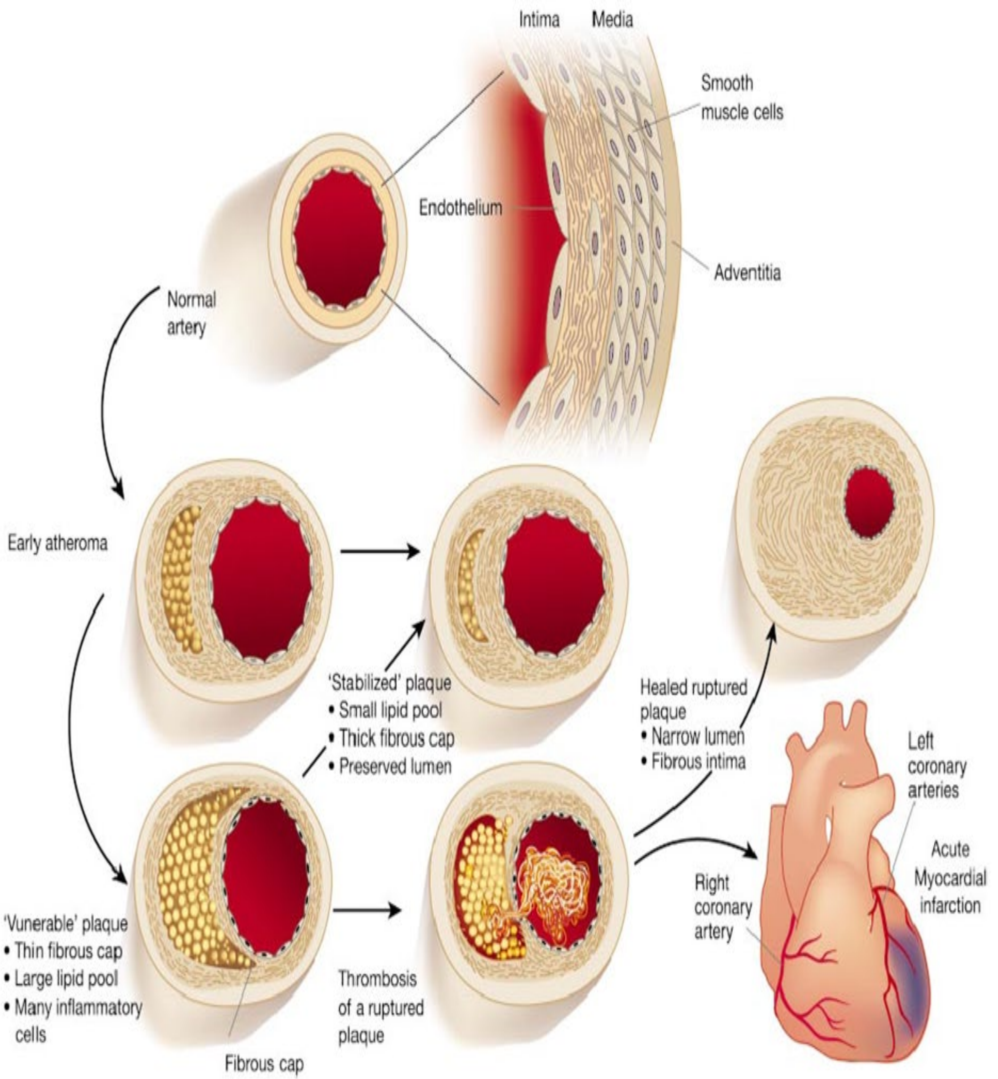
VERICOSE VEINS

Differences Between Arteries and Veins

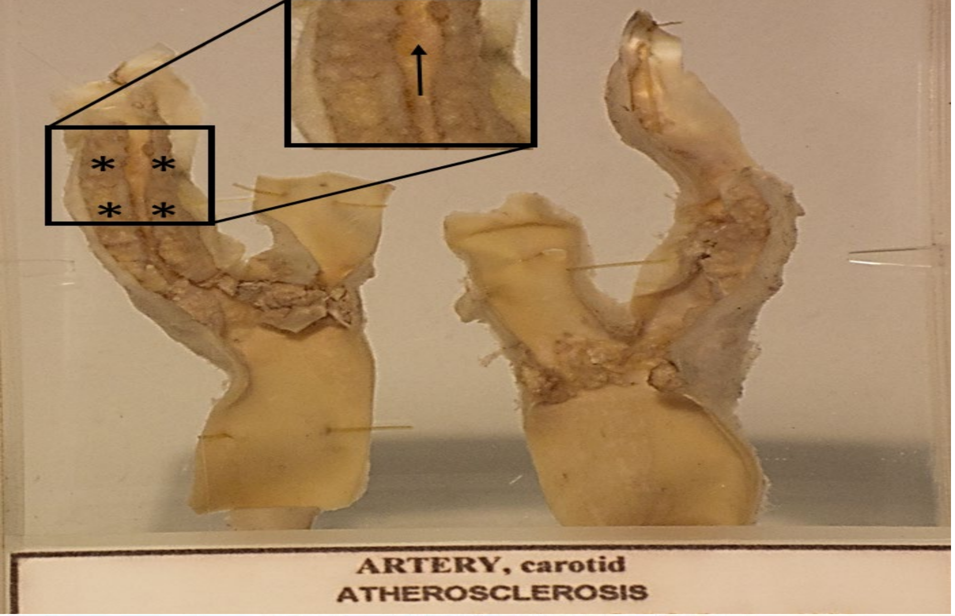
	Arteries	Veins
Delivery	Blood pumped into single systemic artery – the aorta	Blood returns via superior and interior venae cavae and the coronary sinus
Location	Deep, and protected by tissue	Both deep and superficial
Pathways	Fair, clear, and defined	Convergent interconnections
Supply/drainage	Predictable supply	Dural sinuses and hepatic portal circulation

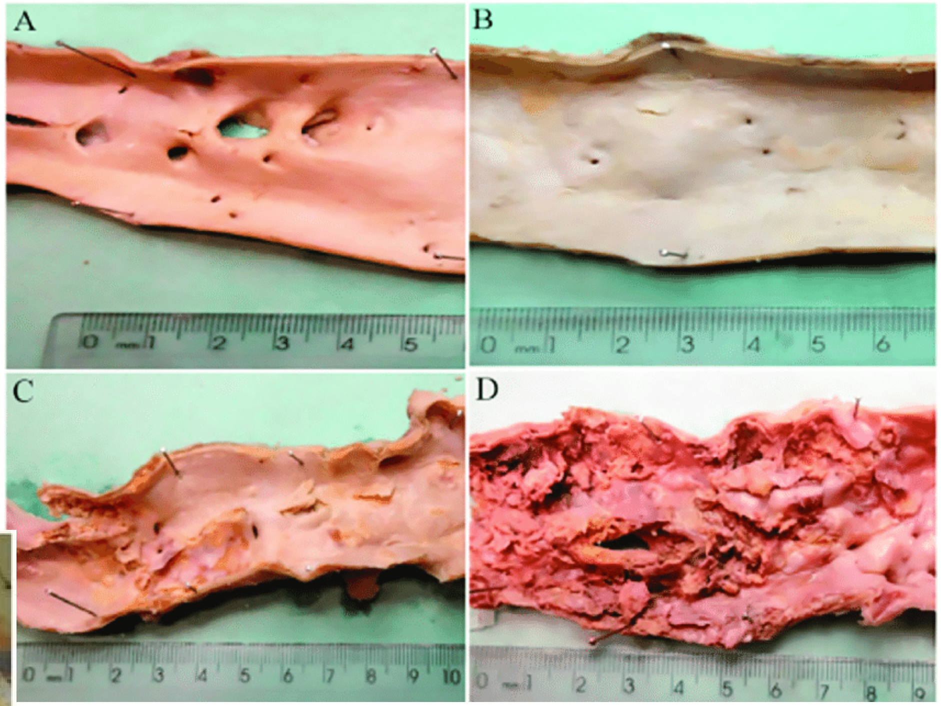

Lumen
Blood in narrowed lumen
Atheroma occluding lumen


Plaque rupture
A
Th
Ca
NC
1mm
Plaque erosion
B
Th
LP
1mm
Calcified nodule
C
Ca
Th
Ca
1mm
Thin-cap fibroatheroma
D
NC
Ca
1mm
Intra-plaque hemorrhage
E
NC+IPH
1mm
Nodular calcification
F
Ca
Ca


Intima
Media
Smooth muscle cells
Endothelium
Adventitia
Normal artery
Early atheroma
'Stabilized' plaque
• Small lipid pool
• Thick fibrous cap
• Preserved lumen
Healed ruptured plaque
• Narrow lumen
• Fibrous intima
Left coronary arteries
Acute Myocardial infarction
Right coronary artery
'Vunerable' plaque
• Thin fibrous cap
• Large lipid pool
• Many inflammatory cells
Fibrous cap
Thrombosis of a ruptured plaque

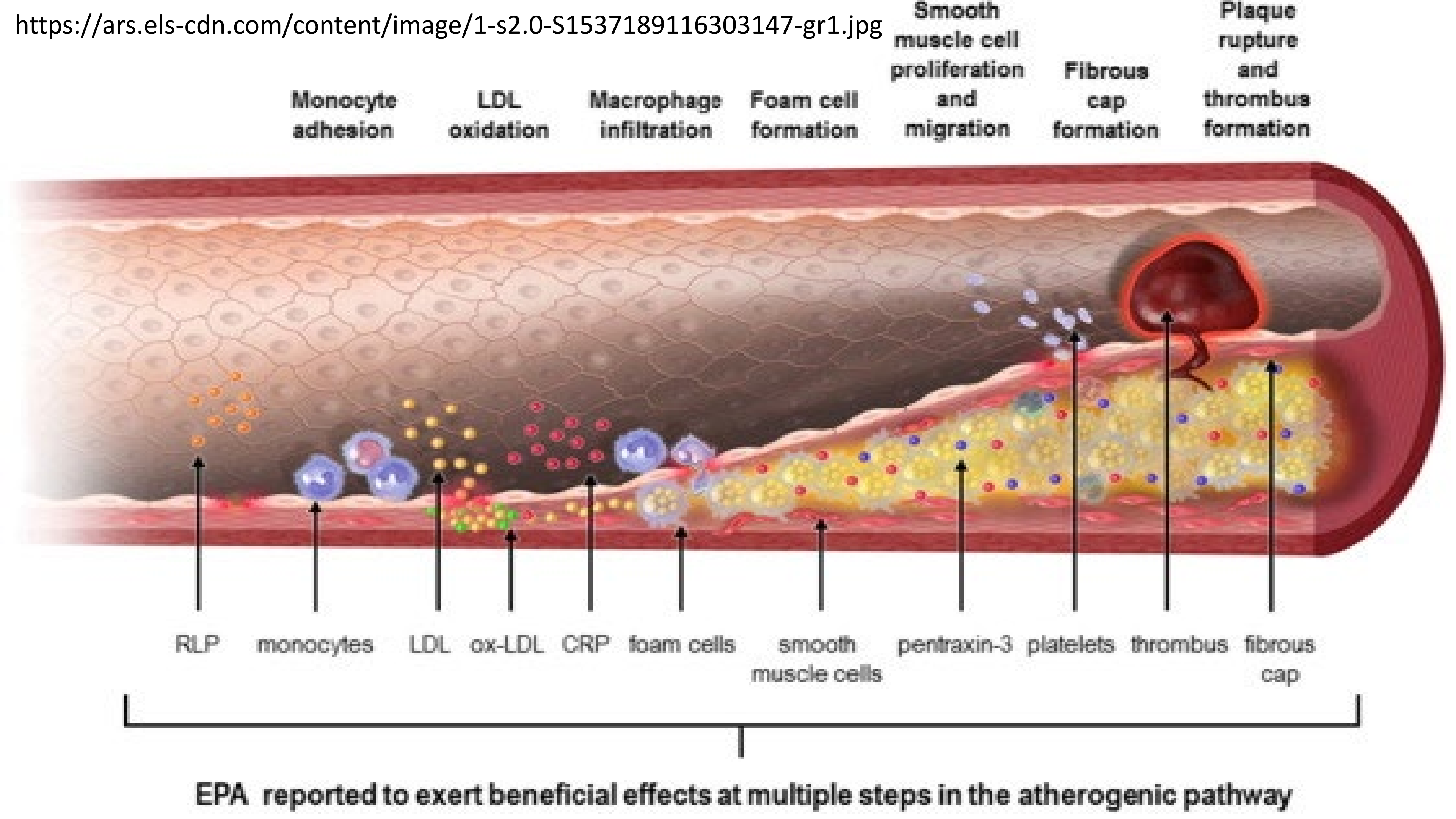
https://surgeonshallmuseums.wordpress.com/2017/12/13/pathology-spotlight-atherosclerosis/





https://www.researchgate.net/publication/320438152/figure/fig2/AS:550600430624768@1508284780494/Evaluation-of-the-severity-of-atherosclerosis-in-the-aorta-A-Absence-of.png

https://lh4.googleusercontent.com/proxy/tsArYydlRGO6bXwSUVBDUdnW9Dyr67qqYEM-S7s3q1AMnGibTocrAb0s6mew0LIhT-pNK5vZHchZGpgY2jyHqClwTFlOxUxNAZRwUa7dK9FxmA https://ars.els-cdn.com/content/image/1-s2.0-S1537189116303147-gr1.jpg



Review review

•**Which layer of the blood vessel is composed primarily of smooth muscle and elastic fibers?** a) Tunica intima
b) Tunica media
c) Tunica externa
d) Endothelium
e) Adventitia

•**Which type of blood vessel has the largest lumen relative to its wall thickness?** a) Arteries
b) Capillaries
c) Veins
d) Arterioles
e) Venules

•**What is the primary cell type found in the endothelium of blood vessels?** a) Smooth muscle cells
b) Fibroblasts
c) Endothelial cells
d) Adipocytes
e) Macrophages

•**Which of the following blood vessels contains a significant amount of elastic tissue in its walls to accommodate high-pressure blood flow from the heart?** a) Capillaries
b) Veins
c) Elastic arteries
d) Muscular arteries
e) Arterioles

•**The vasa vasorum are small blood vessels that supply the walls of which type of blood vessel?**
a) Capillaries
b) Arteries
c) Veins
d) Arterioles
e) All of the above

•**Which type of capillary has large pores and is found in organs such as the liver and bone marrow?**
a) Continuous capillaries
b) Fenestrated capillaries
c) Sinusoidal capillaries
d) Arterioles
e) Venules

•**Which type of blood vessel has a thick tunica media and a prominent internal elastic lamina?** a) Veins
b) Muscular arteries
c) Capillaries
d) Venules
e) Elastic arteries

•**Which structure prevents the backflow of blood within veins?** a) Elastic fibers
b) Endothelial cells
c) Smooth muscle
d) Valves
e) Basement membrane
•**Which type of blood vessel is primarily responsible for regulating blood pressure and flow into capillary beds?** a) Arteries
b) Capillaries
c) Veins
d) Arterioles
e) Venules
•**What is the primary function of pericytes found around capillaries?** a) Secrete hormones
b) Transport oxygen
c) Regulate blood flow and permeability
d) Produce collagen
e) Absorb nutrients

Answer Key

1.b) Tunica media
2.c) Veins
3.c) Endothelial cells
4.c) Elastic arteries
5.e) All of the above
6.c) Sinusoidal capillaries
7.b) Muscular arteries
8.d) Valves
9.d) Arterioles
10.c) Regulate blood flow and permeability

What is located at the junction between arterioles and capillaries?
Precapillary sphincter
Do capillaries contain smooth muscle?
No
What are capillaries composed of?
Single layer of endothelial cells and a surrounding basement membrane
As discussed above, what two features describes capillaries?
1. Low velocity flow
2. High surface area
How do small water-soluble substances enter capillaries?
Through pores (clefts) between adjacent endothelial cells
Can proteins fit through the pores?
Not normally, they are too large
Where are the pores the widest?
In the liver and intestine (sinusoids)
What is unique about the junctions in the sinusoids?
They are wide enough to allow the passage of proteins
How do large water-soluble substances enter capillaries?
Pinocytosis
How do lipid-soluble substances enter capillaries?
Through the membrane of the endothelial cells by simple diffusion
Where are the endothelial pores the tightest?
In the brain; their tight junctions help to create the blood-brain barrier

What are the components of the blood-brain barrier?
Endothelial cells of the cerebral capillaries and astrocytic foot processes
What substances pass readily through the barrier?
Lipid-soluble substances
What substances are excluded by the barrier?
Protein and cholesterol
What are the functions of the blood-brain barrier?
1. Maintains a constant environment for the neurons in the central nervous system (CNS)
2. Protects the brain from toxic substances
3. Prevents movement of neurotransmitter into the circulation

What equation governs fluid exchange across capillaries?

The Starling equation:

$J_v = Kf([P_c - P_i]) - ([\pi_c - \pi_i])$

J_v = fluid movement (mL/min)

K_f = hydraulic conductance (mL/min • mm Hg)

P_c = capillary hydrostatic pressure (mm Hg)

P_i = interstitial hydrostatic pressure (mm Hg)

π_c = capillary oncotic pressure (mm Hg)

π_i = interstitial oncotic pressure (mm Hg)

Transcapillary fluid movement favors ________________________at the arteriolar end of the capillary and ____________________________ at the venous end.

Filtration, reabsorption

What can cause an increase in P_c?
Increased arterial or venous pressure
What can cause a decrease in π_c?
Decreased blood protein concentration
What can cause an increase in π_i?
Inadequate lymphatic function
What is lymph?
Excess fluid that is filtered out of capillaries and not reabsorbed
What is the function of the lymphatic system?
To collect and return excess fluid along with any filtered proteins back into circulation

What type of flow do the lymphatics demonstrate?
Unidirectional
What permits this type of flow?
One-way flap valves
What causes edema?
Essentially, most edematous states can be explained through variation in one of the Starling variables. This perversion results in more interstitial fluid than the lymphatics can return into the circulation.

A 36-year-old man suffers a gunshot wound to the upper thigh. After being rushed to the emergency department, the man is examined and it is found that he has a heart rate of 110, and a blood pressure of 86/40 and he seems cool and clammy to the touch.

What is happening?

He is losing blood volume into the soft tissues of the thigh.

How did the body detect this change?

The body is quickly able to detect blood volume changes through the baroreceptors of both the aortic arch and the carotids.

Why is his heart rate elevated?

To compensate for falling perfusion pressures, the body increases sympathetic output stimulating the heart to beat more rapidly.