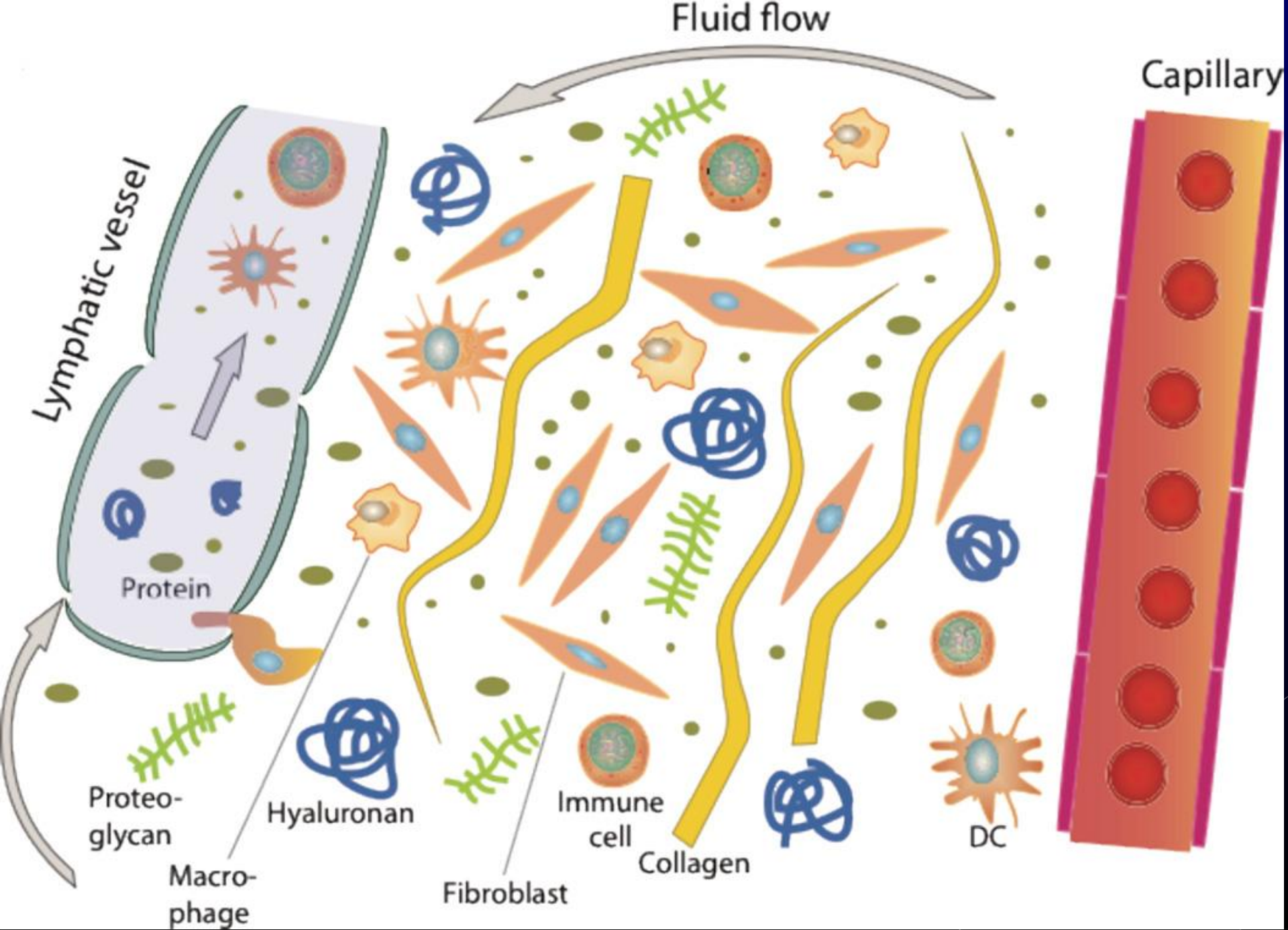


Circulatory system



Circulatory system

A microscopic view of blood cells, including red blood cells and white blood cells, is shown in the background. Two blue arrows point from the top center towards the descriptions of the two circulatory systems below.

Cardio-vascular system - two-way circulation

Carries blood in both directions
between the heart and tissues

Lymphatic vascular system - one-way transport

Collects the **lymph** - the excess
extracellular tissue fluid, and
delivers it back to the
cardiovascular system

Cardio-vascular system

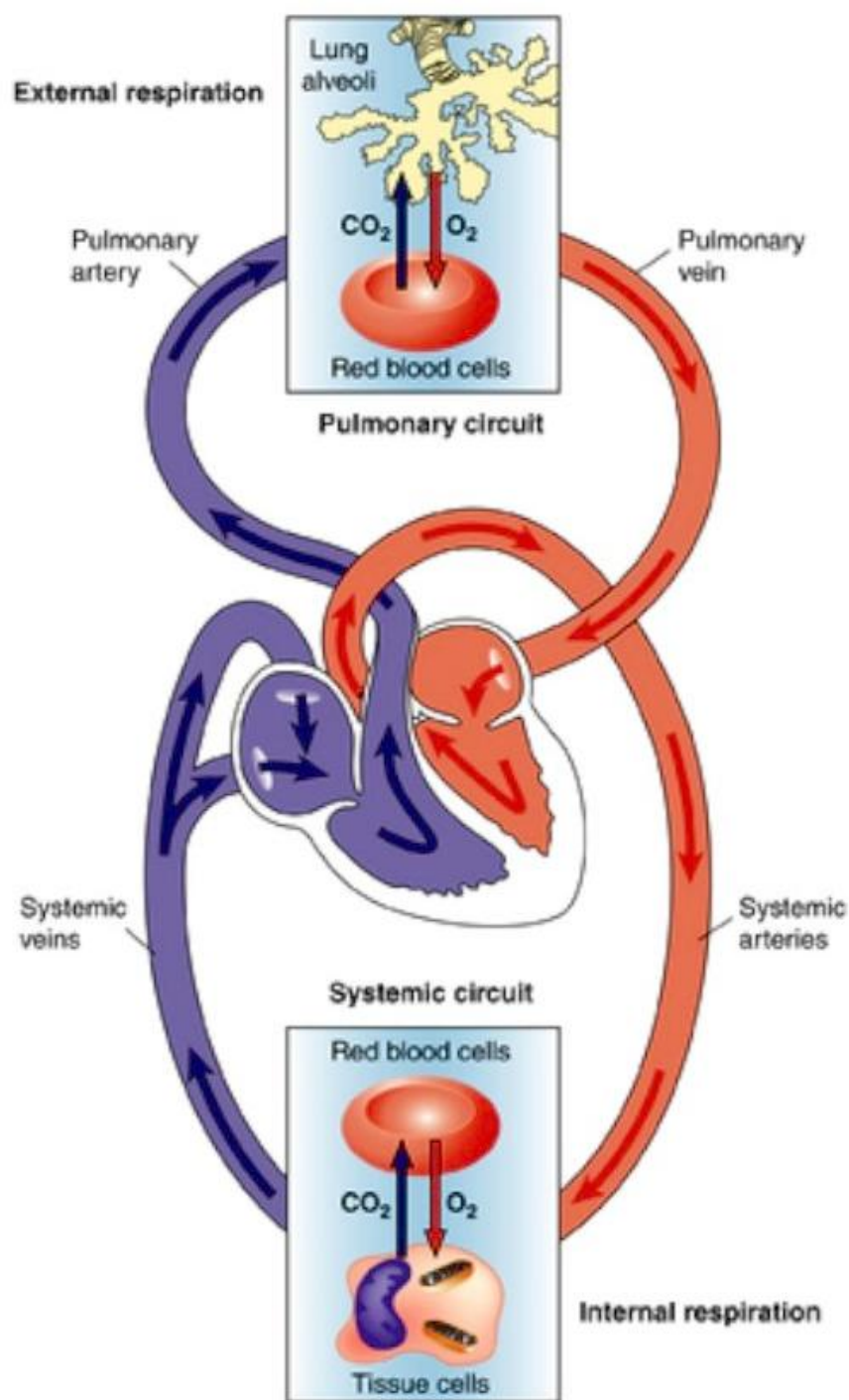
- heart
- blood
- blood vessels.

Pulmonary circulation -

carries deoxygenated blood away from the heart, to the lungs, and returns oxygenated (oxygen-rich) blood back to the heart.

Systemic circulation -

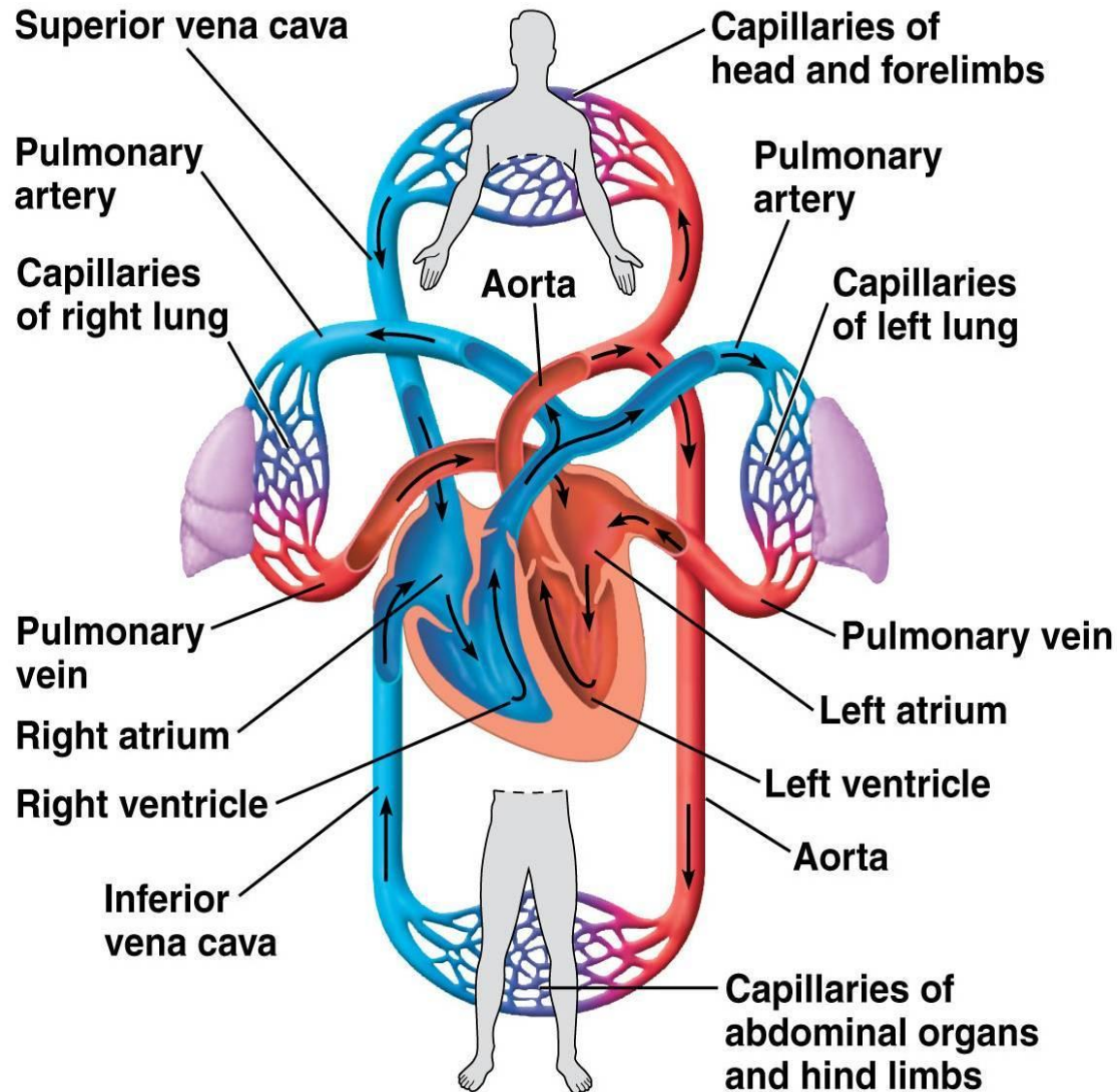
carries oxygenated blood away from the heart to the body, and returns deoxygenated blood back to the heart.



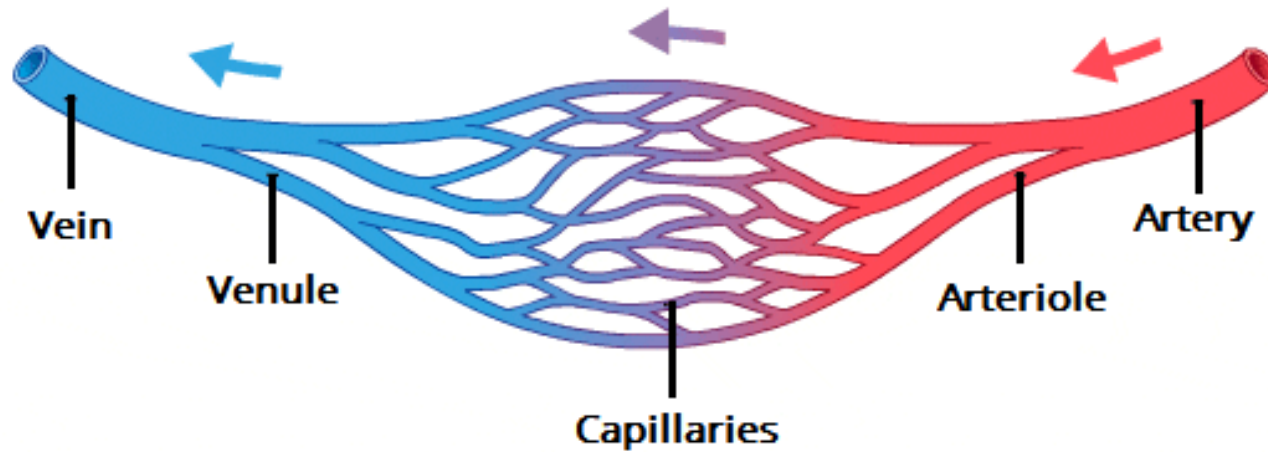
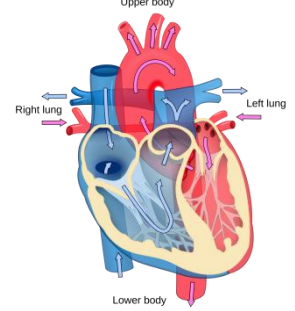
- **Venae cavae** return systemic, deoxygenated blood to the **right atrium**
- the blood passes through tricuspid valve into the **right ventricle**.
- deoxygenated blood from the right ventricle is pumped out the **pulmonary artery** to the lungs for gaseous exchange.

Oxygenated blood returns to the heart via the **pulmonary veins** - into the **left atrium**. the blood passes through mitral valve to the **left ventricle** and is transported by **aorta** to the tissues of the body.

Atria - receive blood,
Ventricles - discharge blood from the heart



Classification of blood vessels



VEINS

- return the blood to the heart

ARTERIES

- transport the blood from the heart

CAPILLARIES

- exchange of gases, nutrients

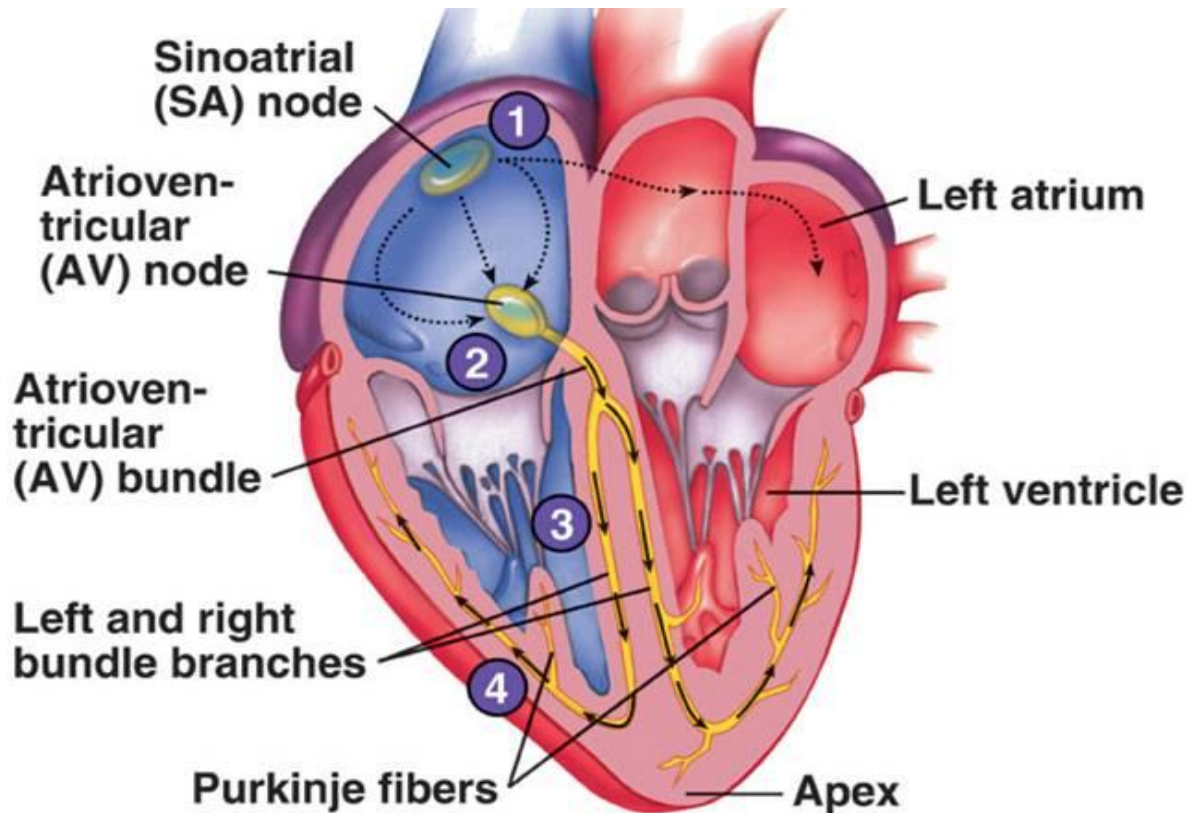
Conducting system of the heart

- **sinoatrial node (pacemaker)** - located in the wall of the right atrium spontaneously depolarize 70 times per minute, impulses spread by internodal pathways to the:

- **atrioventricular node** - impulses are slowed, spontaneously depolarize 40 - 60 times per minute, transmit signals to the myocardium via:

- **atrioventricular bundle (bundle of His)** - travels in the subendocardial connective tissue as large, modified cardiac muscle cells:

- **Purkinje fibers**



**Purkinje fibers:
Specialized
cardiac muscle
cells !!**

HEART - IMPULSE GENERATION AND CONDUCTION

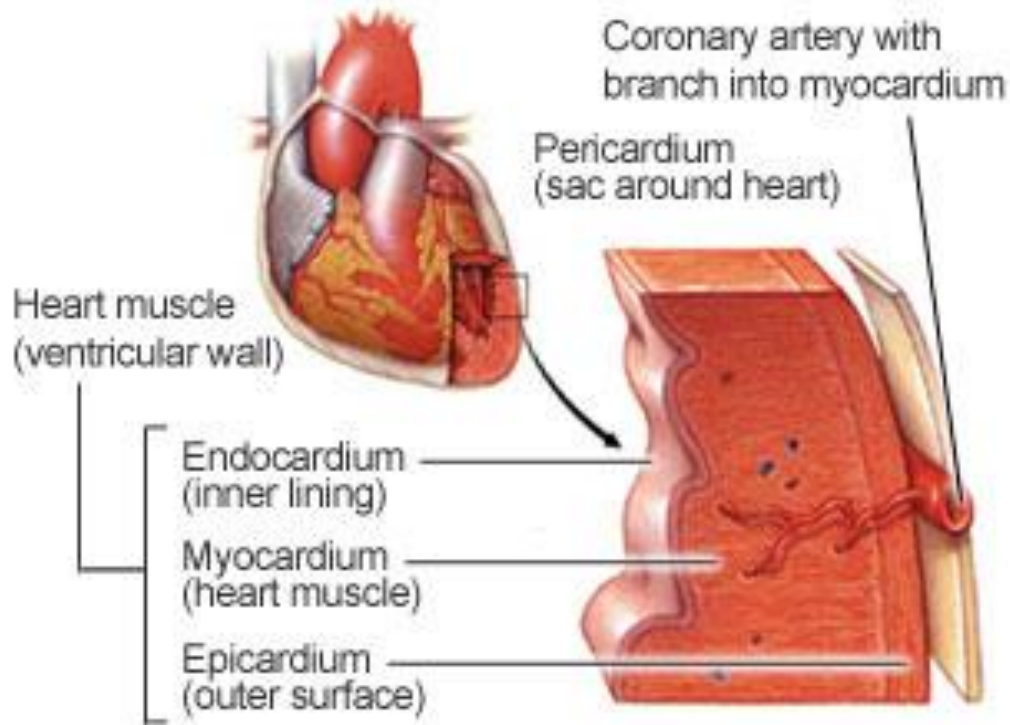


SINUS RHYTHM



ATRIAL FIBRILLATION
disorganized electrical impulses

GENERAL STRUCTURE OF THE HEART



Endocardium – endothelium, connective tissue layer (elastic fibers and smooth muscle cells).

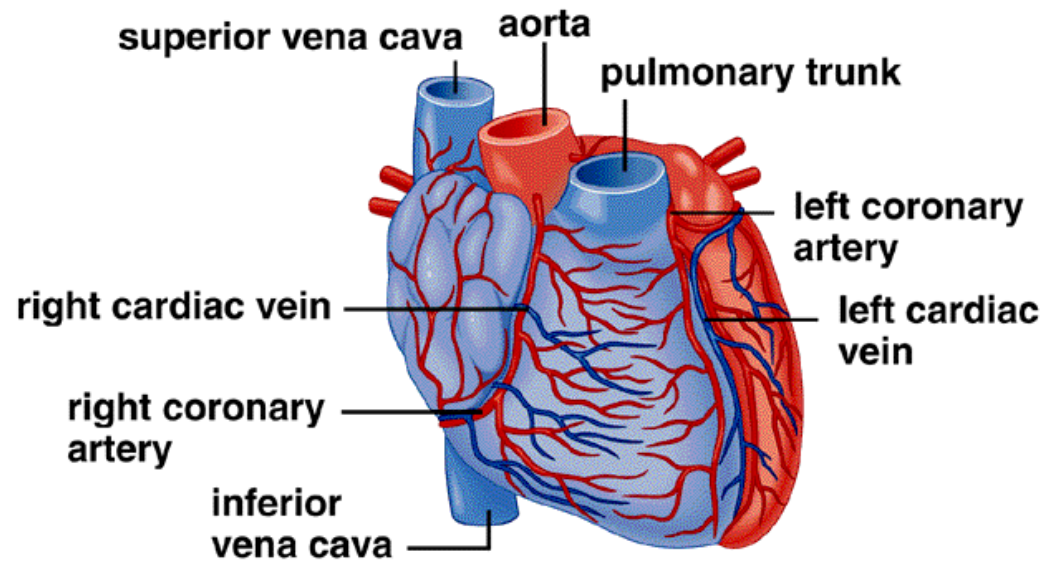
Subendocardial layer – loose connective tissue with blood vessels and **Purkinje fibers**, adipocytes

Myocardium – cardiac muscle cells, connective tissue proper

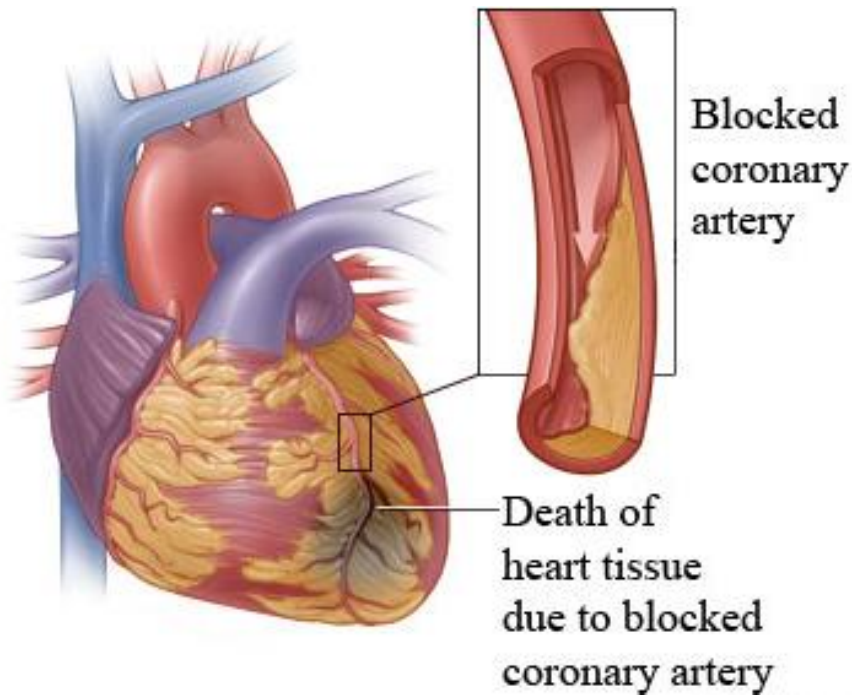
Epicardium - visceral layer of the pericardium - mesothelium, loose connective tissue with **coronary vessels**

Coronary vessels

- deliver oxygen-rich blood to the myocardium - **coronary arteries**
- remove the deoxygenated blood from the heart muscle - **cardiac veins**

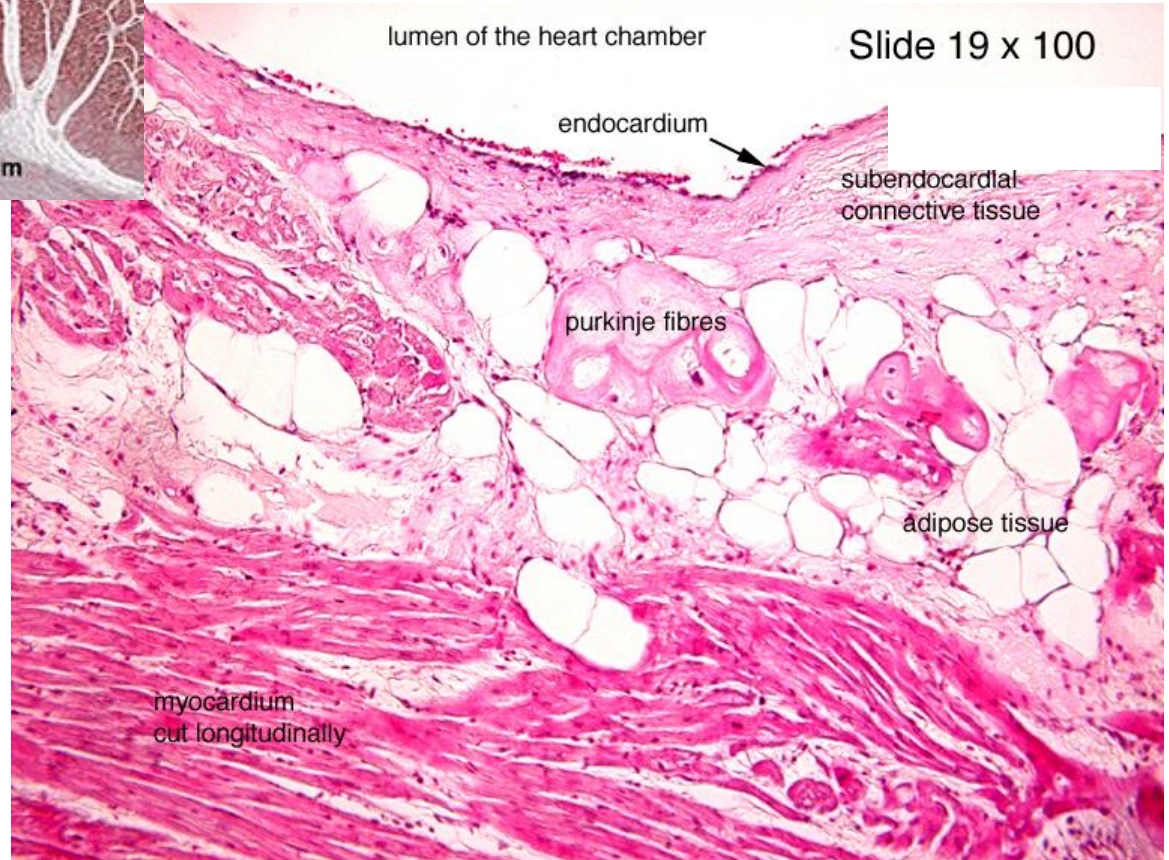
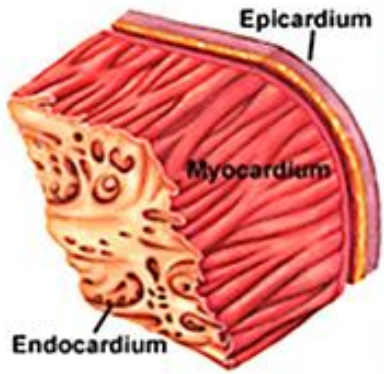


Left and right coronary artery run on the surface of the heart (epicardium). Latter, branch out in the myocardium

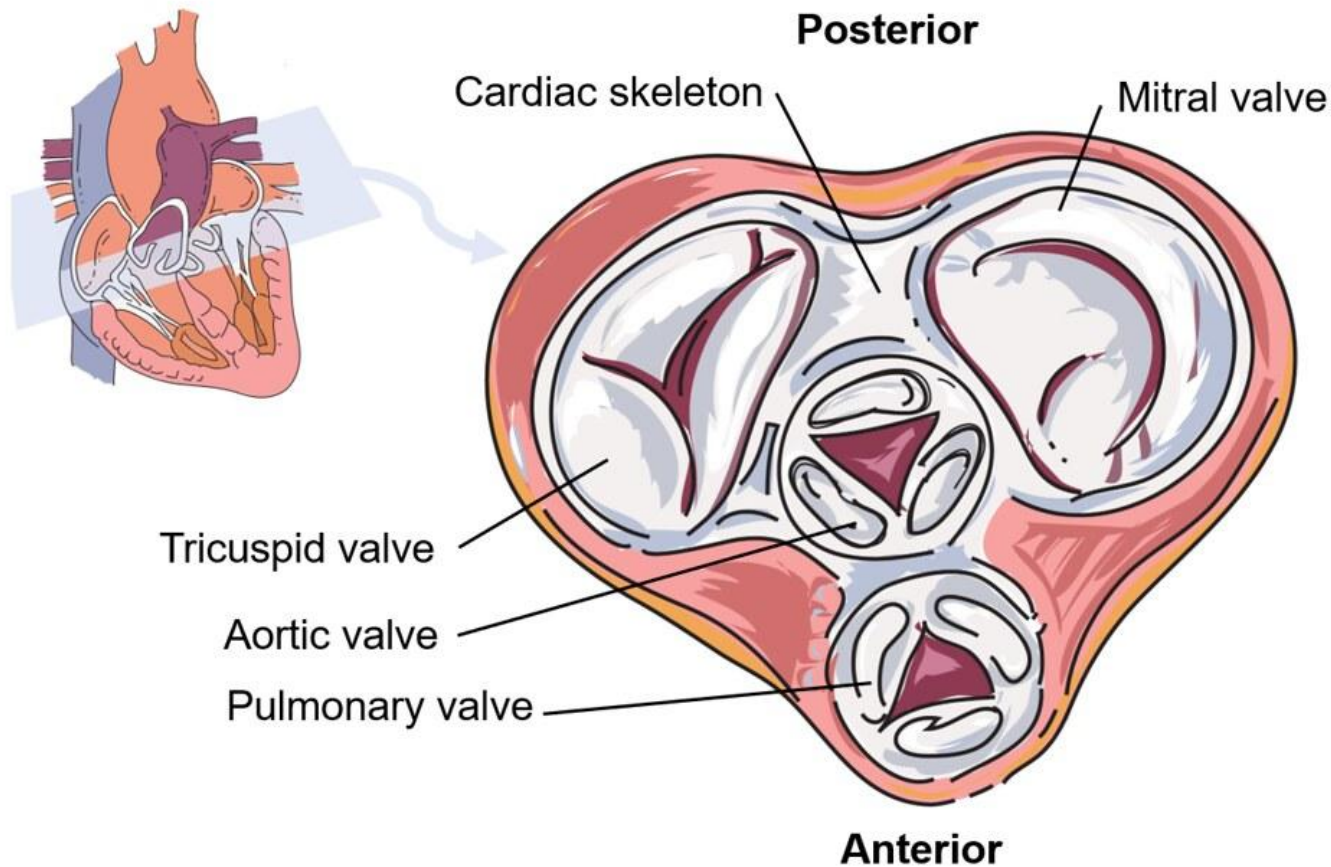


- coronary arteries are blocked (white blood cells, cholesterol and fat) – death of heart muscle – heart attack

The wall of the heart

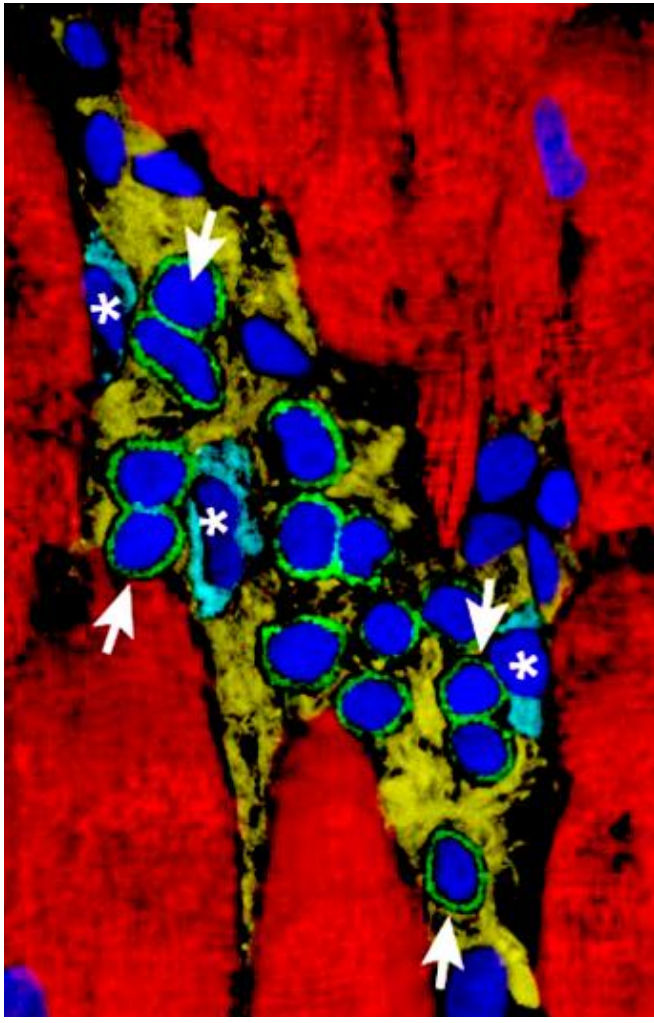
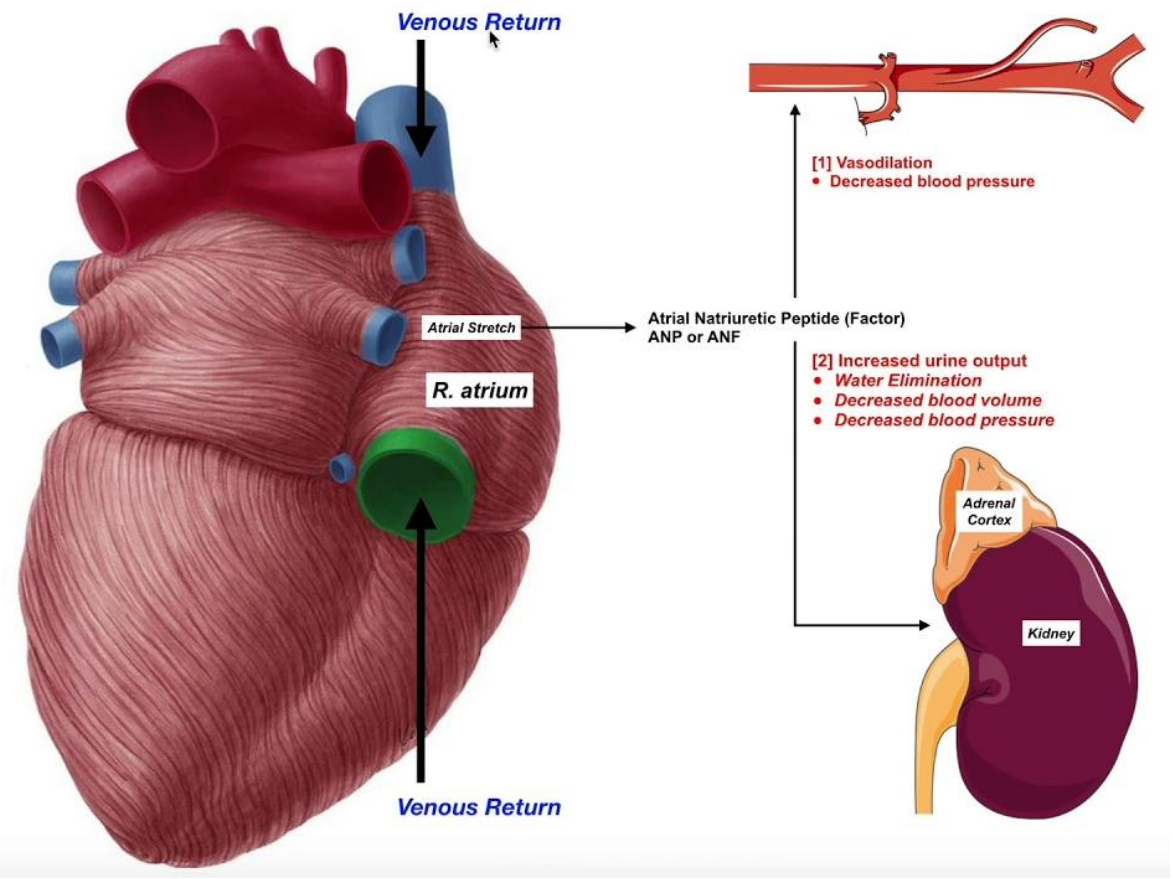


Fibrous Skeleton of the Heart



The cardiac skeleton consists of four rings of **dense connective tissue** that surround the AV canals (mitral and tricuspid) and extend to the origins of the aorta and the pulmonary trunk, providing structure and support for the heart as well as electrical isolation between the atria and the ventricles.

GENERAL STRUCTURE OF THE HEART



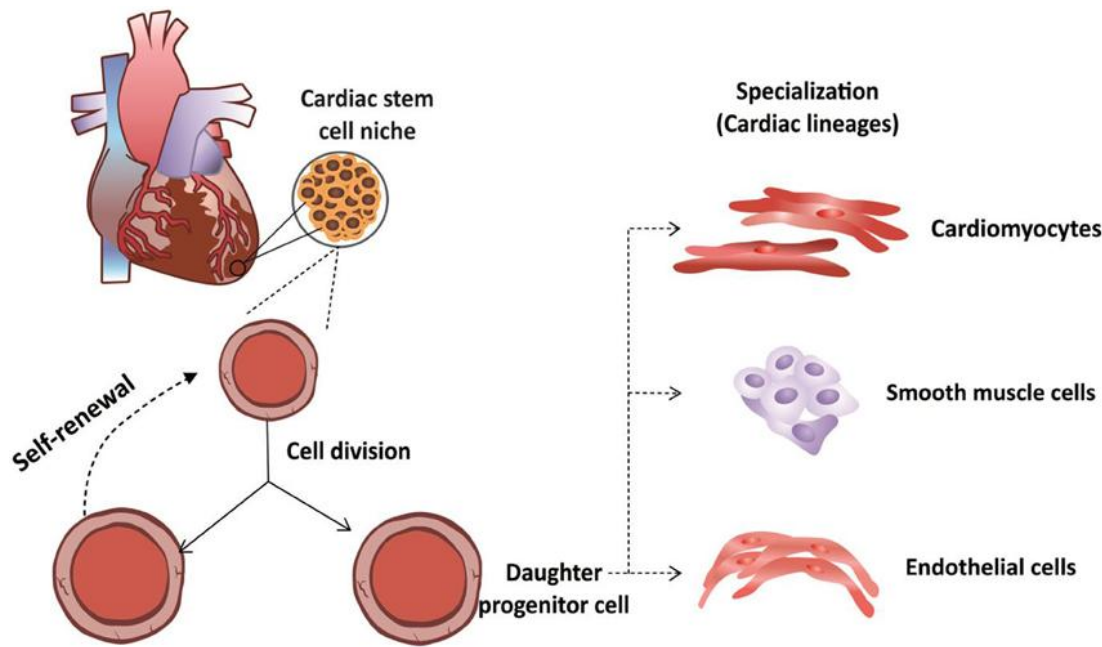
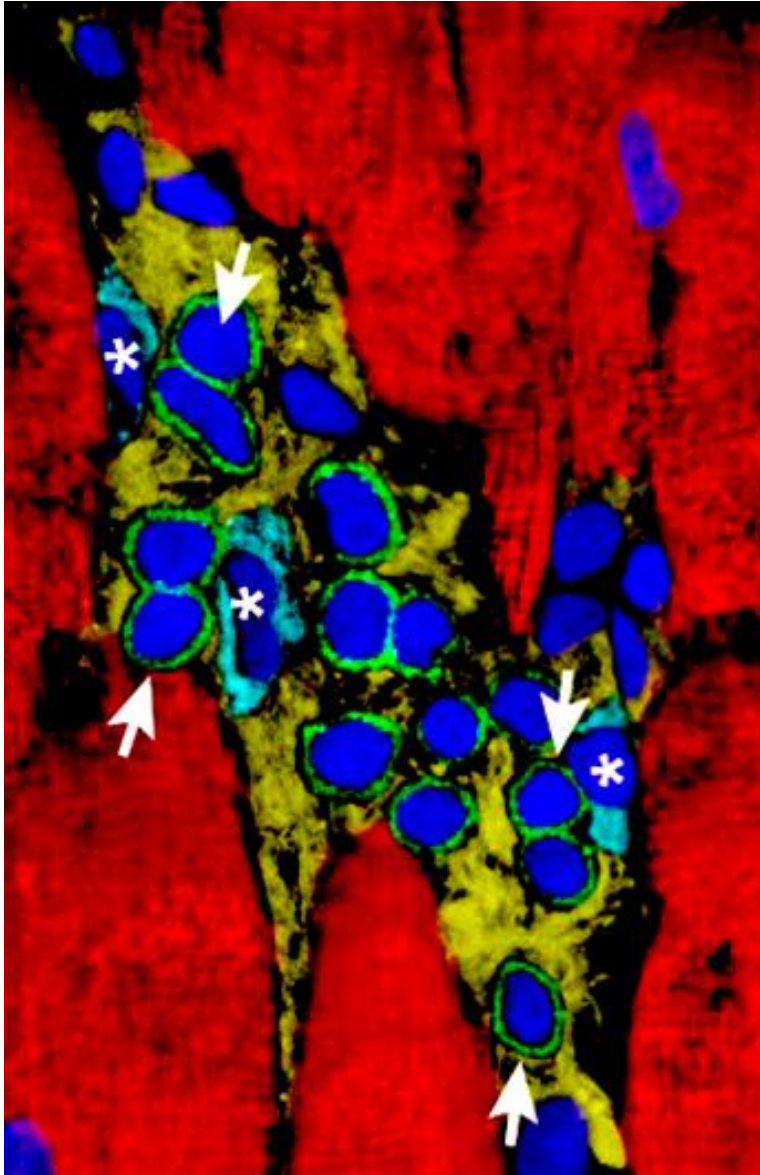
Atrial muscle cells - produce **atriopeptin (ANP)**

- reduces blood pressure (vasodilator).

Atriopentin = atrial natriuretic polypeptide = regulates electrolyte balance (acts on the kidney)

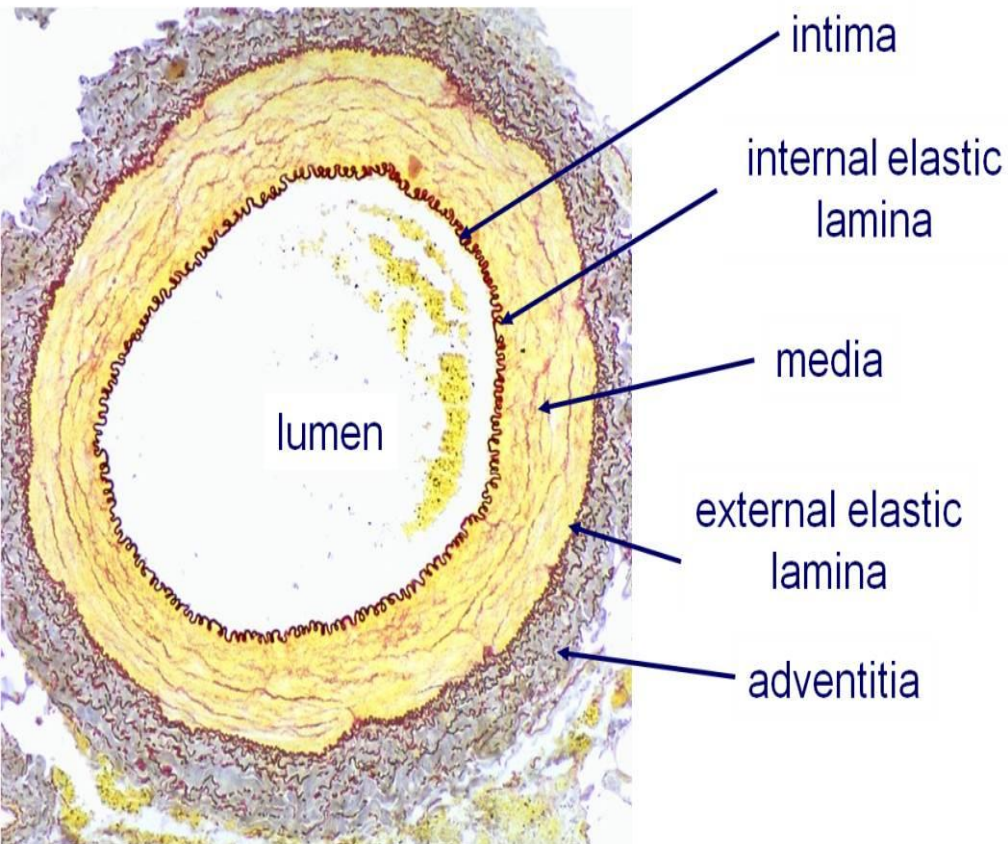
cardiodilatin = cardionatrin

The myocardium possesses **stem cells**. In humans, cardiac stem cells exist in the interstitial spaces among mature cardiomyocytes.



The myocardium possesses **stem cells**. In humans, cardiac stem cells exist in the interstitial spaces among mature cardiomyocytes.

General Structure of Blood Vessels

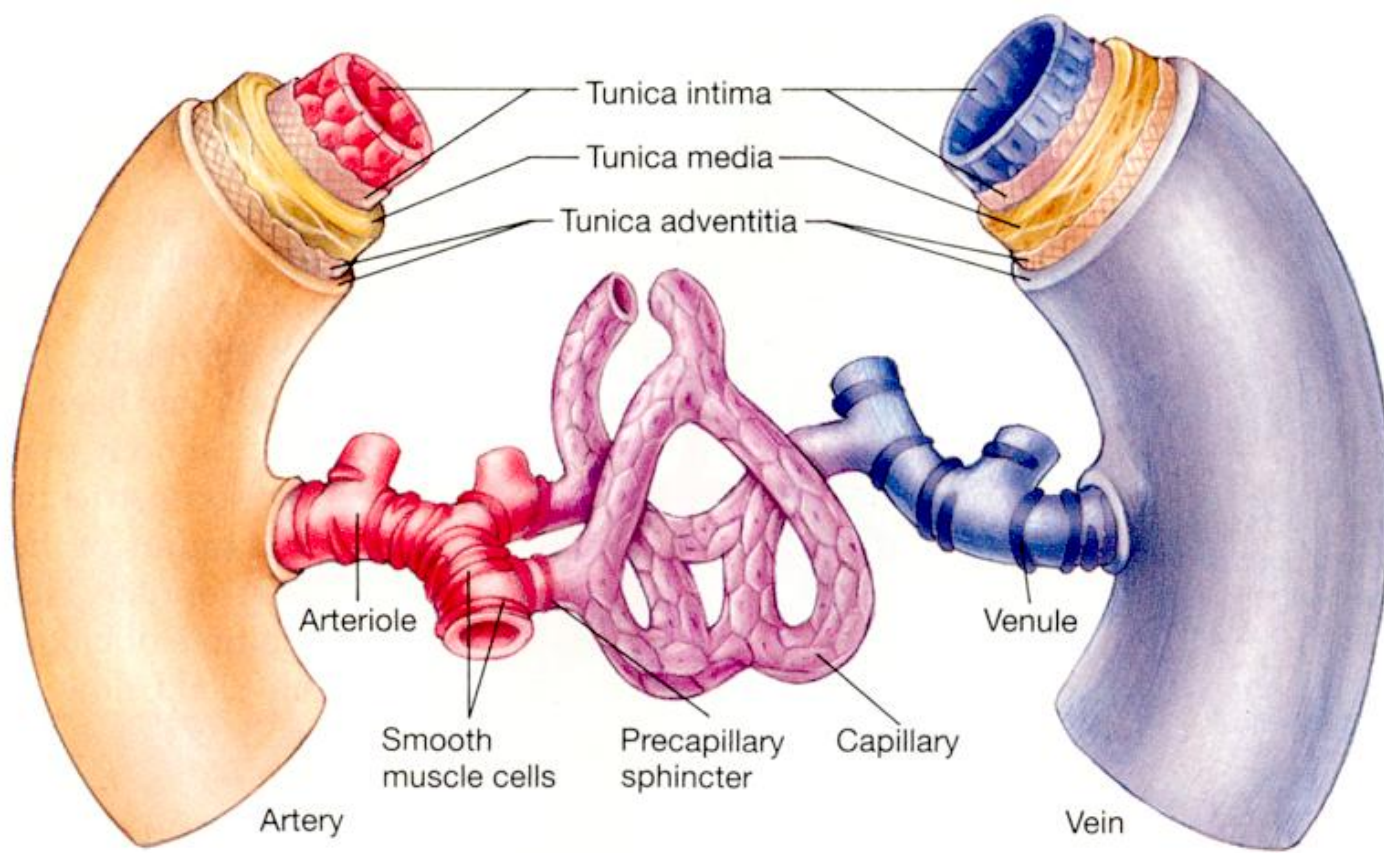


Tunica intima - single layer of endothelial cells and the underlying connective tissue
outermost layer - internal elastic lamina.

Tunica media - smooth muscle cells (elastic fibers) oriented concentrically around the lumen,
outermost layer - external elastic lamina

Tunica adventitia - connective tissue.

Capillaries consist of a layer of endothelium, pericytes and occasional connective tissue.



ARTERIES:

- elastic (conducting) arteries
- muscular (distributing) arteries
- arterioles
- metarterioles

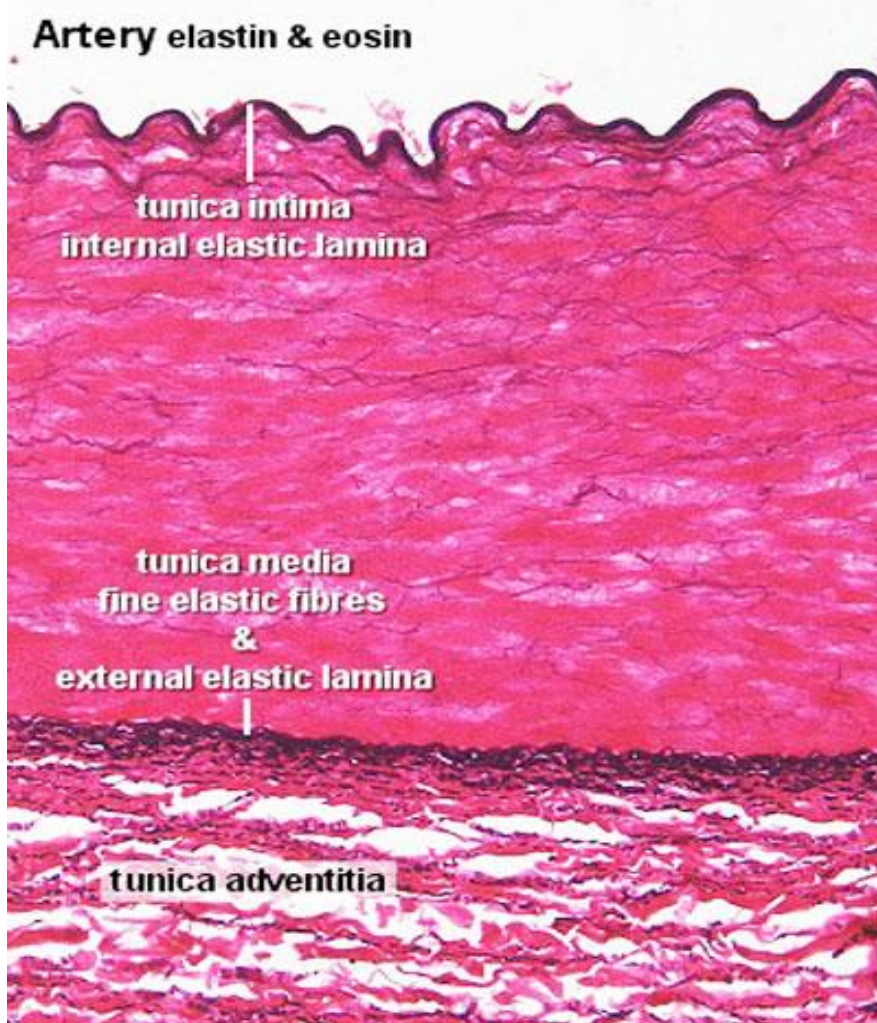
VEINS:

- large veins
- medium and small veins
- venules

CAPILLARIES:

- continous
- fenestrated
- sinusoidal

GENERAL STRUCTURE OF ELASTIC (CONDUCTING) ARTERIES

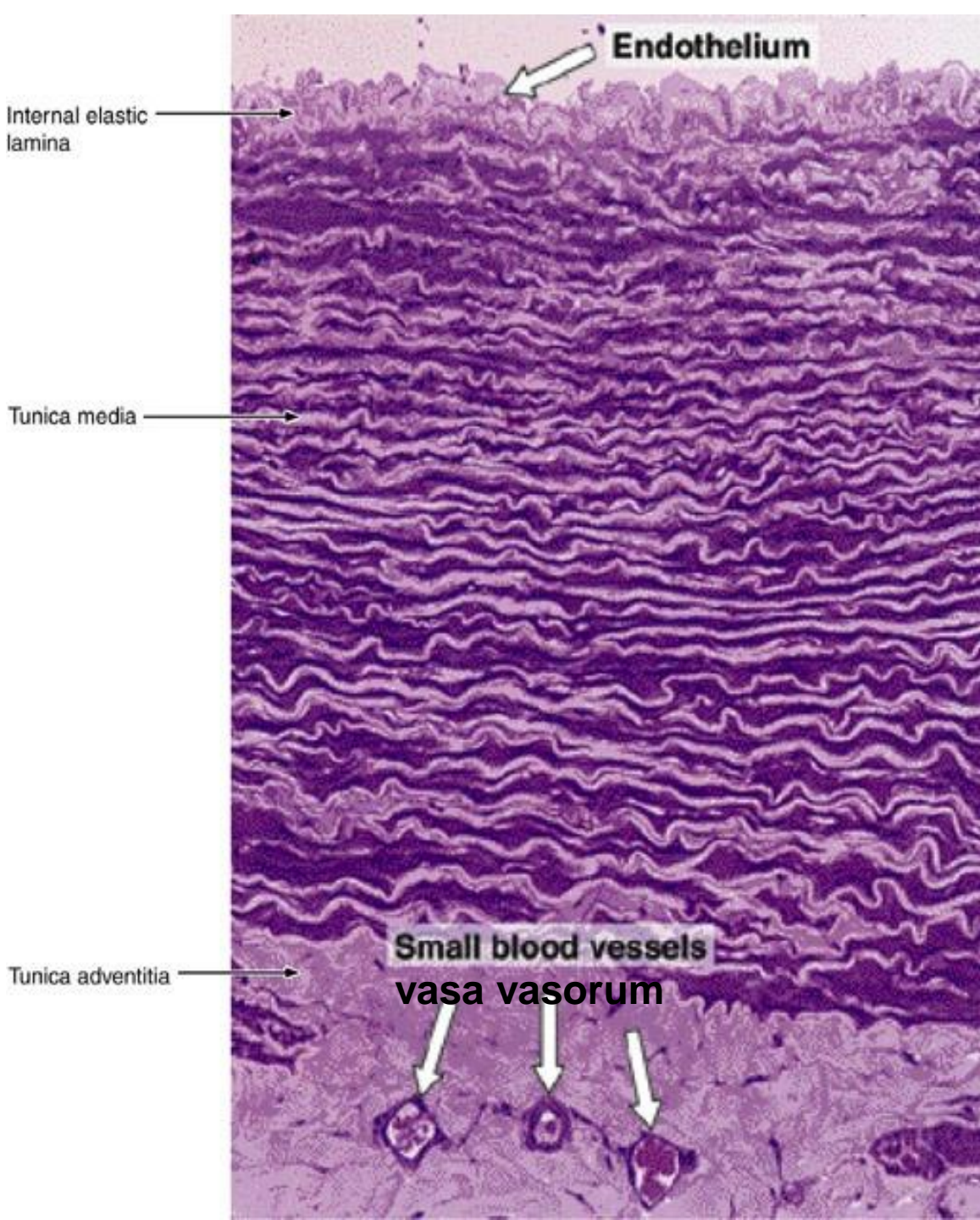


TUNICA INTIMA - endothelium, basal lamina, subendothelial connective tissue with smooth muscle cells, laminae of elastic fibers, thin, incomplete - internal elastic lamina – outermost layer

TUNICA MEDIA - many fenestrated elastic membranes - fenestrated membranes, alternating with circularly oriented layers of smooth muscle cells, thin external elastic lamina - outermost layer

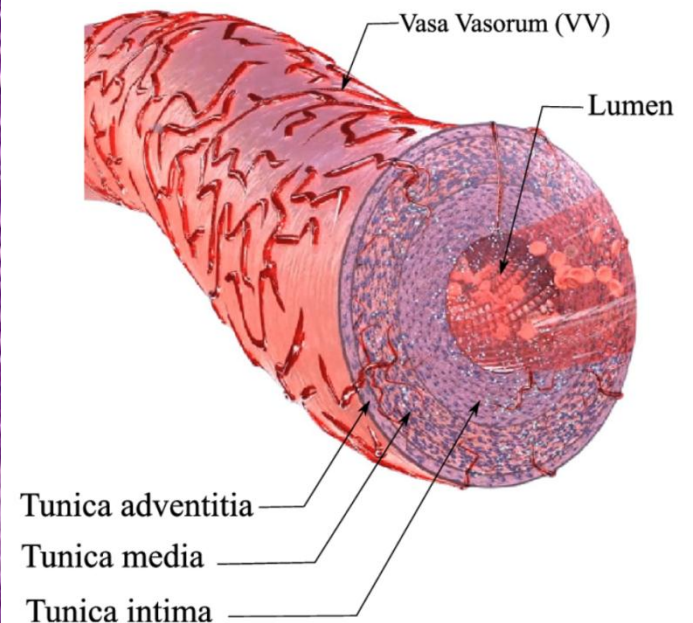
TUNICA ADVENTITIA - loose fibroelastic connective tissue with **vasa vasorum**, lymphatic vessels, nerve fibers.

- aorta, common carotid artery, subclavian artery, common iliac arteries, pulmonary trunk



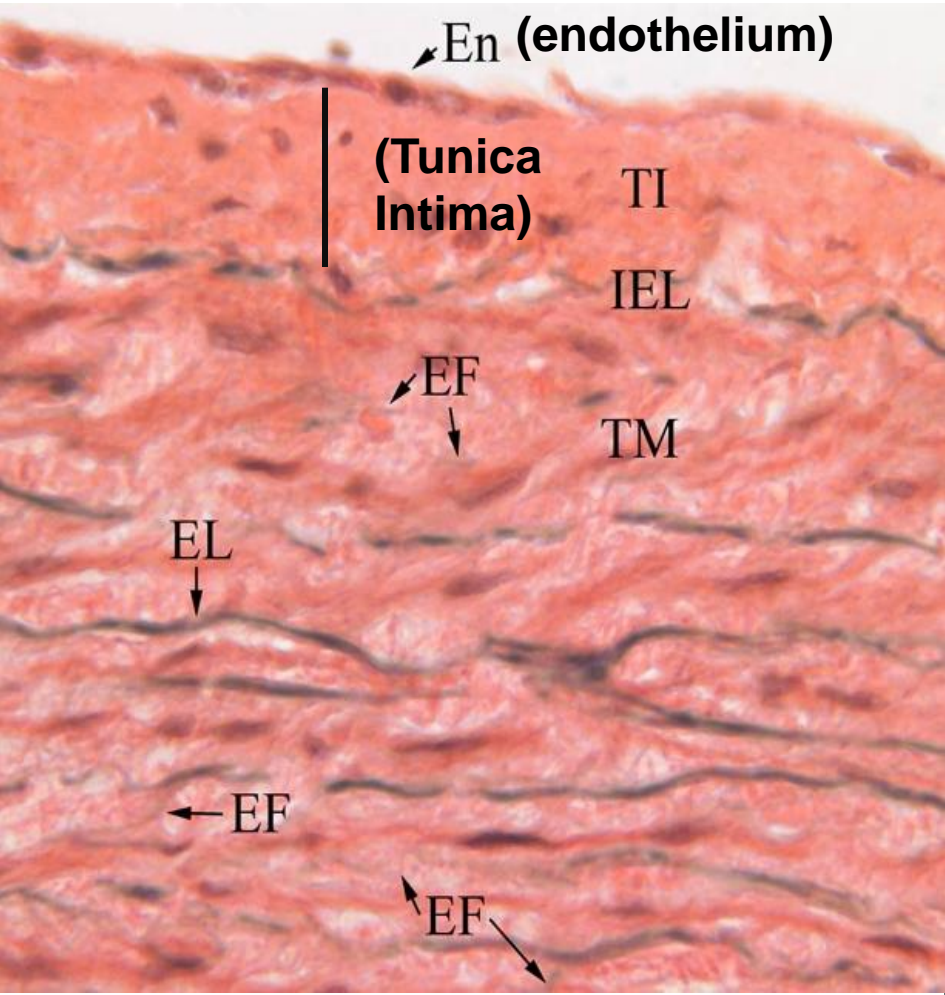
Elastic artery

- the wall (thick) - smaller blood vessels in tunica adventitia which supply the tunica adventitia and the outer part of the tunica media - **vasa vasorum**.

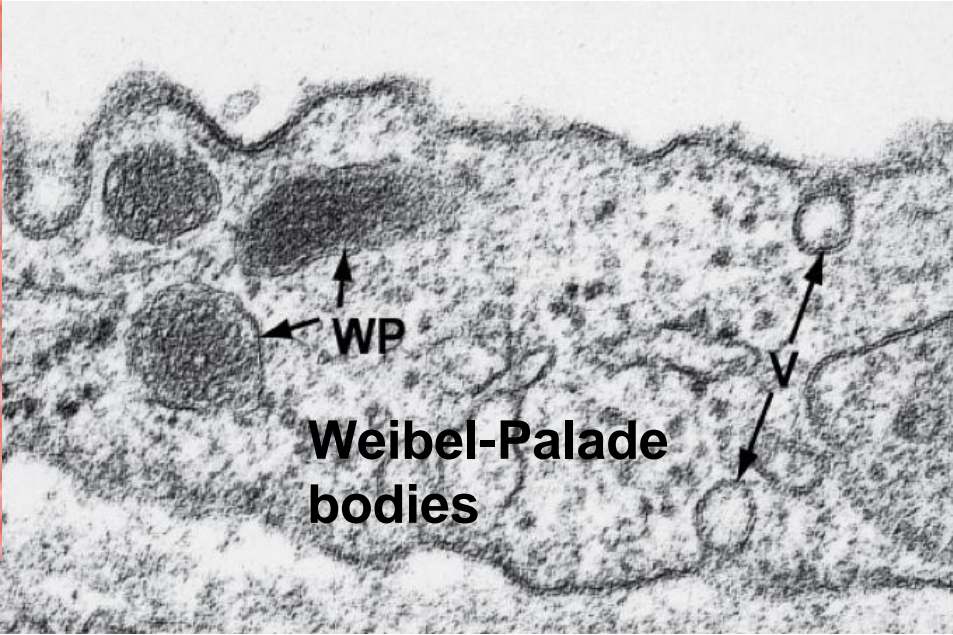


General structure of elastic (conducting) artery.

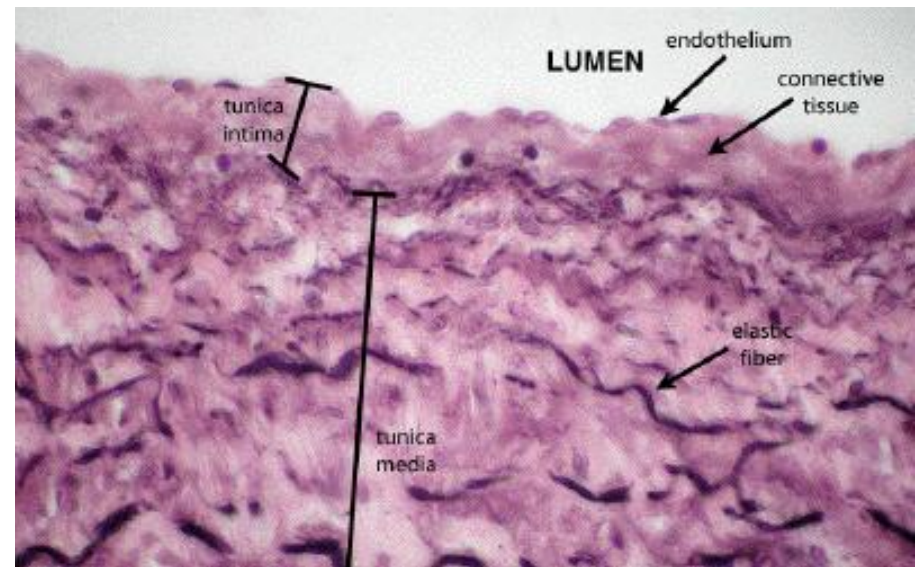
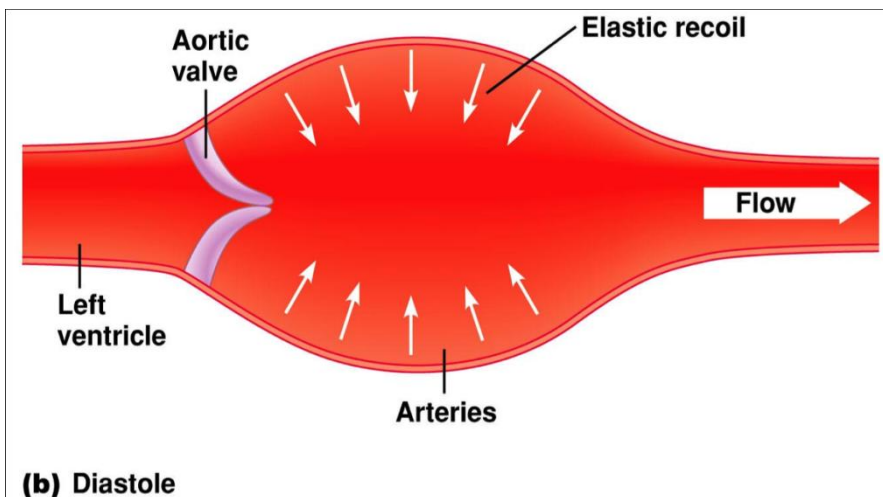
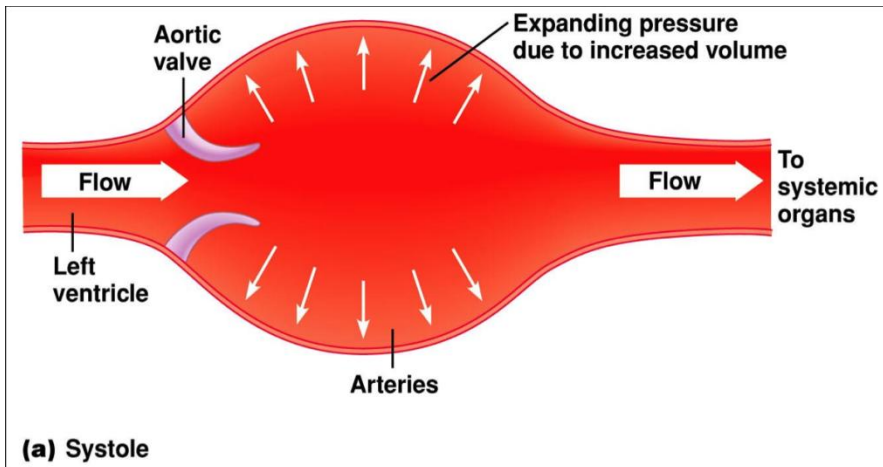
- **Tunica intima** is thicker than in other arteries.



- **Endothelial cells**
- connected by occluding junctions,
- contain membrane-bound **Weibel-Palade bodies** housing tubular elements with glycoprotein **von Willebrand factor** (involved in **hemostasis** – facilitates the coagulation of platelets during clot formation).



General structure of elastic (conducting) artery.

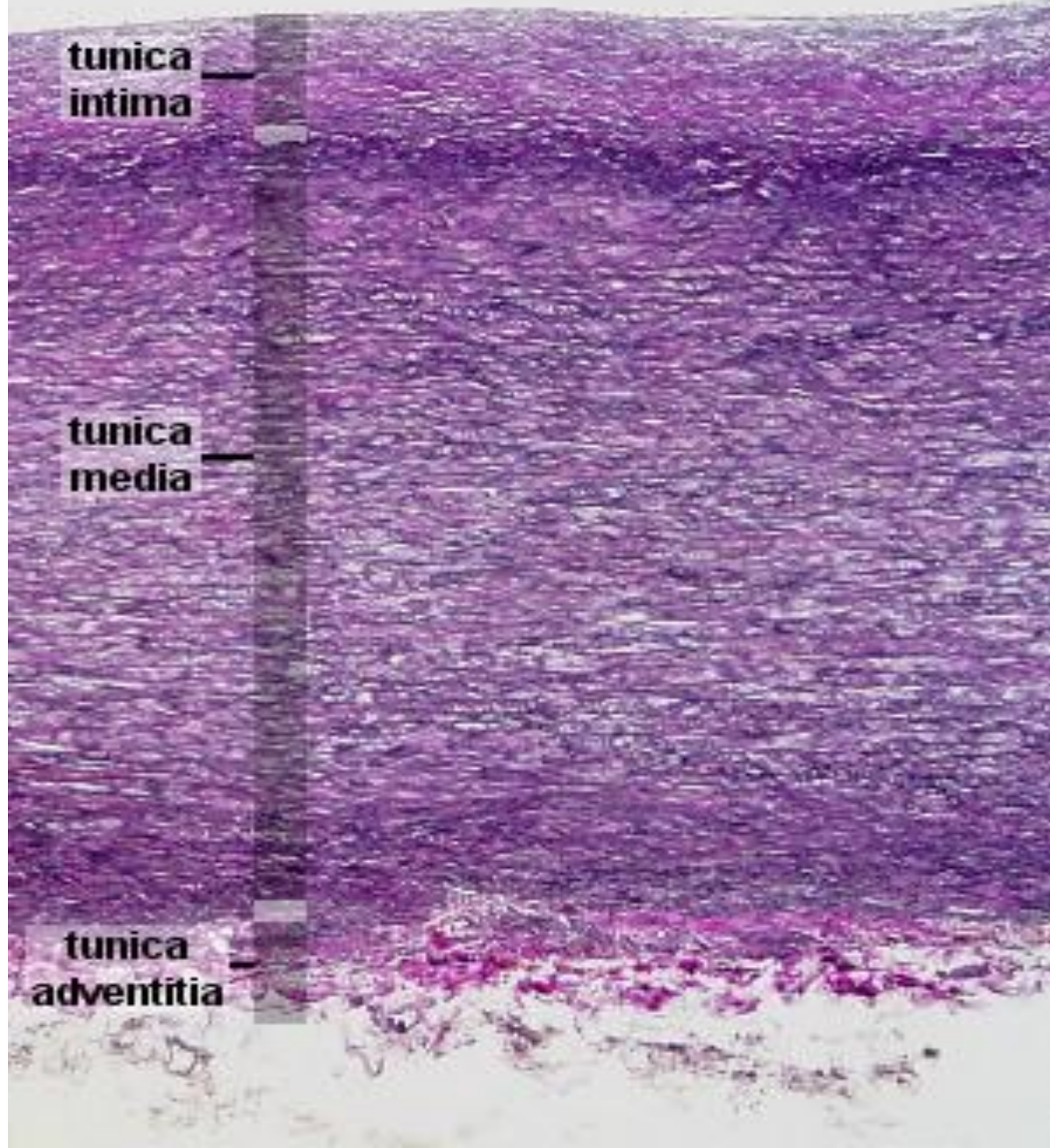


Subendothelial connective tissue

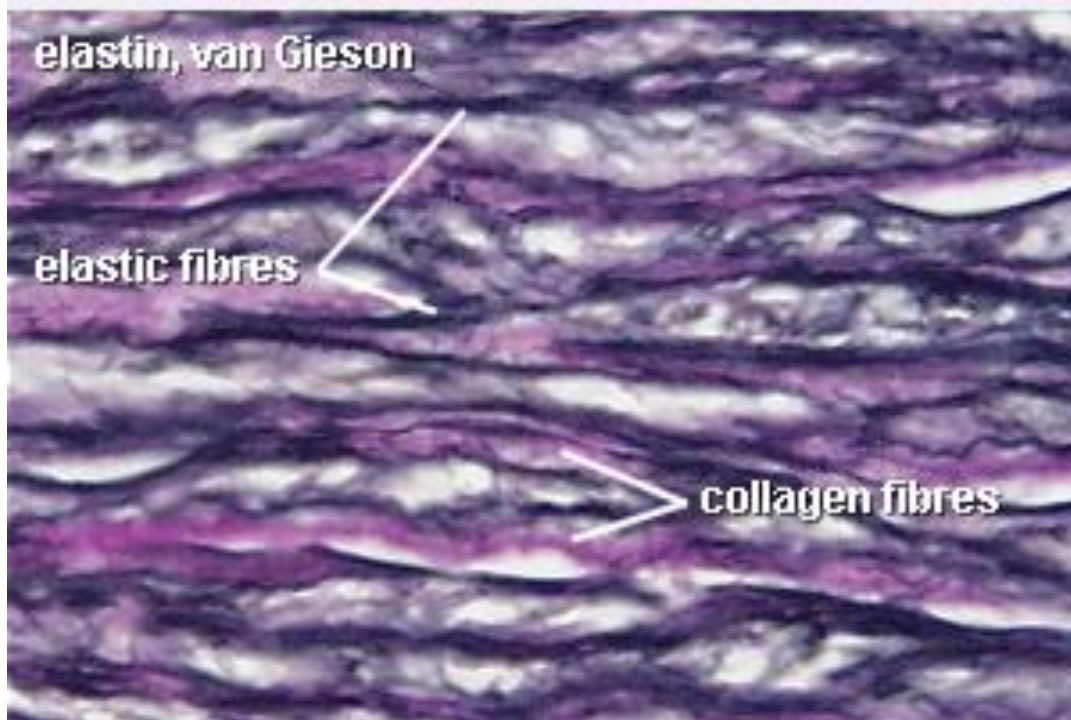
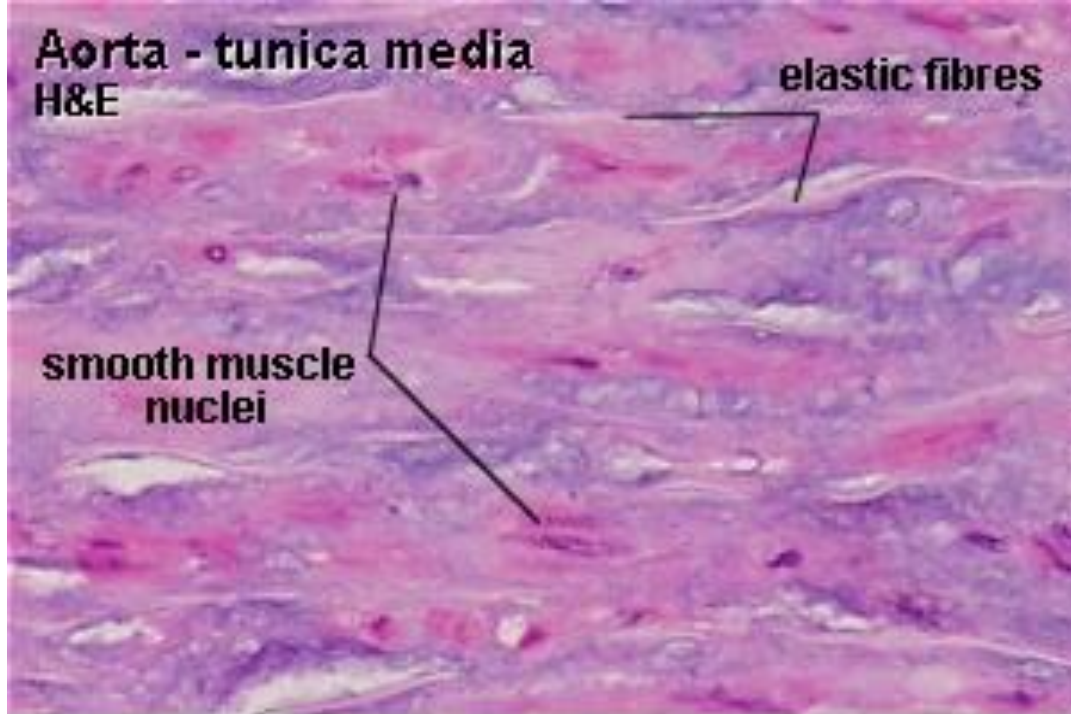
- allows the tunica intima to move independently from other layers
- **systole** - arteries distend with the increase blood pressure.
- during diastole spring back.

Distension of the walls is facilitated by concentric fenestrated lamellae of elastic fibers in a thick **tunica media**.

Aorta elastin & van Gieson



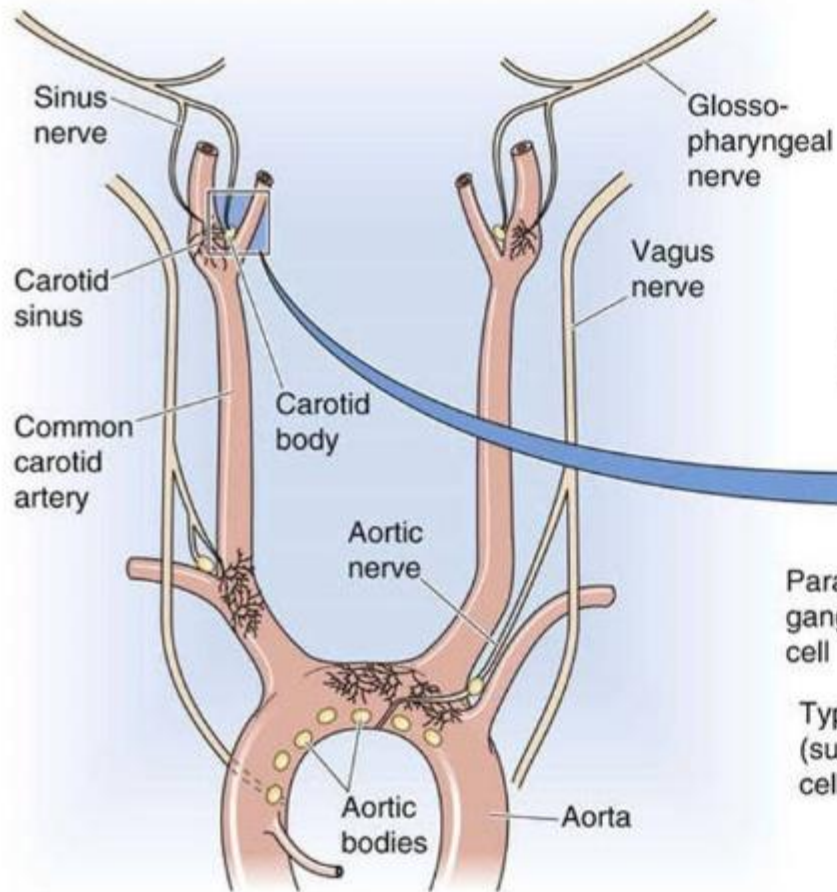
The tunica adventitia is thinner than the tunica media.



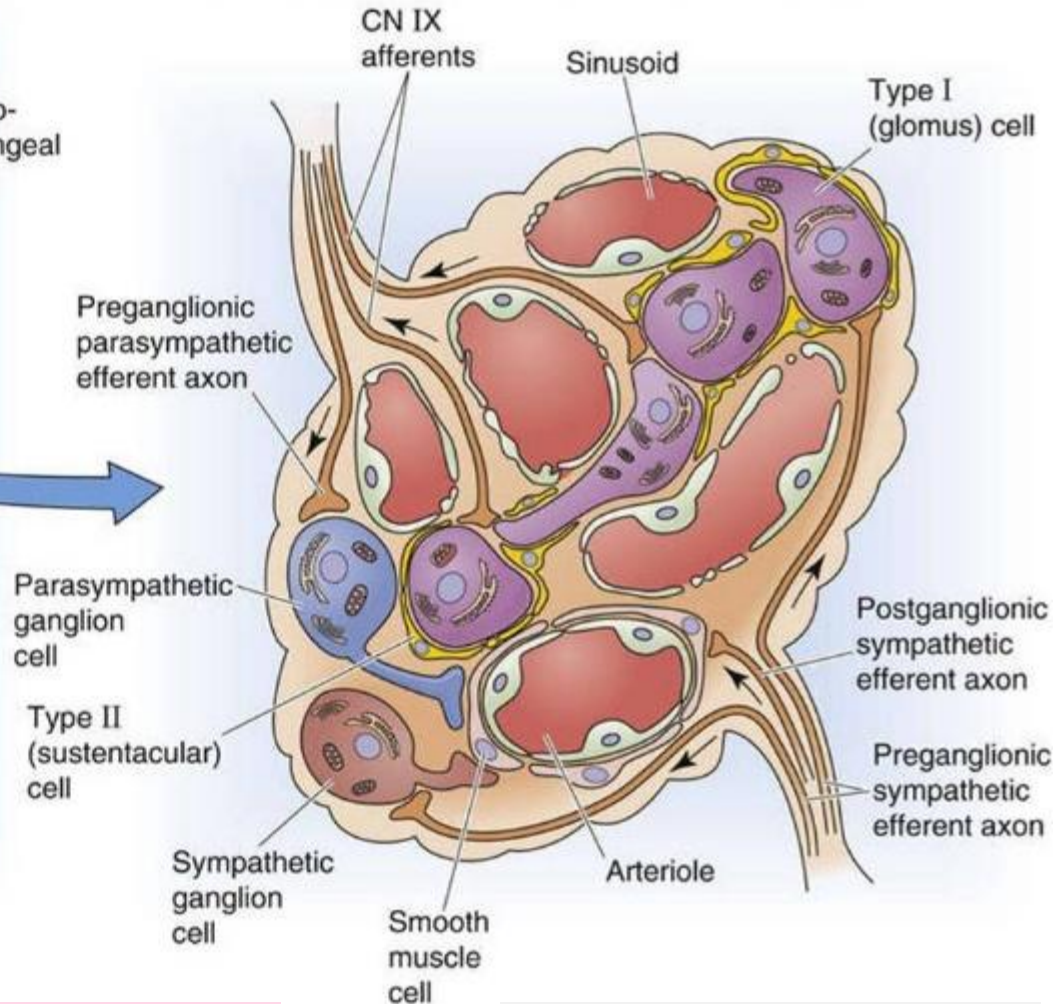
tunica media of elastic arteries contains:

- elastic fibers
- collagen fibers
- smooth muscle cells

A LOCATION OF CAROTID AND AORTIC BODIES



B MICROSCOPIC ANATOMY OF CAROTID BODY

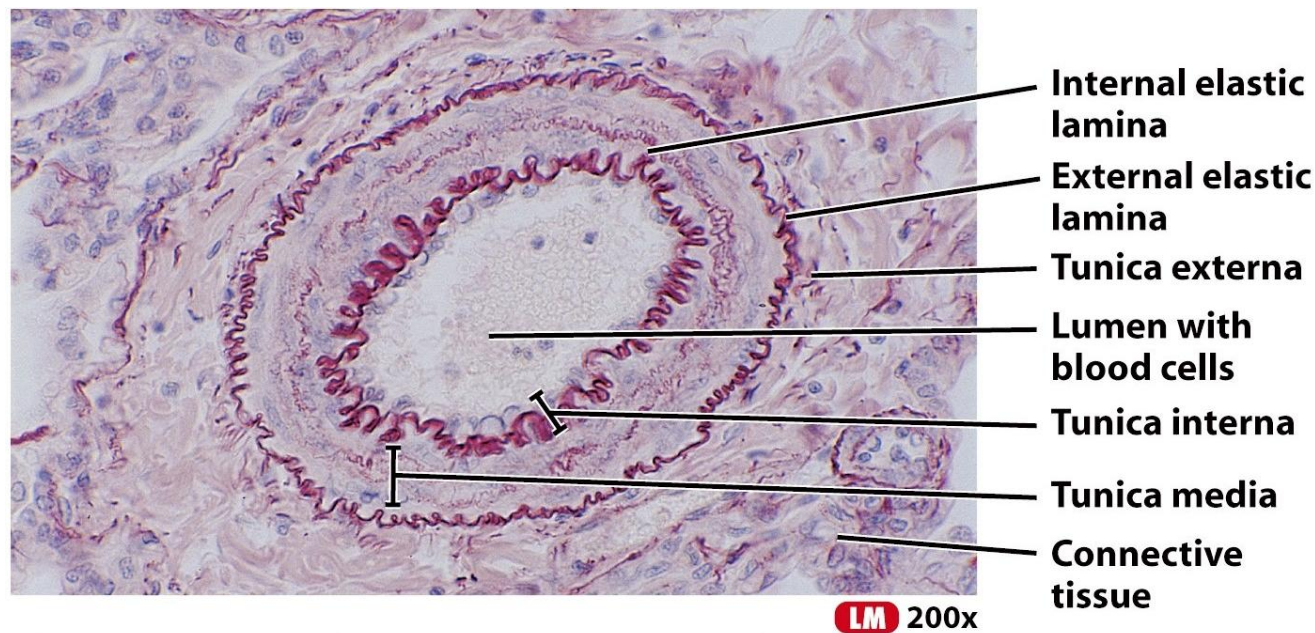


The carotid body (CB) is a key chemoreceptor organ in which **glomus cells sense changes in blood O₂, CO₂, and pH levels**

The glomus cell is the chemosensor in the carotid and aortic bodies

GENERAL STRUCTURE OF MUSCULAR (DISTRIBUTING) ARTERIES

- most vessels arising from the aorta, except elastic arteries



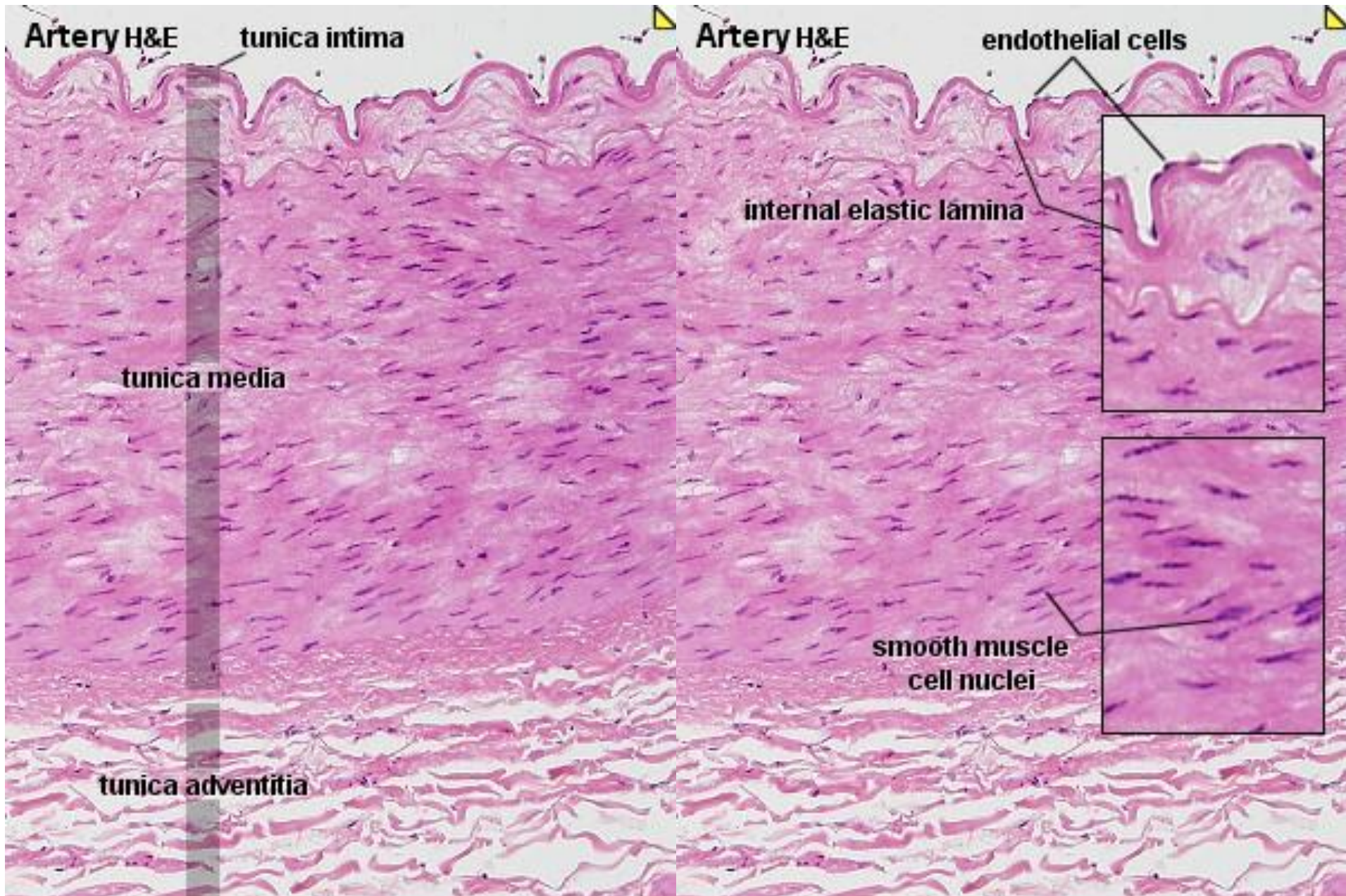
Transverse section through a muscular artery

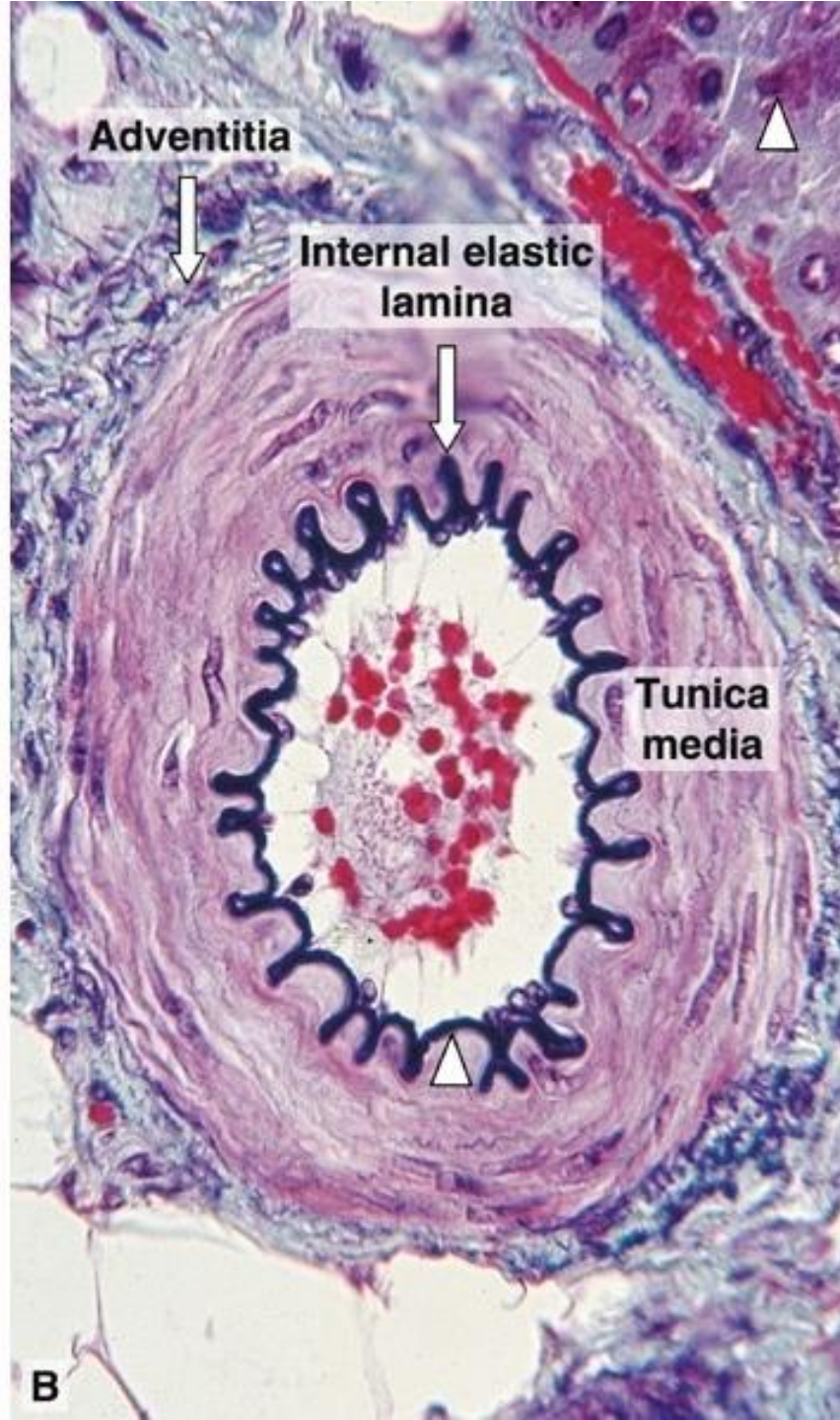
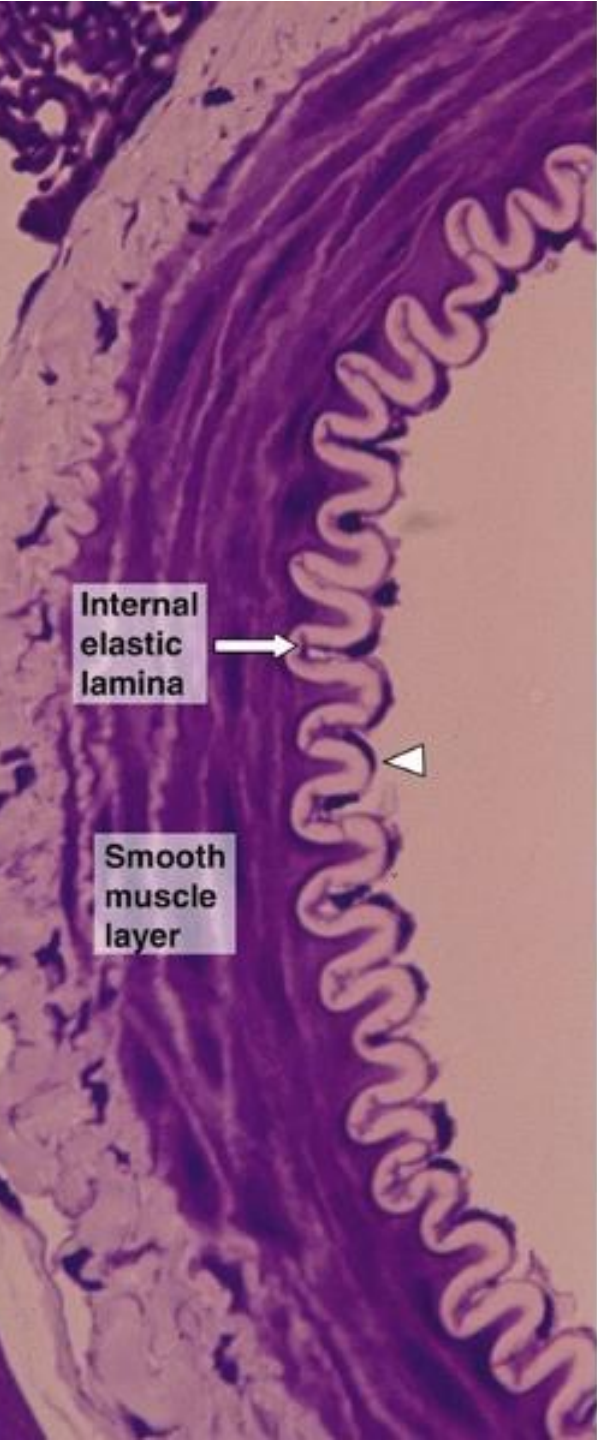
Tunica intima - thinner than that in elastic arteries. Endothelium with Weibel-Palade bodies, basal lamina, subendothelial layer (a few smooth muscle cells); **internal elastic lamina** is prominent and displays an undulating surface.

Tunica media is composed predominantly of smooth muscle cells whose orientation is circular. The number of smooth muscle cell layers decreases as the diameter of the artery diminishes. **External elastic lamina** (thick) - several layers of thin elastic membranes; they display fenestrations.

Tunica adventitia – fibroelastic connective tissue with **vasa vasorum**, lymphatic vessels, nerve fibers.

Undulating luminal surface of muscular artery

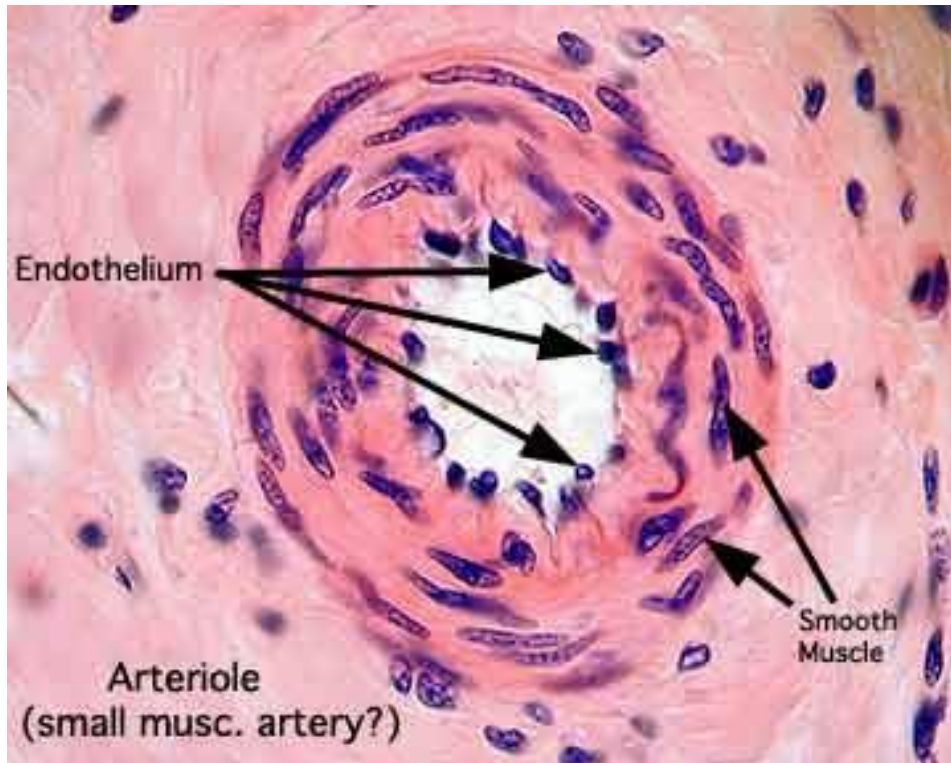




**Medium size
arteries -
characteristic
undulation**

ARTERIOLES

Arteries with a diameter of less than 0.1 mm.



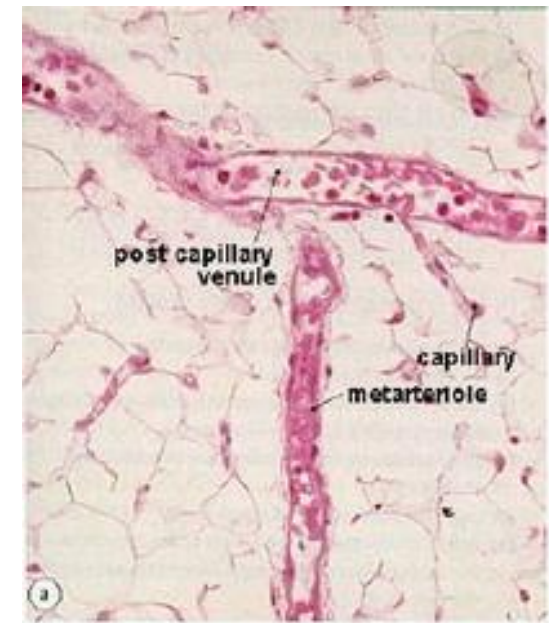
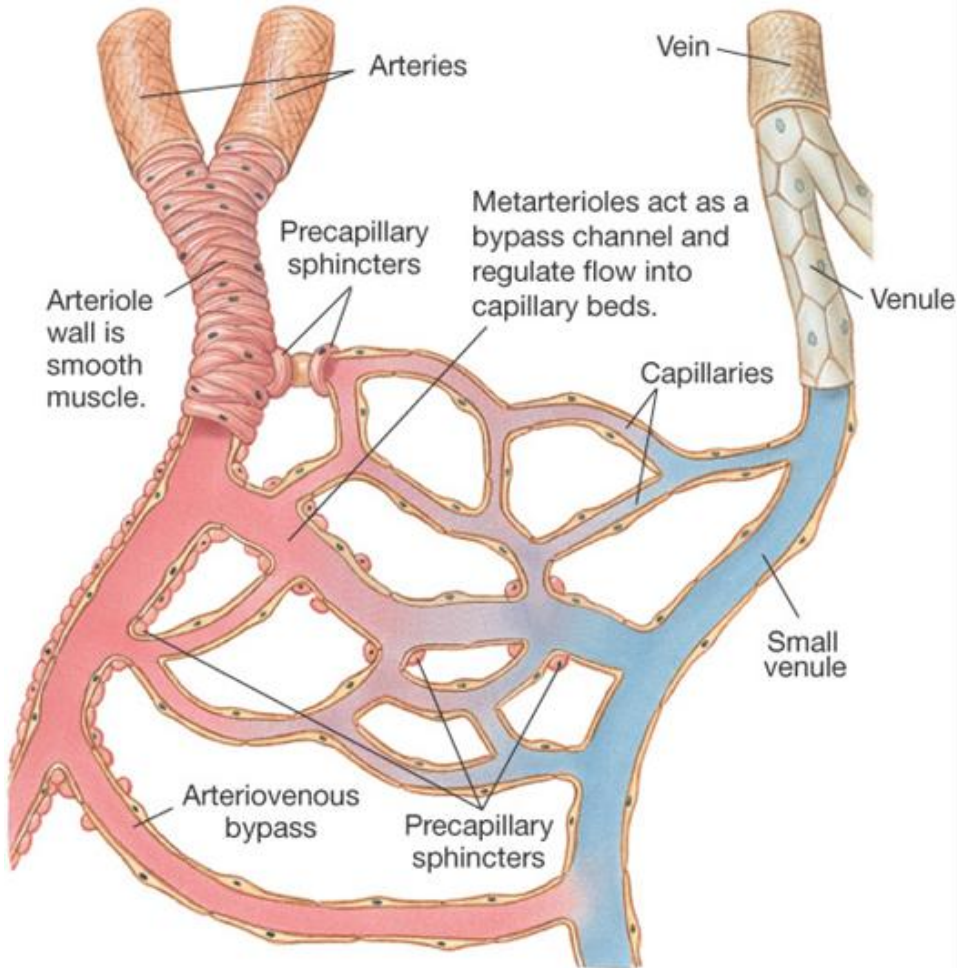
Tunica intima – endothelium, with Weibel-Palade bodies, basal lamina, a thin subendothelial connective tissue (type III collagen and a few elastic fibers). Fenestrated internal elastic lamina present only in large arterioles.

Tunica media - one, two or three smooth muscle cell layers. **Arterioles do not have an external elastic lamina.**

Tunica adventitia - scant connective tissue

METARTERIOLES

- short vessels that link arterioles with capillary bed.



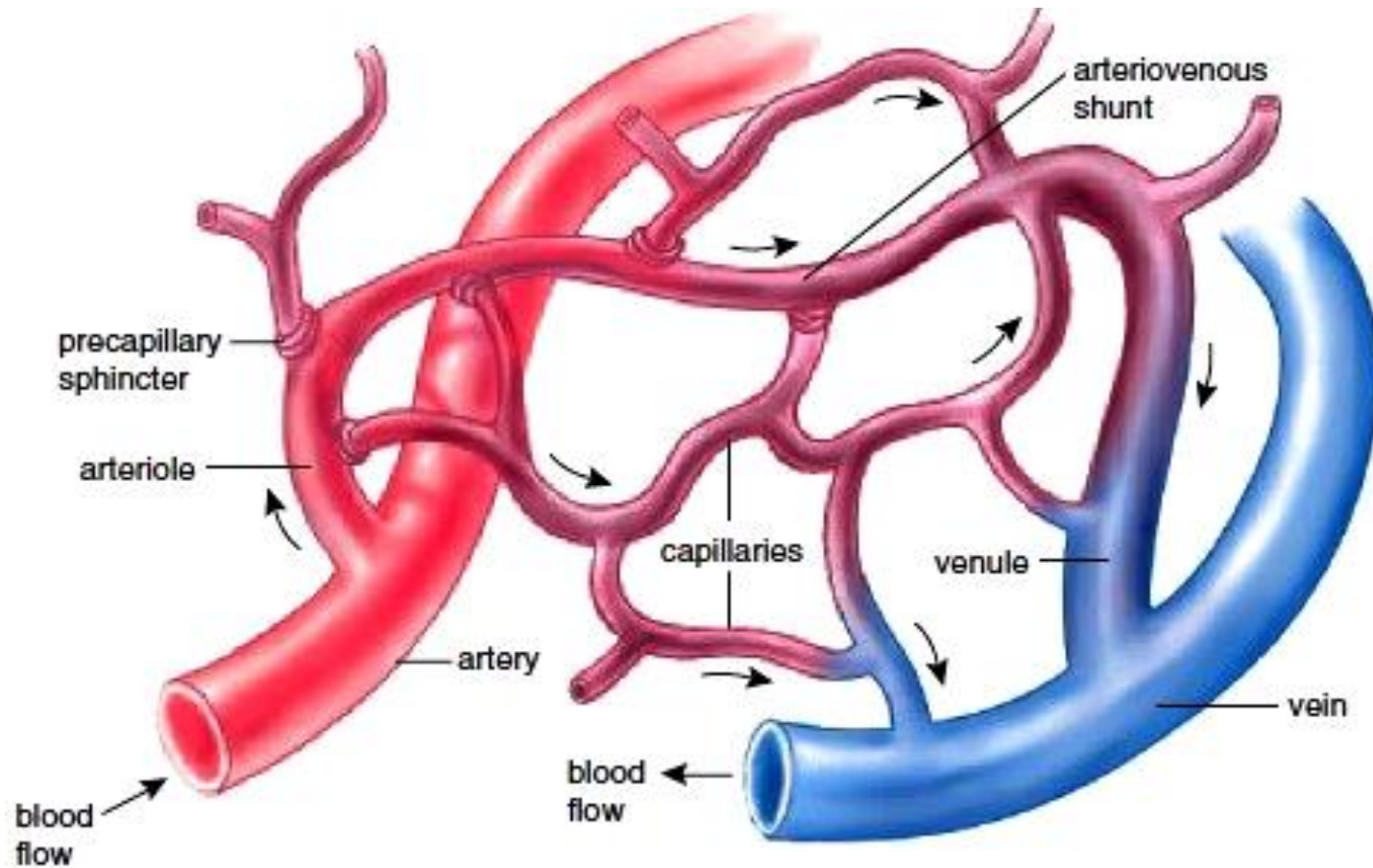
Tunica intima – endothelium, basal lamina

Tunica media – smooth muscle layer is not continuous (precapillary sphincter – controls blood flow into capillary bed)

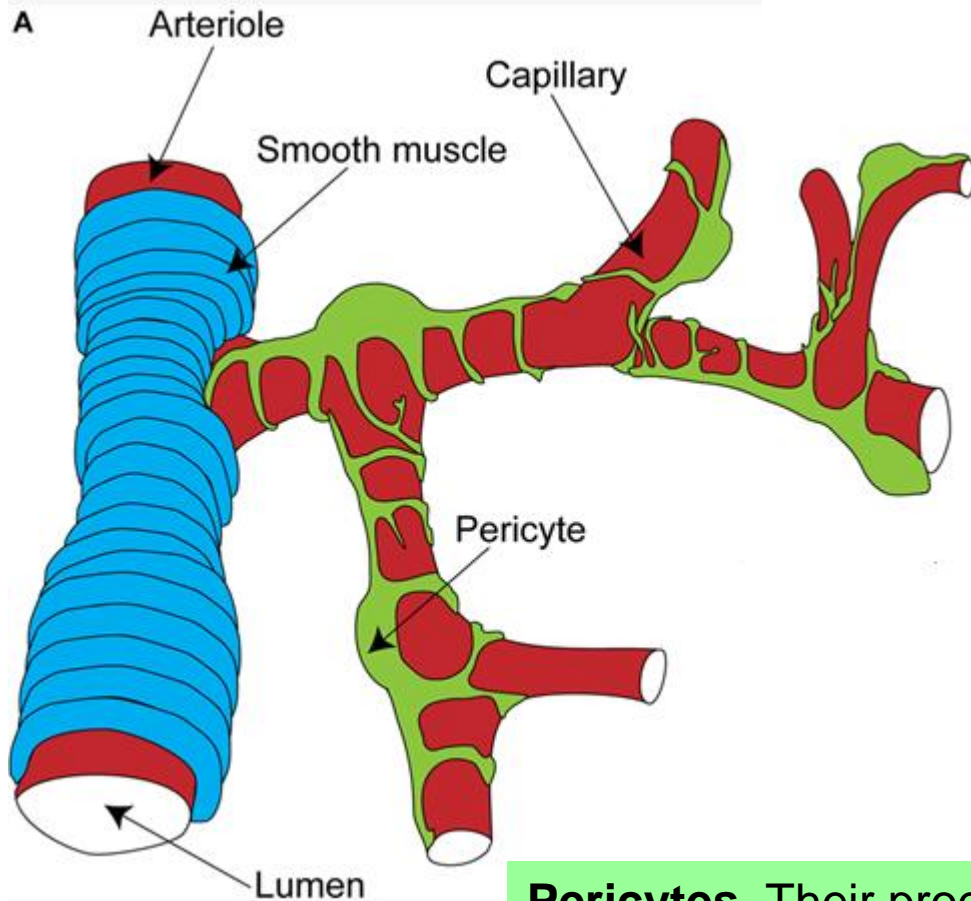
Tunica adventitia – loose connective tissue

GENERAL STRUCTURE OF CAPILLARIES

Capillaries form capillary bed (network) between arterioles and venules.



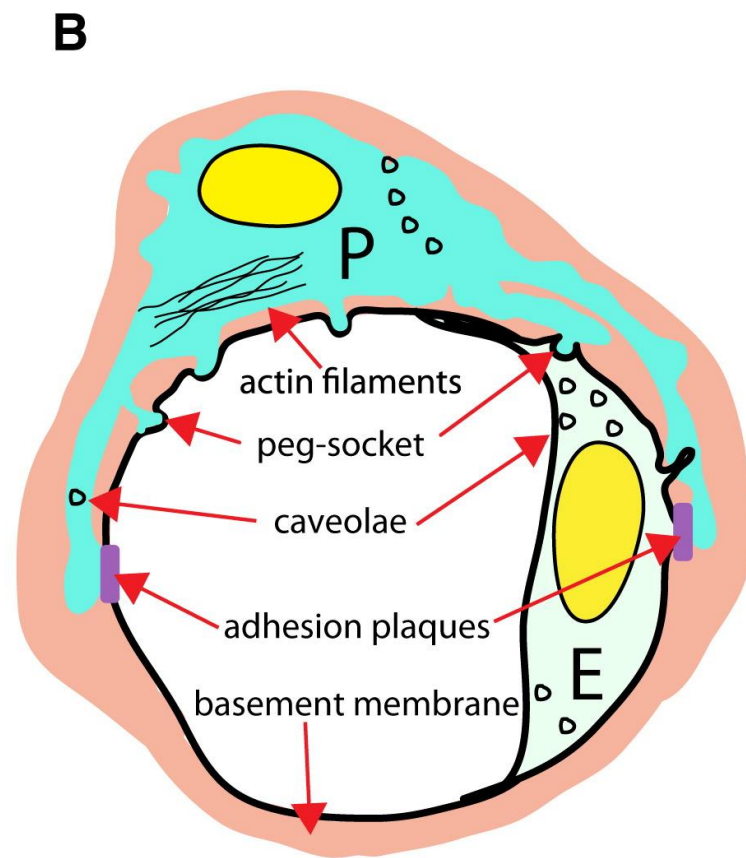
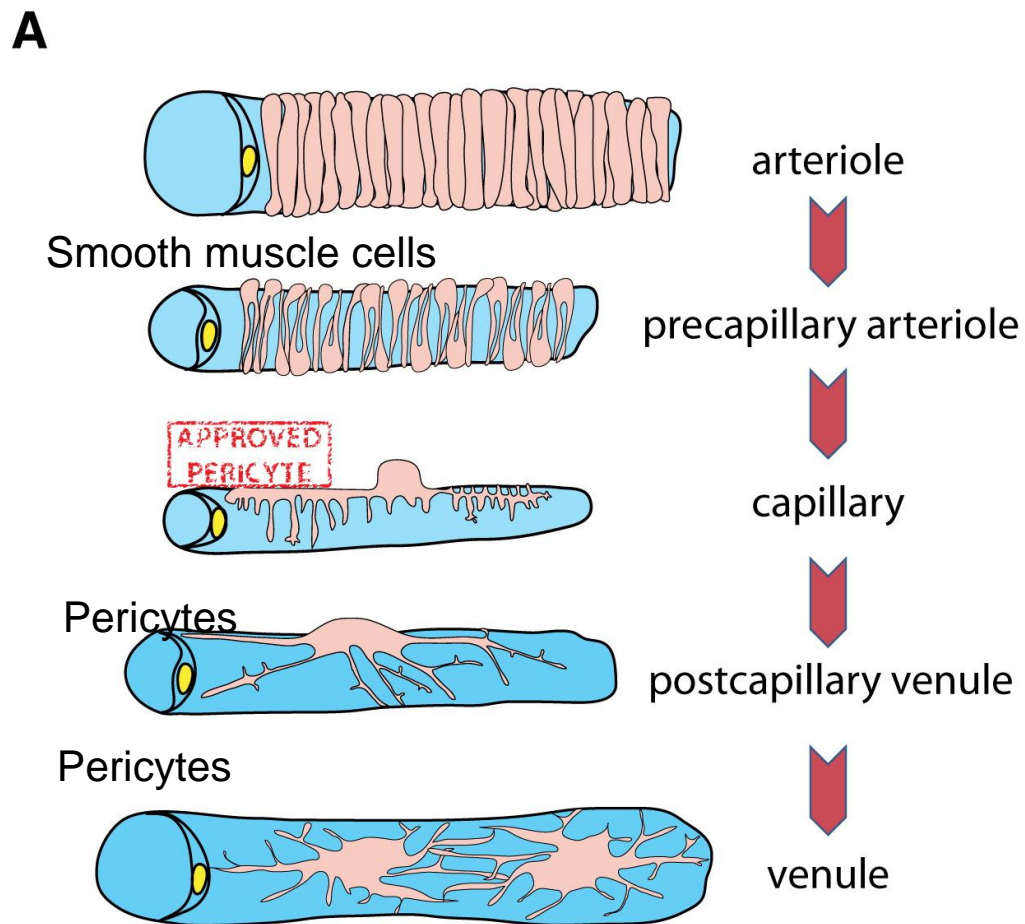
GENERAL STRUCTURE OF CAPILLARIES

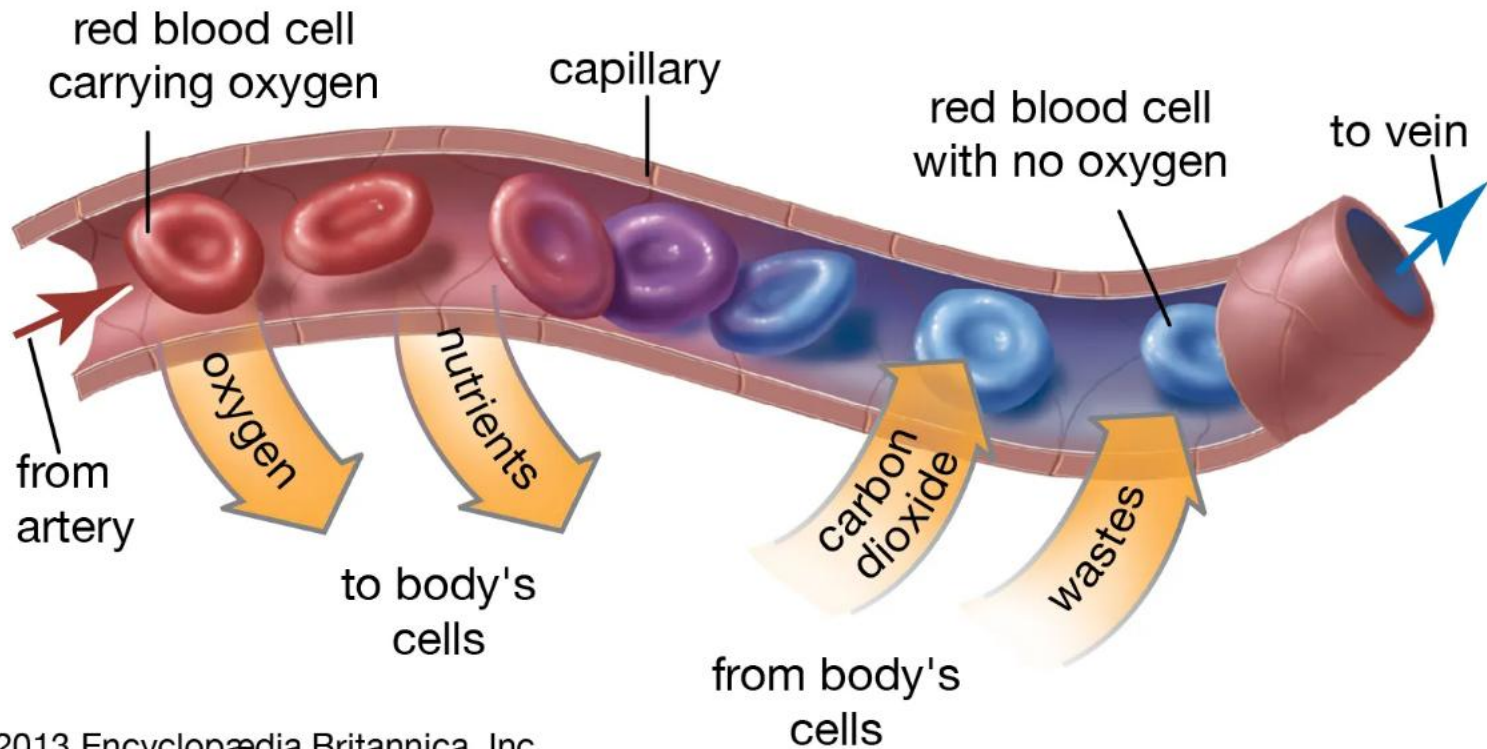


Single layer of squamous endothelial cells. Cells are joined by **tight junctions**.

Basal lamina

Pericytes. Their processes form gap junction with endothelial cells and surround endothelium of capillaries. **Pericytes possess their own basal lamina**, contain **actin, myosin and tropomyosin**, may function in contraction (regulation of blood pressure)

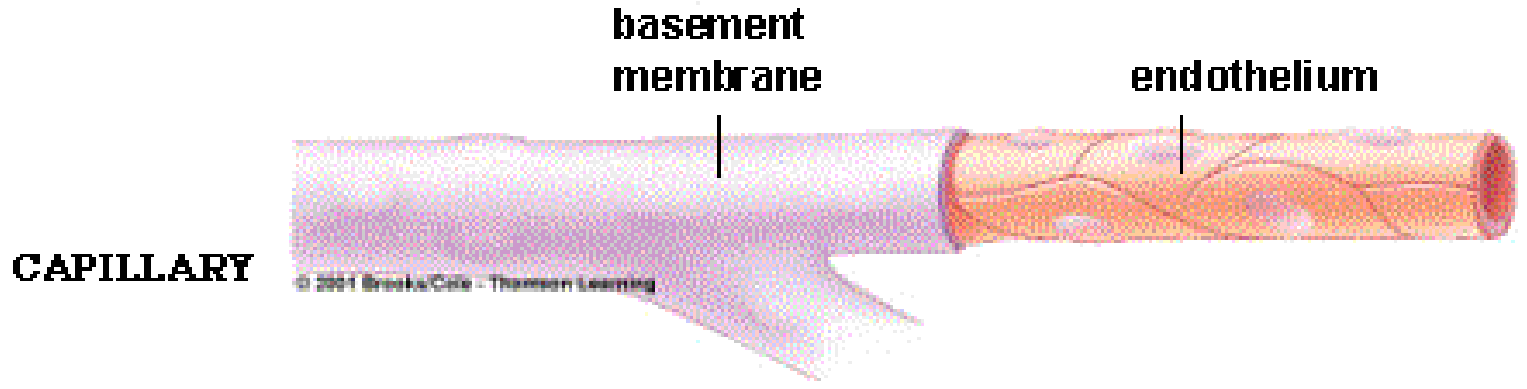
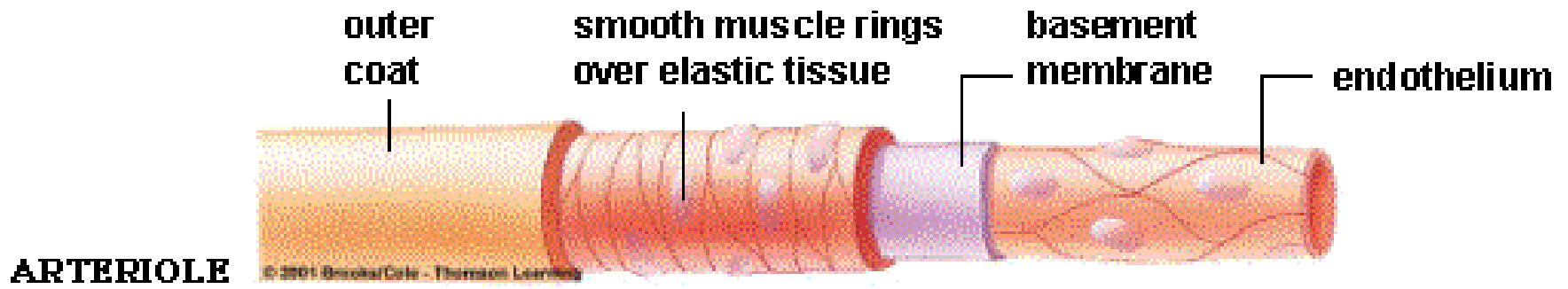
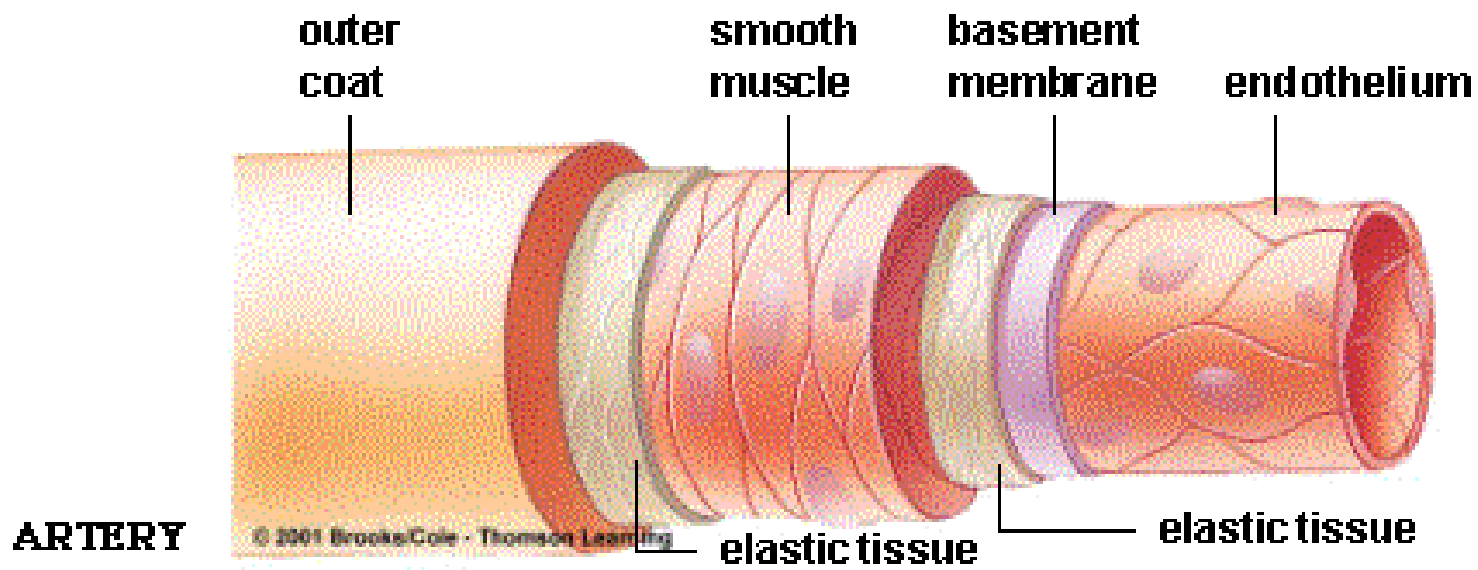




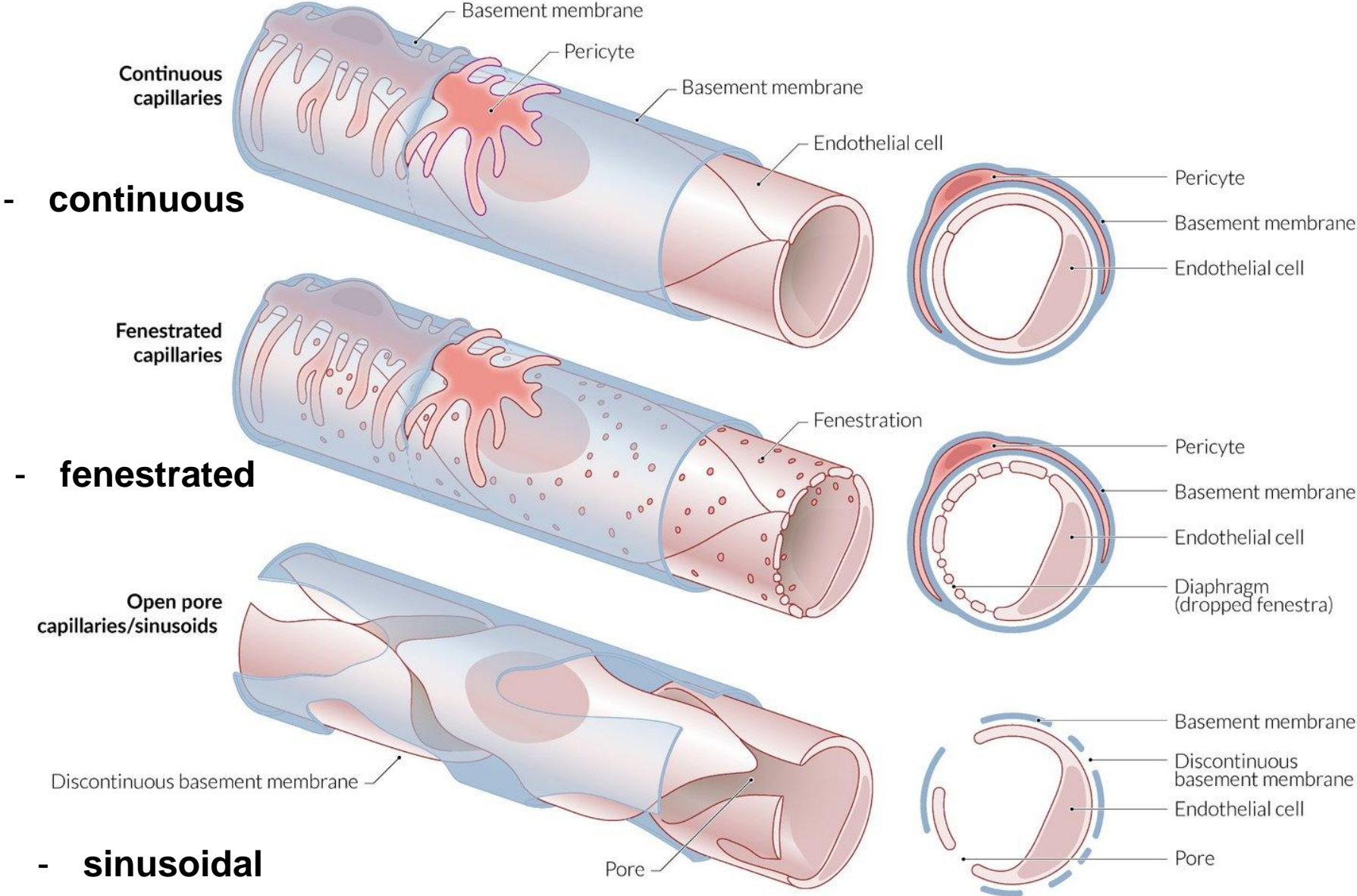
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CAPILLARIES

- exchange of water, oxygen, carbon dioxide, and many other nutrients and waste chemical substances between blood and the tissues surrounding them



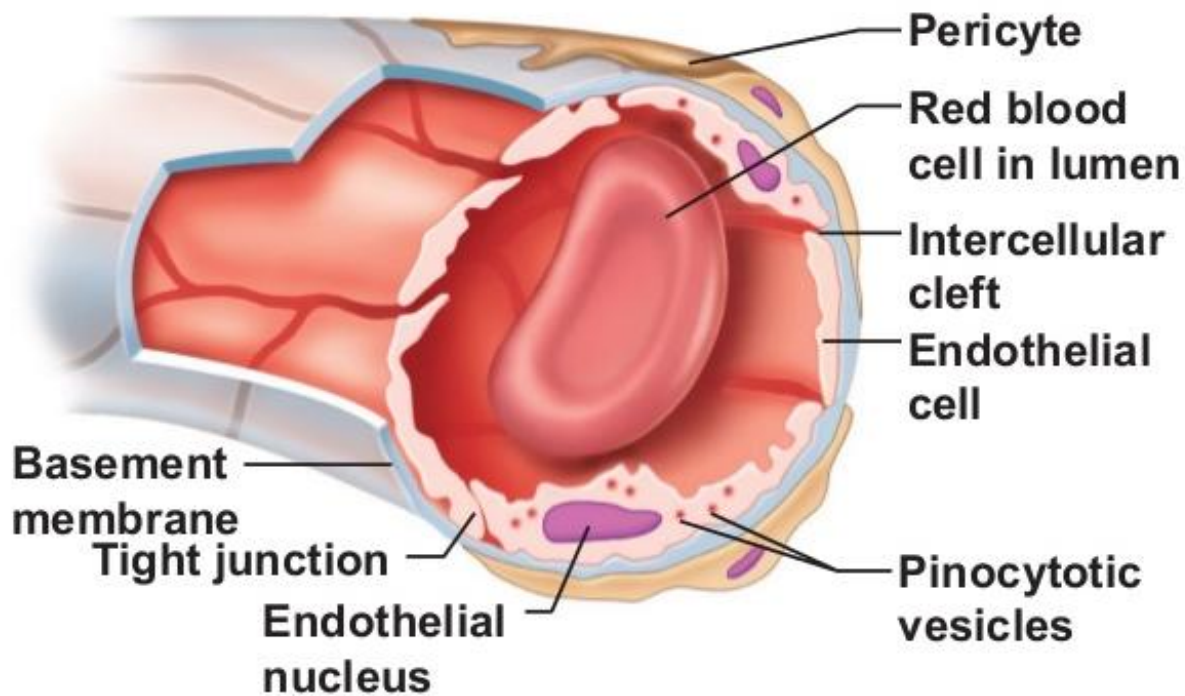
- three types of capillaries:



- continuous

- fenestrated

- sinusoidal

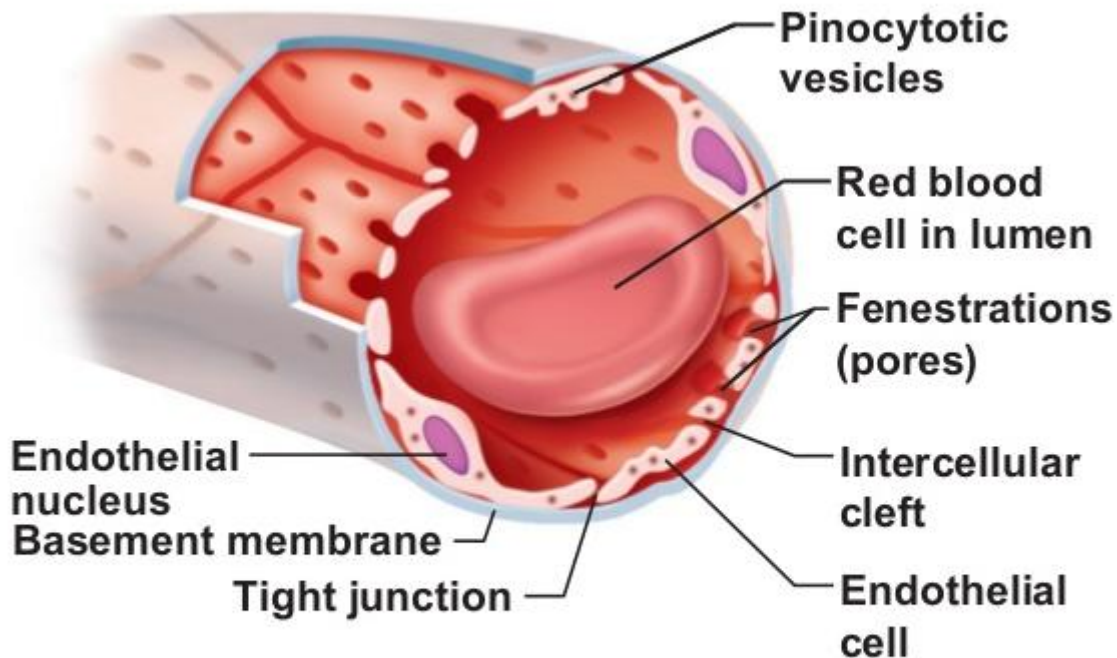


Present in:
Muscle, nervous (in the brain) and connective tissue

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

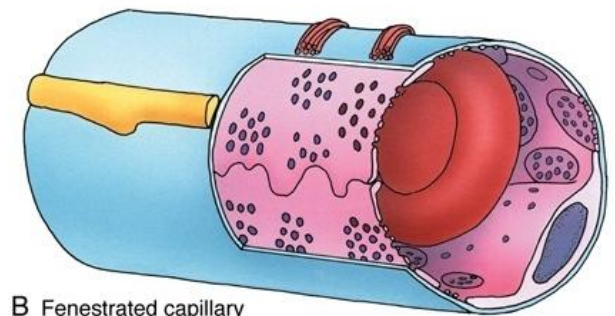
Continuous capillaries - formed by continuous endothelial cells and basal lamina (no pores or fenestrae).

- endothelial cells are joined by fasciae occludens (tight junction) which prevent passage of large molecules (barriers).
- endothelial cells and the basal lamina act as selective filter. Amino acids, glucose, purines and nucleosides move across the capillary walls via carrier-mediated transport.



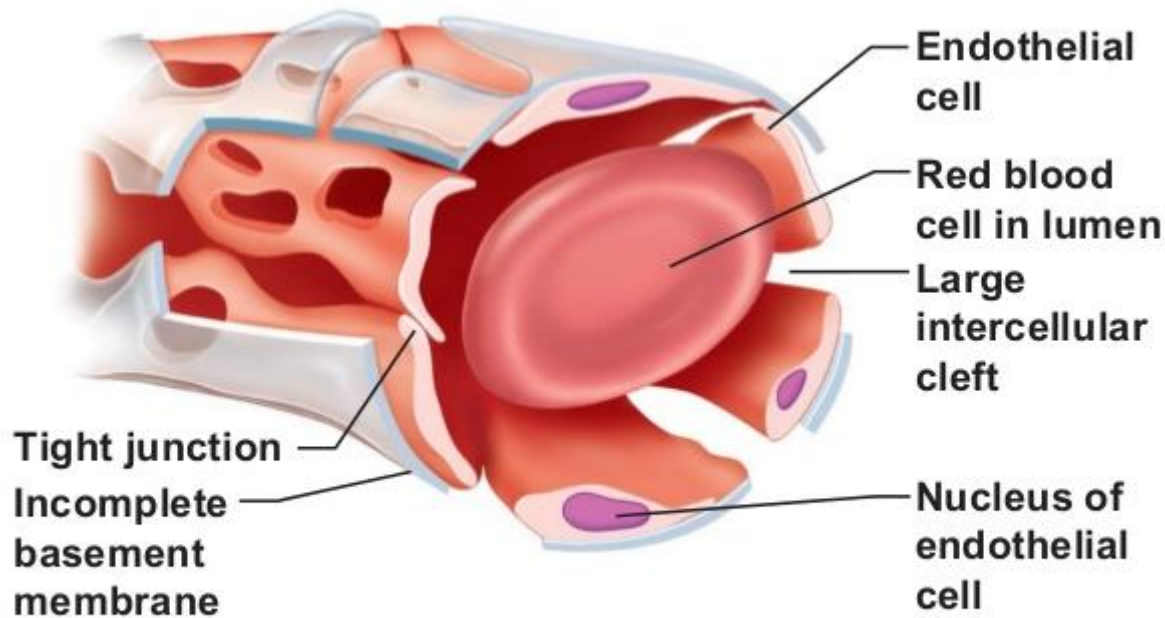
(b) Fenestrated capillary. Large fenestrations (pores) increase permeability. Occurs in special locations (e.g., kidney, small intestine).

Present in:
Pancreas, intestine, endocrine glands, and kidney (renal glomerulus)



Fenestrated capillaries

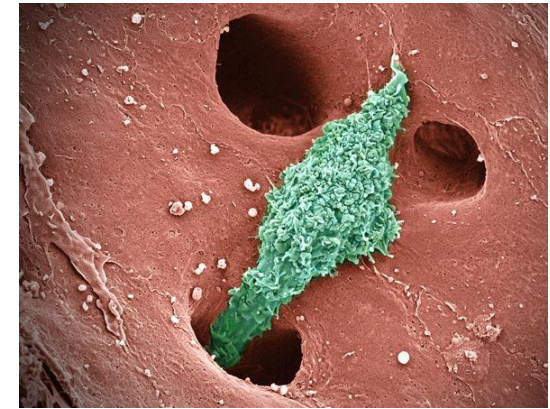
- possess pores (fenestrae) - are covered by pore diaphragms (only in renal glomerulus without diaphragms).
- pores - small openings in endothelial cell - allow components of the blood and interstitial fluid to bypass the endothelial cells to or from the capillary - pores located in clusters
- endothelial cells - surrounded by a continuous basal lamina - can act as a selective filter.



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

Present in:

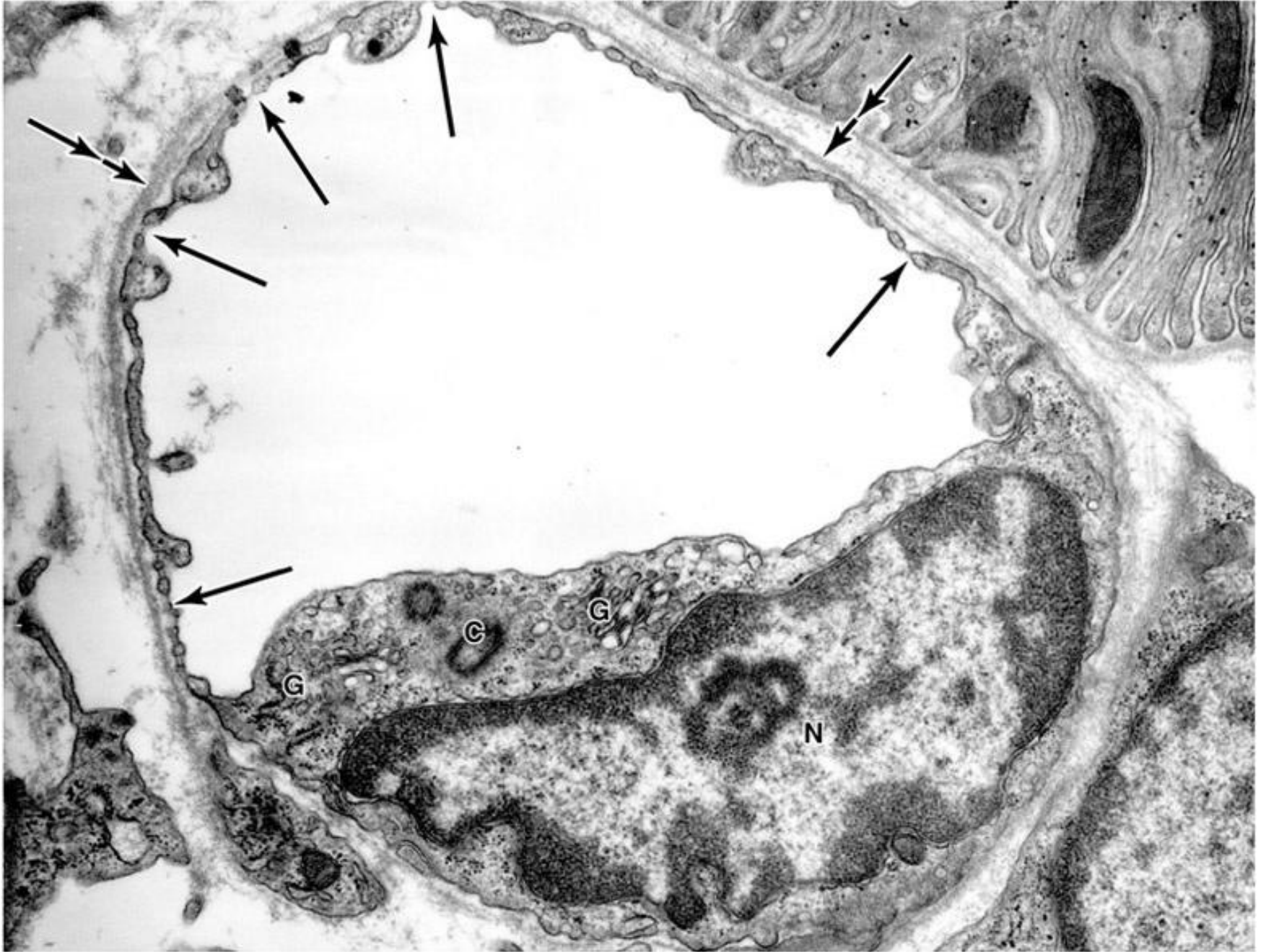
Bone marrow, liver, spleen, lymphoid organs and certain of endocrine glands.



Macrophage migrates through the „hole”

Discontinuous (sinusoidal) capillaries

- discontinuous endothelial cells and basal lamina.
- contain a lot of large fenestrae without diaphragms.
- allow a free exchange of substances or even cells between bloodstream and surrounding tissue.
- have an enlarged diameter 30-40 μm (5 to 10 μm of continuous capillary) (slowing the flow of blood).

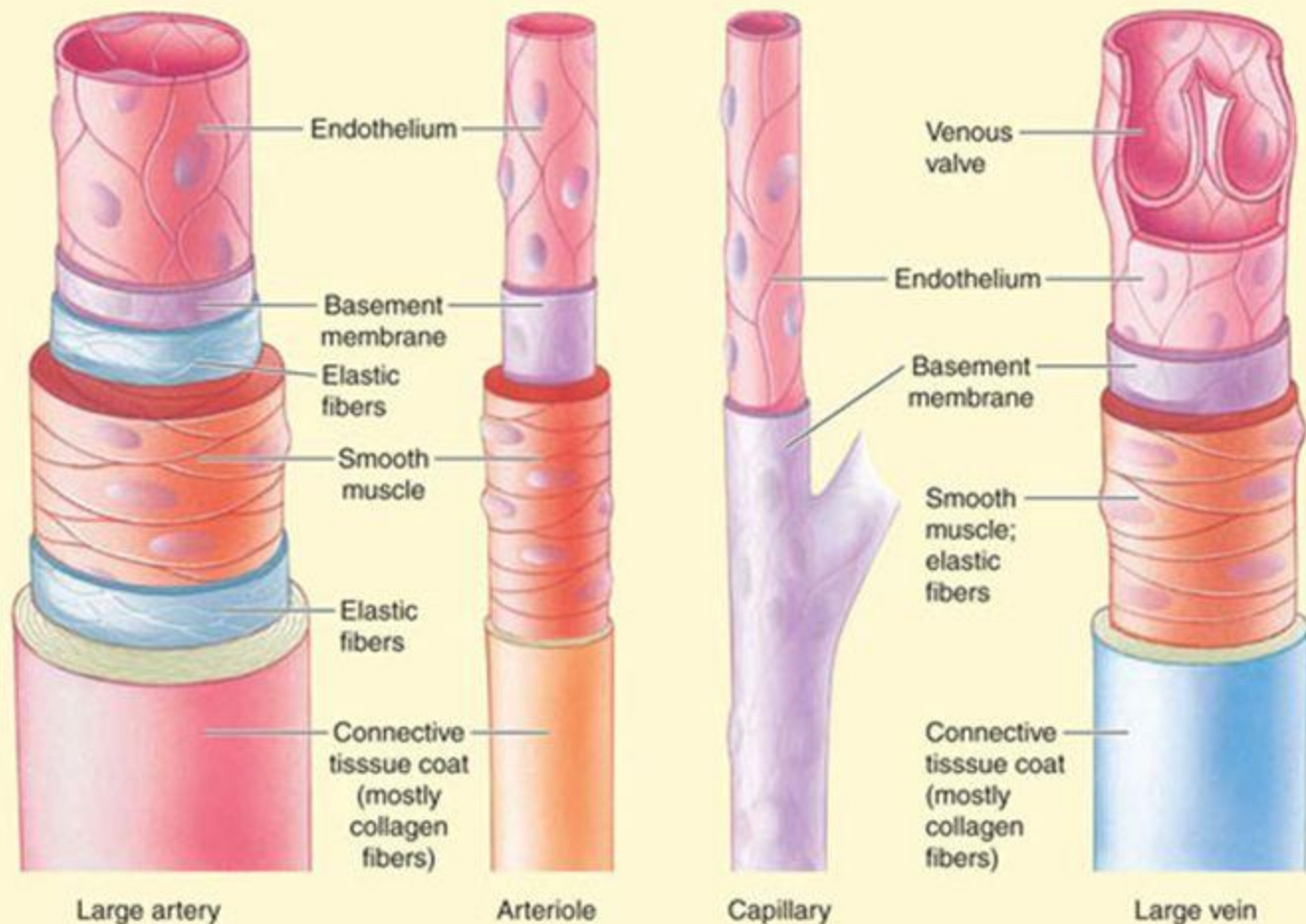


Fenestrated capillary in the kidney

VESSEL TYPE

Feature	Arteries	Arterioles	Capillaries	Veins
Number	Several hundred*	Half a million	Ten billion	Several hundred*
Special Features	Thick, highly elastic, walls; large radii*	Highly muscular, well-innervated walls; small radii	Very thin walled; large total cross-sectional area	Thin walled compared to arteries; highly distensible; large radii*
Functions	Passageway from heart to organs; serve as pressure reservoir	Primary resistance vessels; determine distribution of cardiac output	Site of exchange; determine distribution of extracellular fluid between plasma and interstitial fluid	Passageway to heart from organs; serve as blood reservoir

Structure



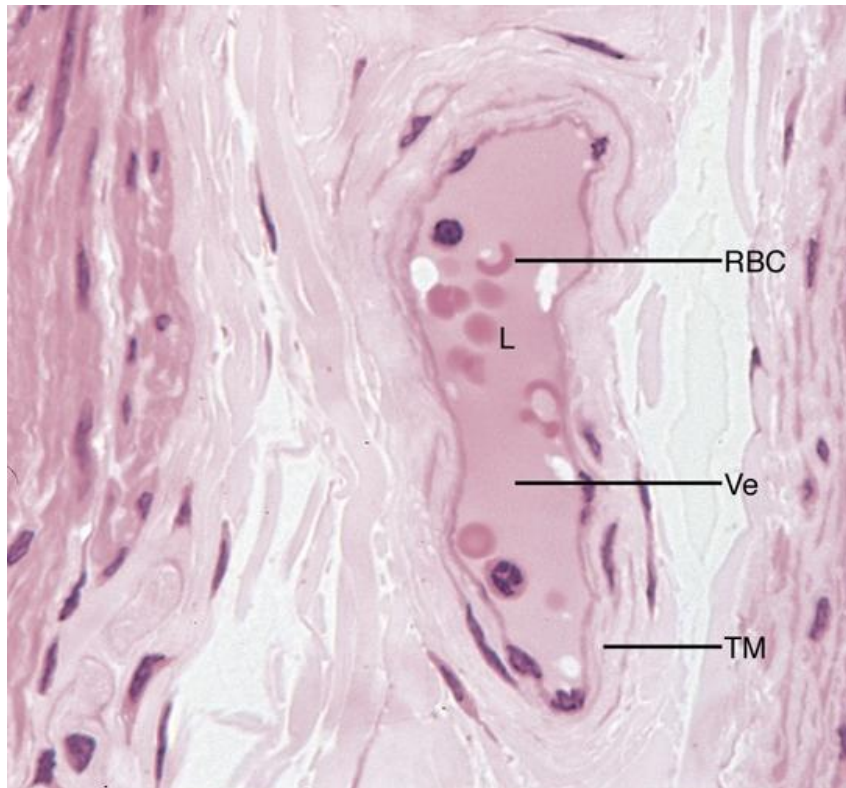
VENULES

Postcapillary venules (15 to 20 μm in diameter) receive blood from capillaries.

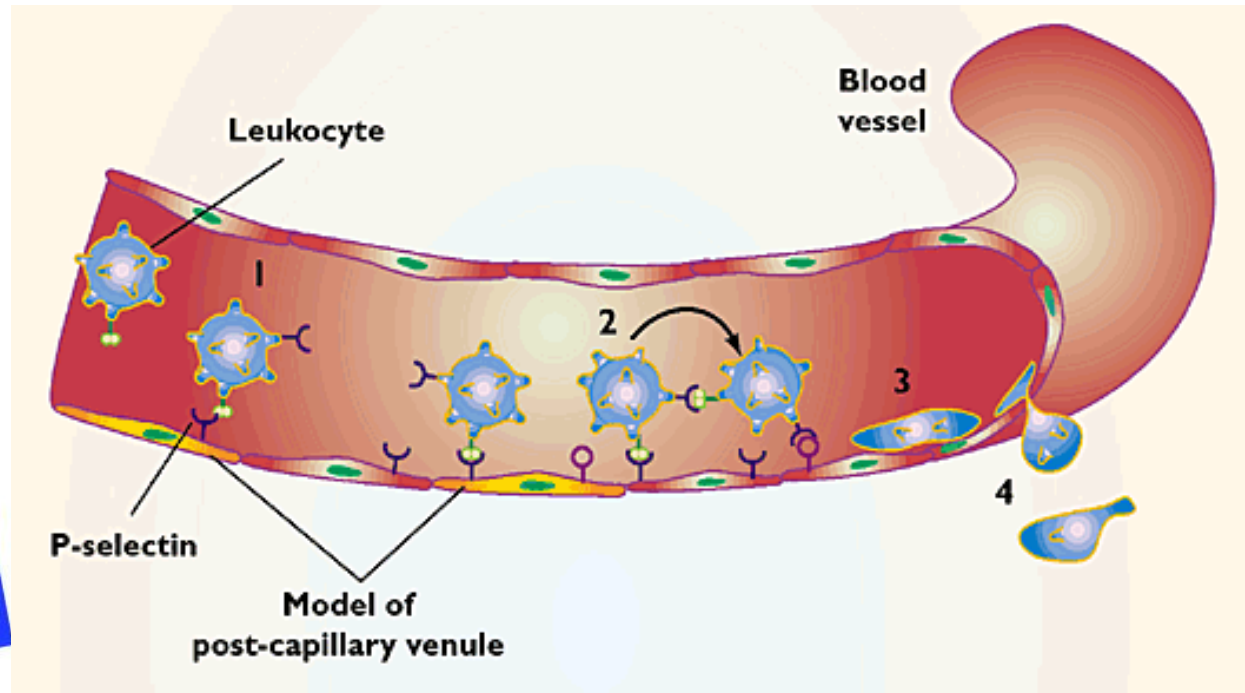
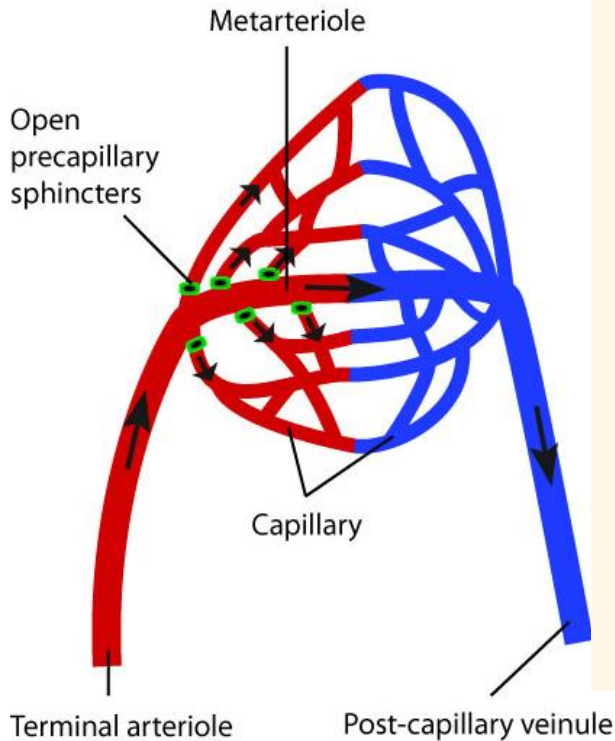
Tunica intima - endothelium, basal lamina, reticular fibers (pericytes in postcapillary venules)

Tunica media - sparse connective tissue, a few smooth muscle cells in larger venules (>1 mm in diameter), first as scattered smooth muscle cells, then, as venule diameter increases, the smooth muscle cells become more closely spaced.

Tunica adventitia - some collagen fibers and a few fibroblasts

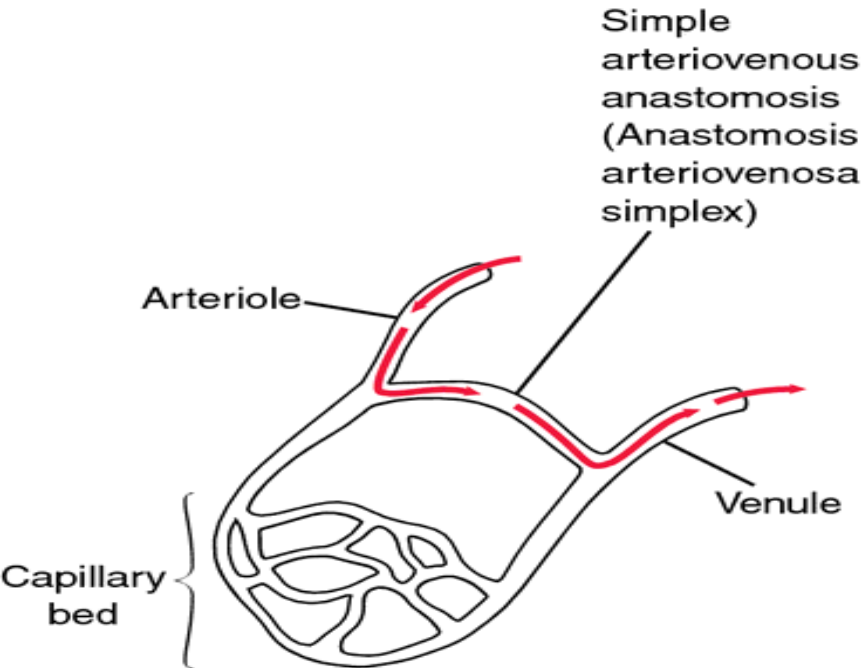


POSTCAPILLARY VENULES

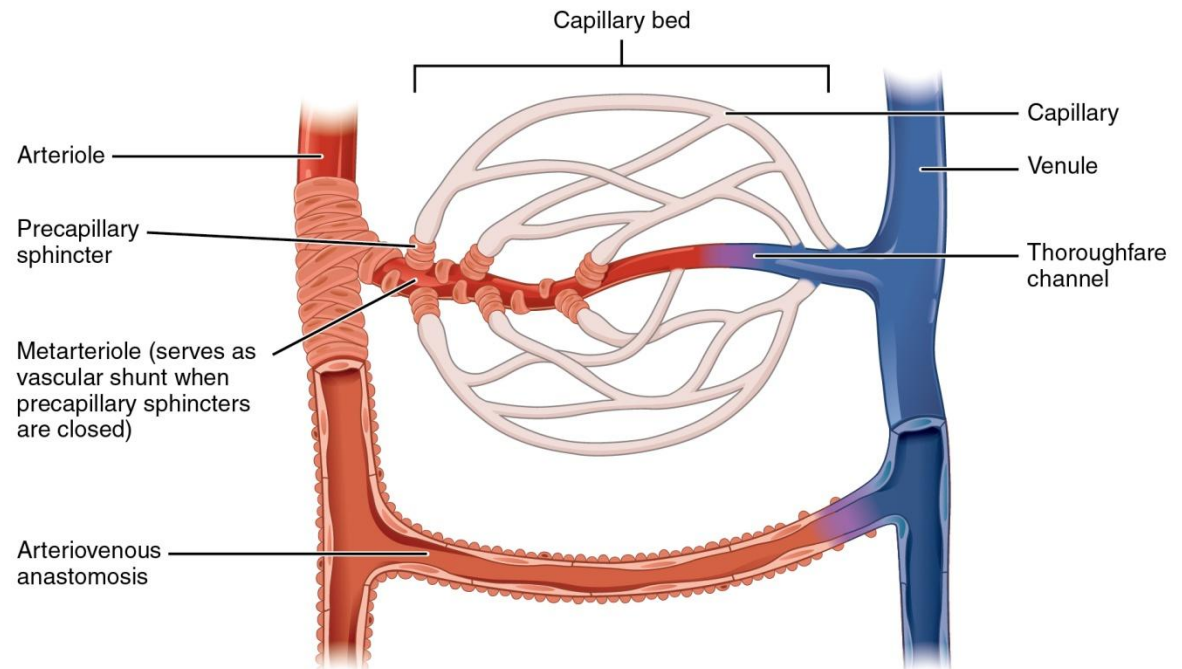


- walls of these vessels are even more permeable than capillaries.
- the exchange of material between blood and connective tissue
- the **migration of leukocytes !!!** from the bloodstream to the connective tissue

ARTERIOVENOUS ANASTOMOSES

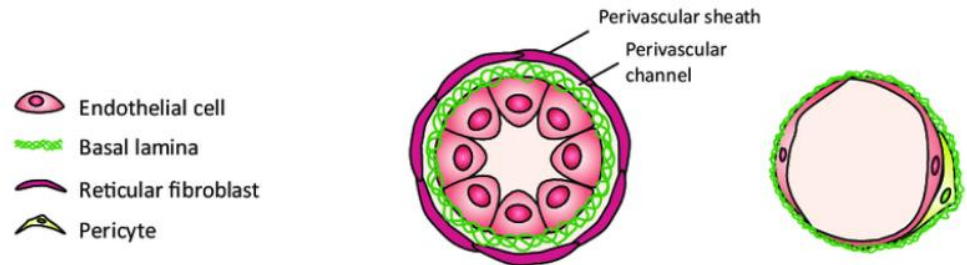


- serve as backup routes for blood if another link is blocked. (blood can bypass the capillary network under normal conditions).
- arteriovenous anastomoses - in distal parts of limbs and nose - participate in **thermoregulation.**



High endothelial venule (HEV) in a lymph node

- HEVs allow lymphocytes circulating in the blood to enter lymph organs (by crossing through the HEV).



	HEV	Normal venule
Endothelium	Tall and plump	Flat
Basal lamina	Thick	Thin
Perivascular sheath	Concentrically arranged reticular fibroblasts	Thin layers of pericytes or smooth muscle cells

MEDIUM AND SMALL VEINS

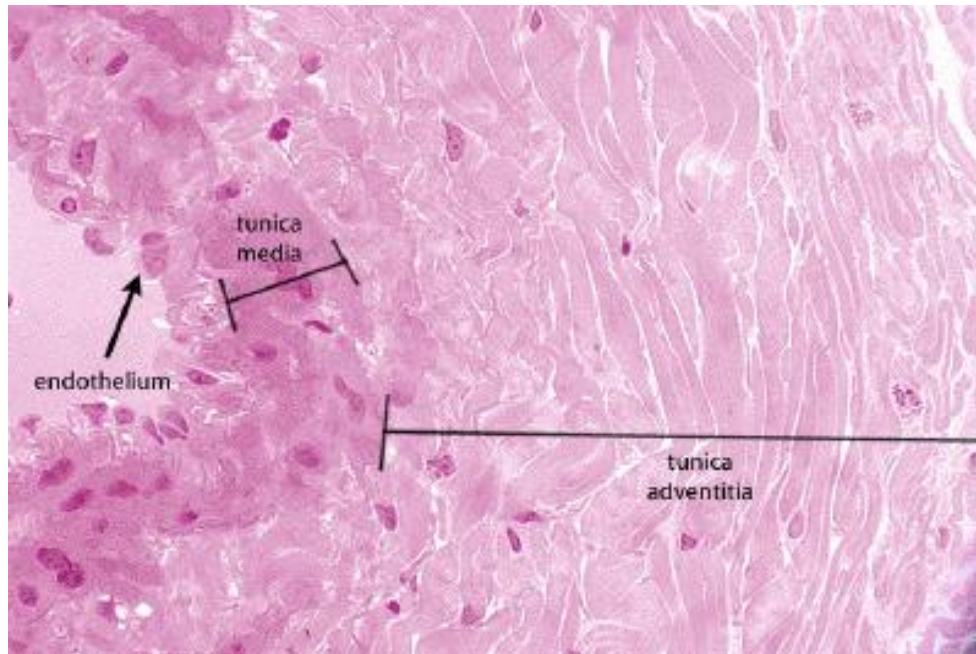
Medium veins, less than 1 cm in diameter, drain most of the body.



Tunica intima - endothelium, basal lamina, valves in some, reticular fibers, sometimes elastic fibers.

Tunica media - loosely organized smooth muscle cells, collagen fibers and fibroblasts.

Tunica adventitia – the thickest tunica, collagen bundles and elastic fibers and a few smooth muscle cells.



Vein Valve H&E

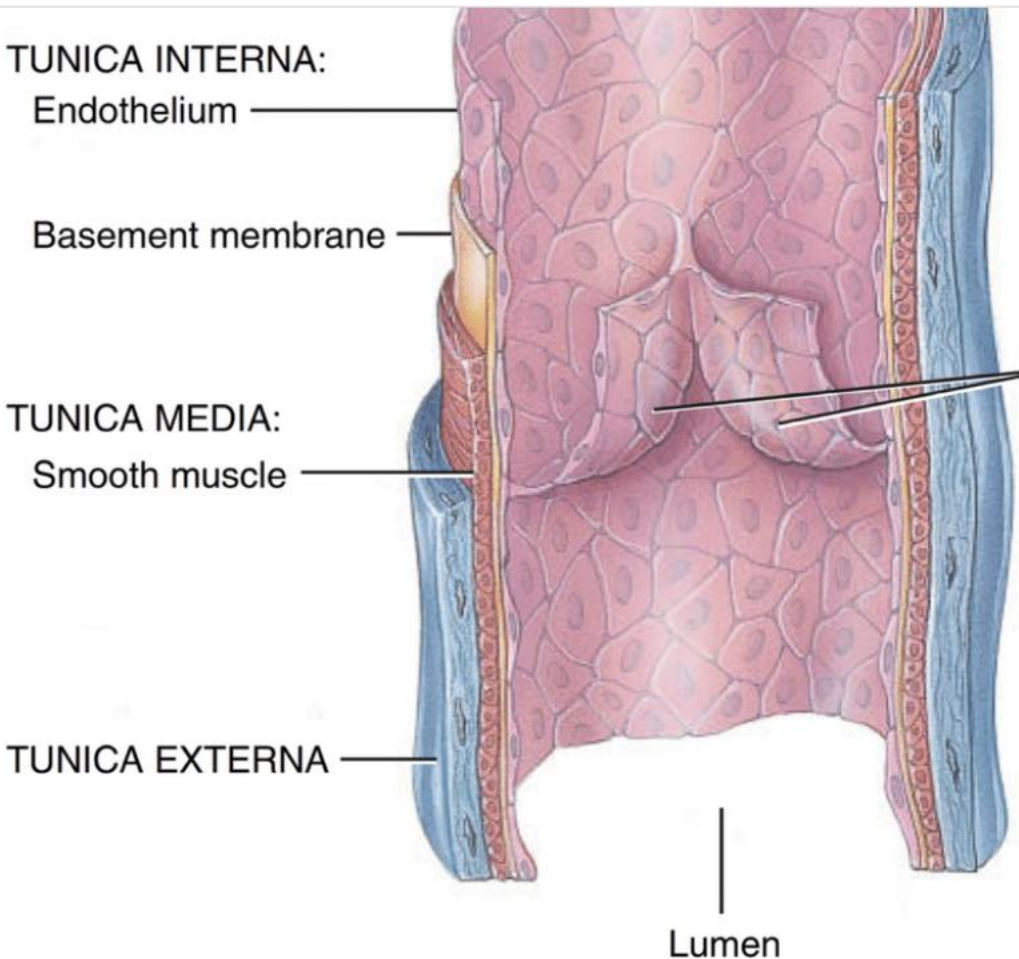
arteriole

**folds of the tunica intima
forming the valve**

VALVES OF VEINS

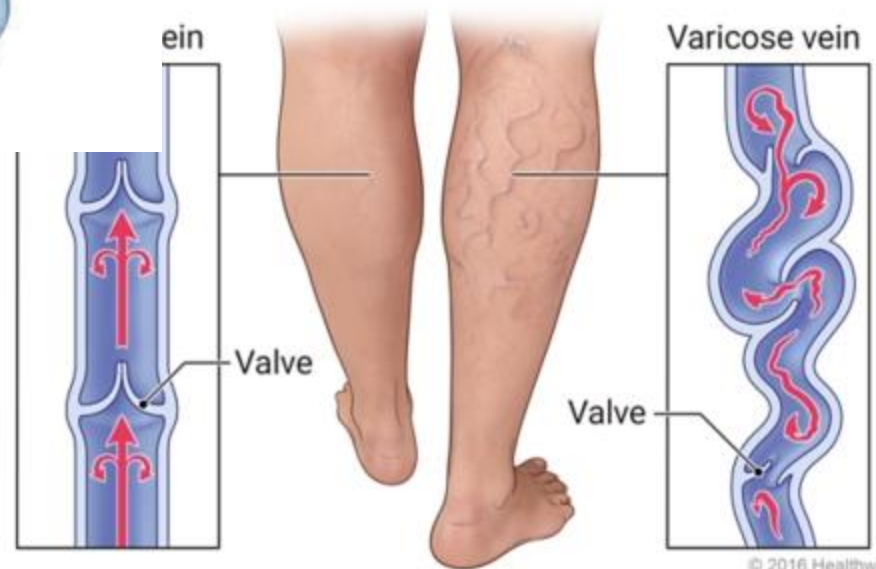
- two leaflets of tunica intima protruding out from the wall into the lumen.
- are reinforced by collagen and elastic fibers.

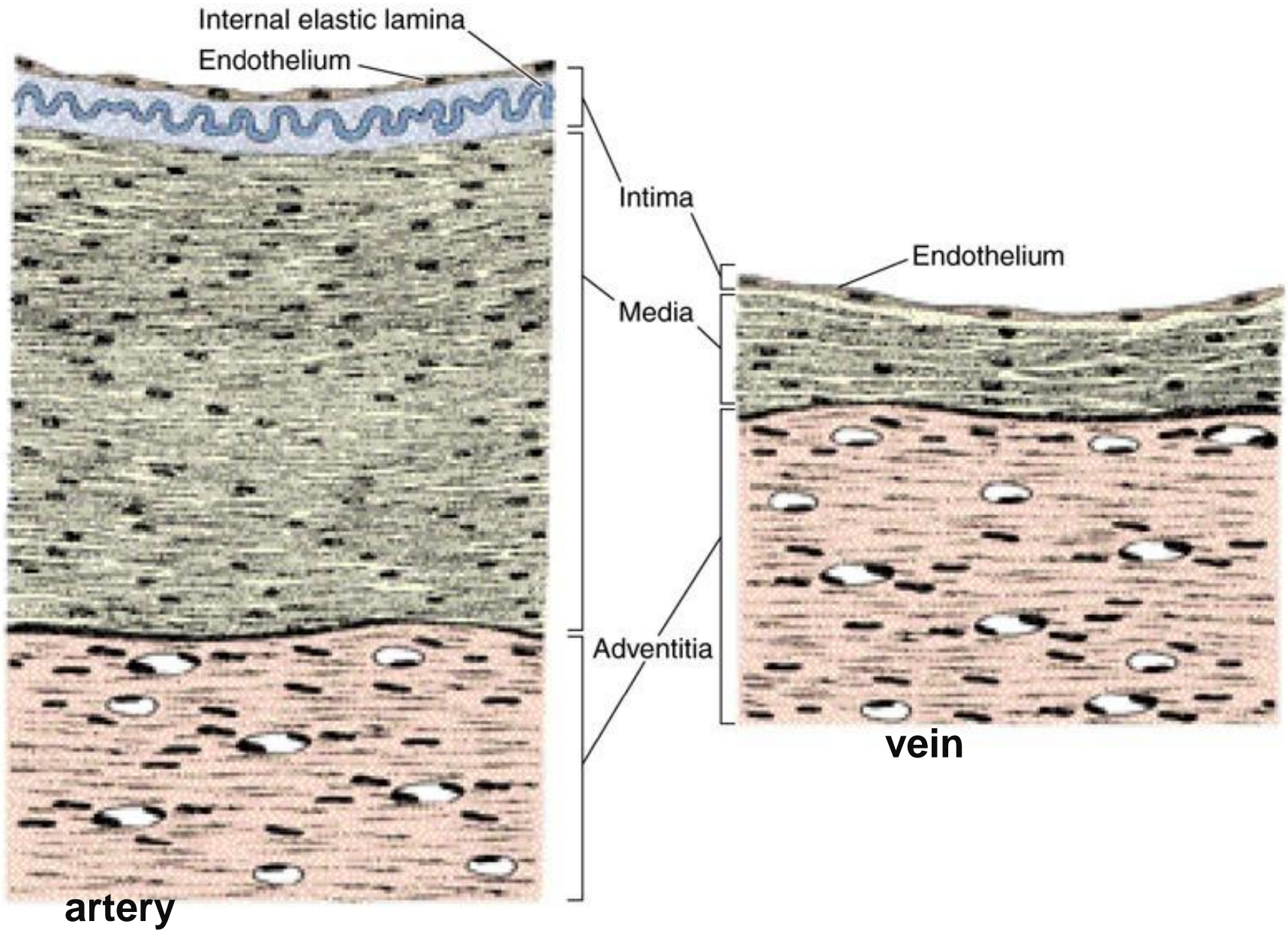
**folds of the tunica intima
forming the valve**



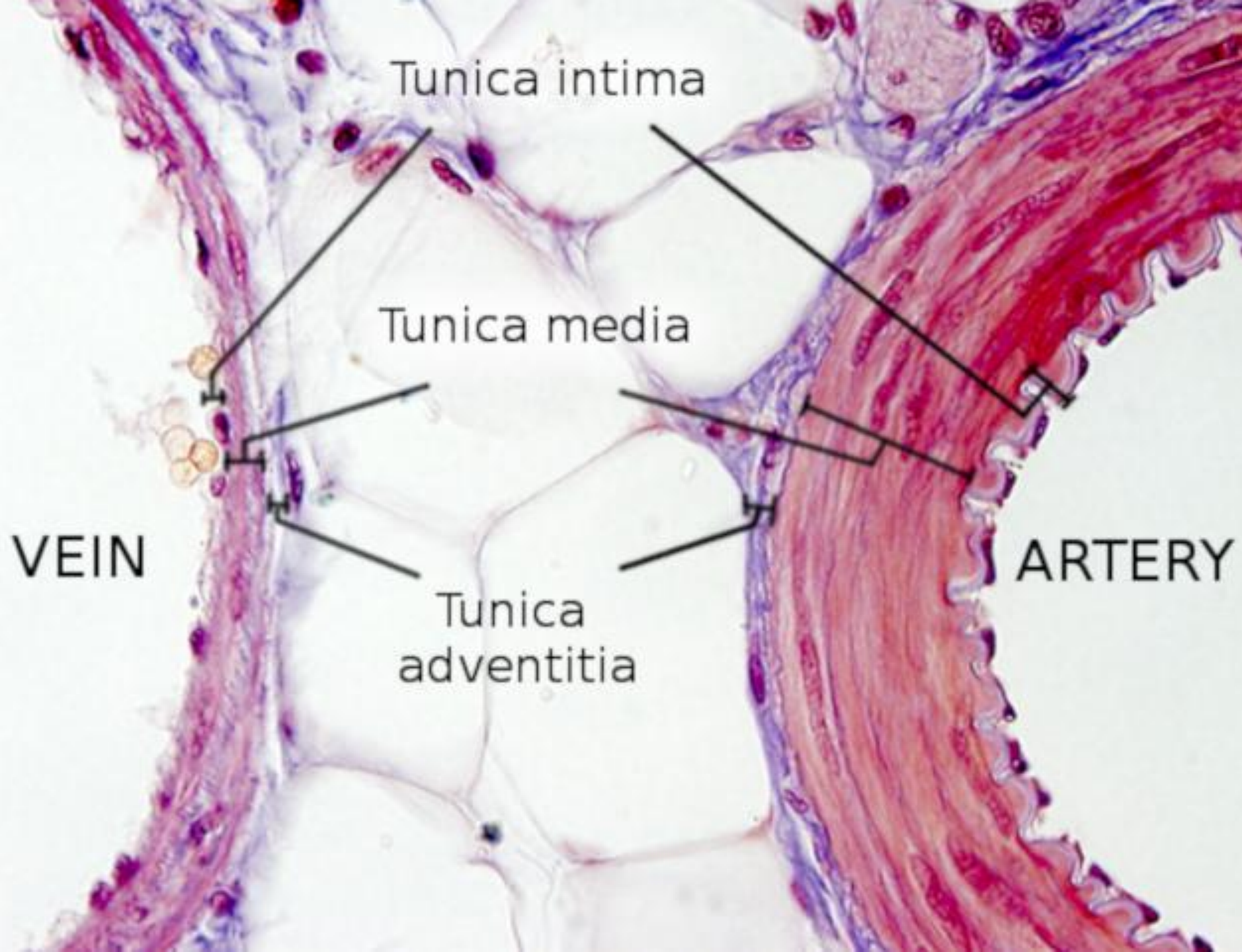
Valve

Valves prevent the backflow of blood.
 - are especially abundant in the veins of legs - act against gravity force.





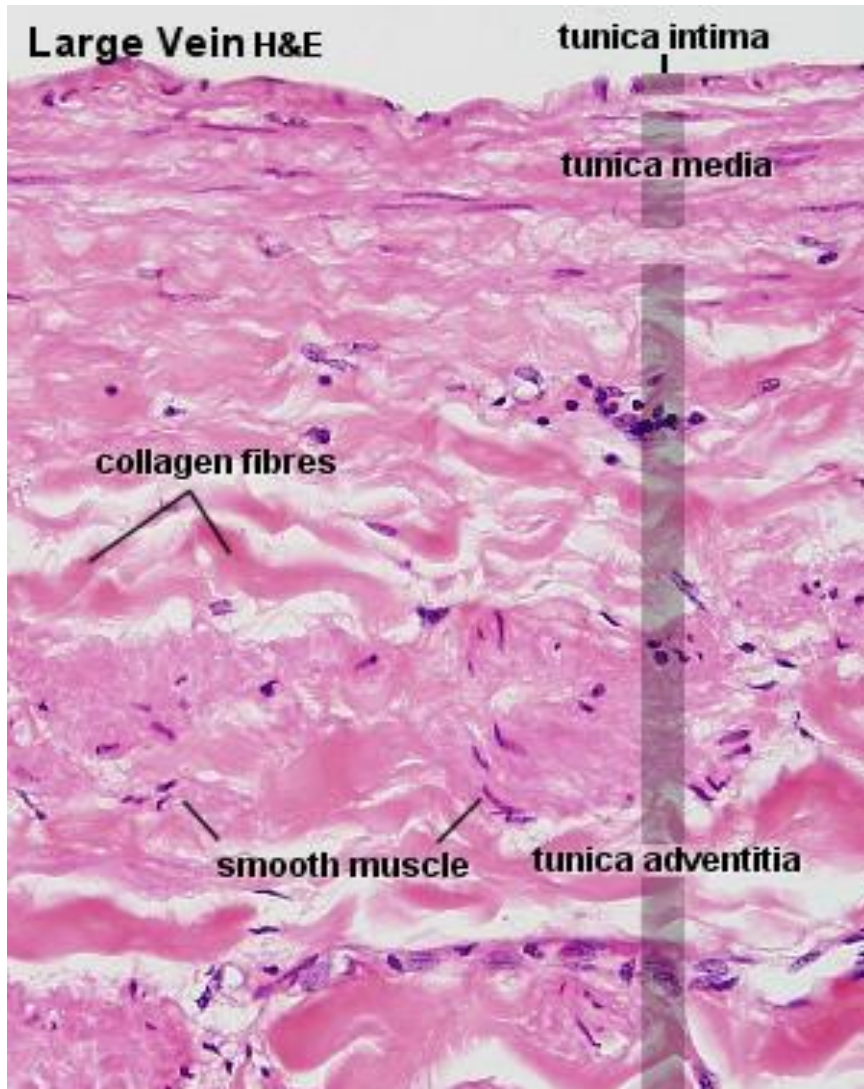
Comparison of muscular artery and accompanying vein.



Return blood directly to the heart.
**Venae cavae, pulmonary, portal,
renal, jugular, iliac vein.**

LARGE VEINS

Large Vein H&E



tunica intima

tunica media

collagen fibres

smooth muscle

tunica adventitia

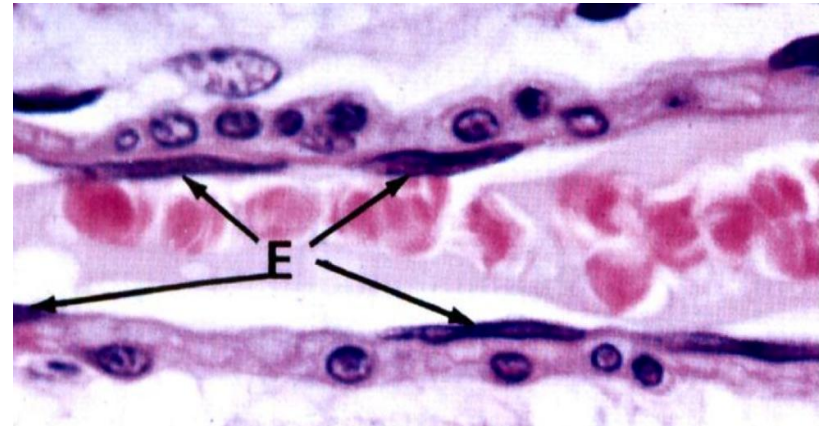
Tunica intima - endothelium, basal lamina, valves, connective tissue (fibroblasts, elastic fibers).

Tunica media - reticular and elastic fibers, smooth muscle cells. Only a few major veins (pulmonary veins, superficial veins of the legs) have well developed smooth muscle layer. **Most large veins have very thin tunica media.**

Tunica adventitia - many elastic and collagen fibers, vasa vasorum. **Pulmonary veins and venae cavae** have some **cardiac muscle** near their entry into the heart.

ENDOTHELIUM

- lines the interior surface of **blood vessels** and **lymphatic vessels**,
- forms an interface between circulating blood or lymph in the lumen and the rest of the vessel wall.

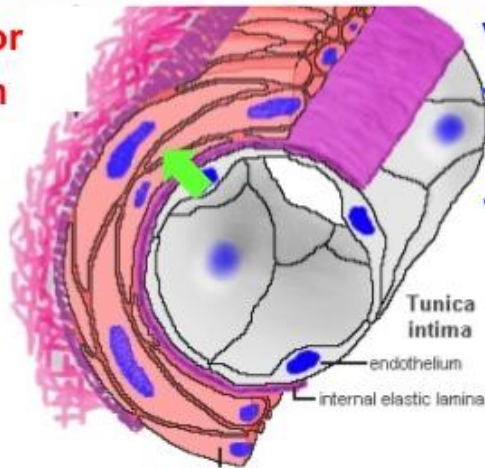


Endothelial control of vascular tone:
Endothelial cells secrete

Vasoactive substances:

Vasoconstrictor

- **Endothelin**
(peptide)



Vasodilators

- **NO**
(gas)
- **Prostacyclin**
(prostaglandin)

Endothelial cells are involved in:

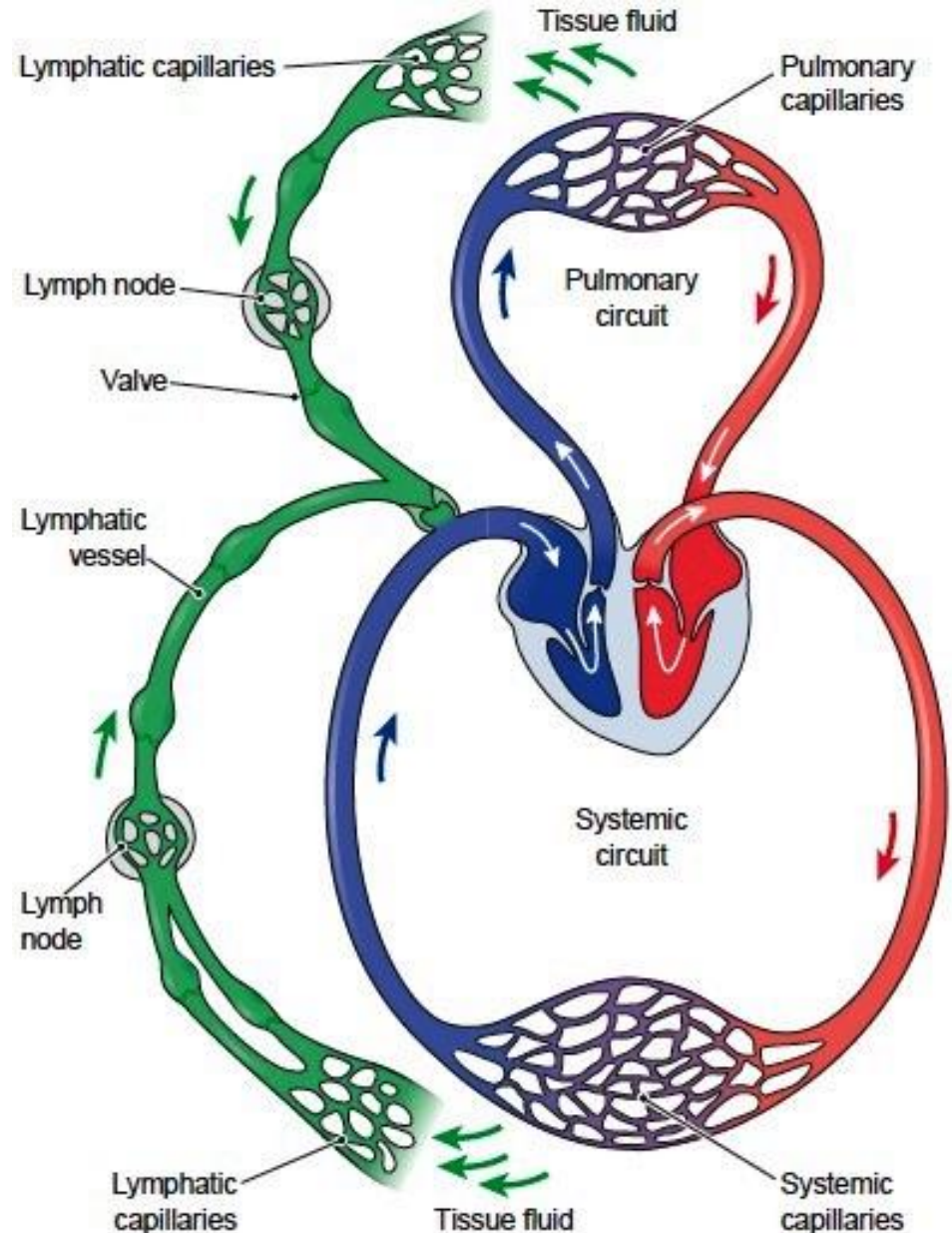
- coagulation of platelets during clot formation (**von Willebrand factor** stored in **Weibel-Palade bodies**)

- control of blood pressure (cells secrete **endothelins** (vasoconstrictors), **nitric oxide** and **prostacyclin** (vasodilators))

LYMPHATIC VASCULAR SYSTEM

Collects lymph - the excess extracellular tissue fluid, and delivers it back to the cardiovascular system
- absent in **CNS, cartilage, bone, internal ear, epidermis**)

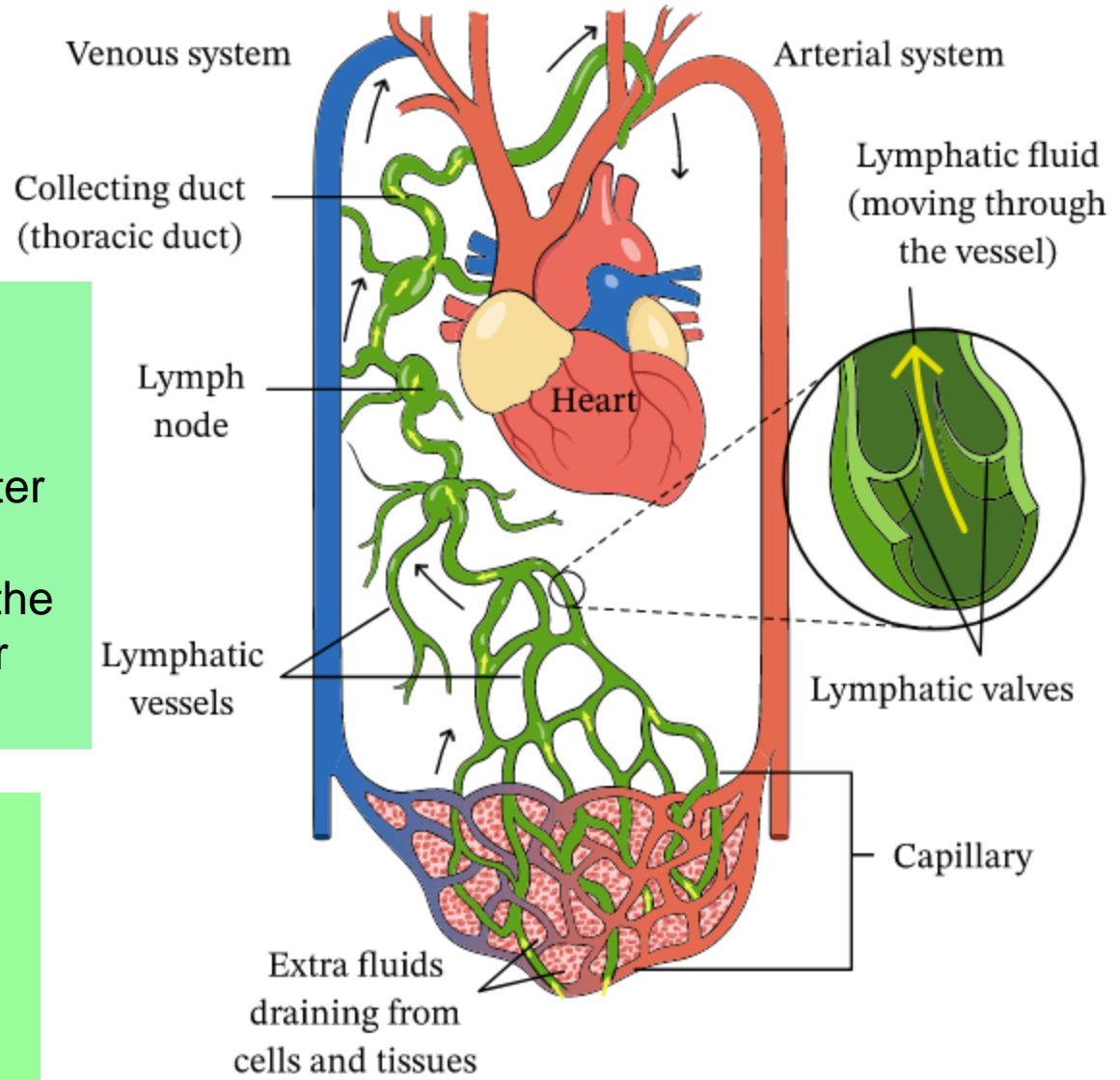
unlike the cardiovascular system the lymphatic system:
- **is not a closed system**
- **does not contain a pump**

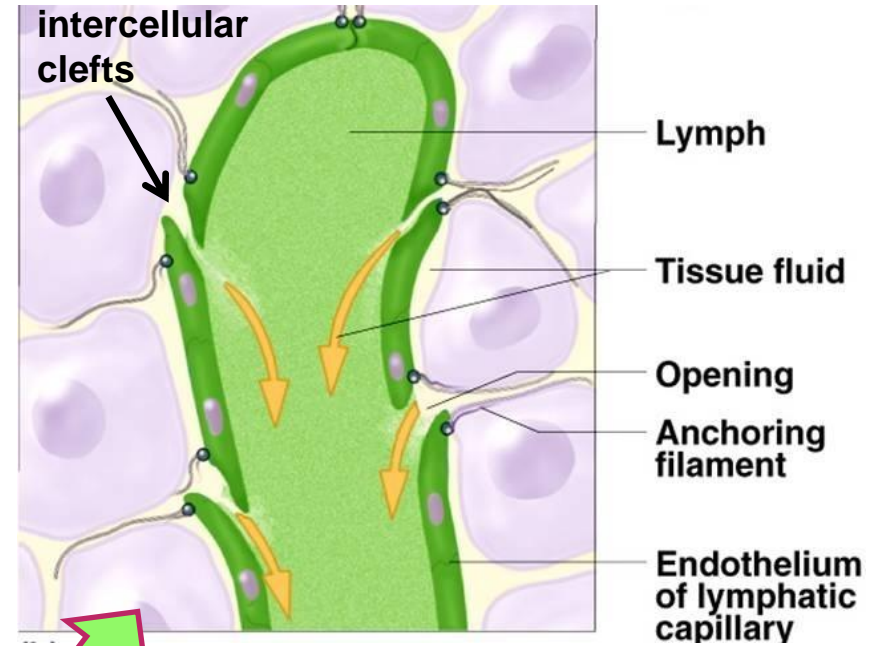
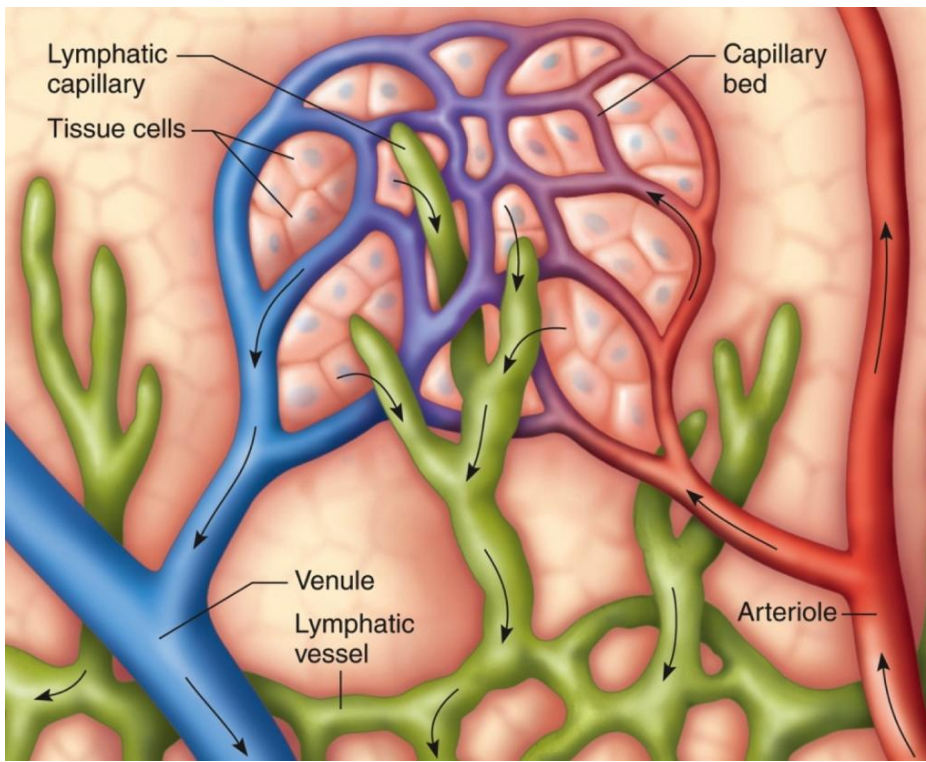


LYMPHATIC VASCULAR SYSTEM

- **Lymphatic capillaries** (collect the lymph)
- **Lymphatic vessels** (transport, lymph nodes filter the lymph)
- **Lymphatic ducts** (deliver the lymph to the cardiovascular system)

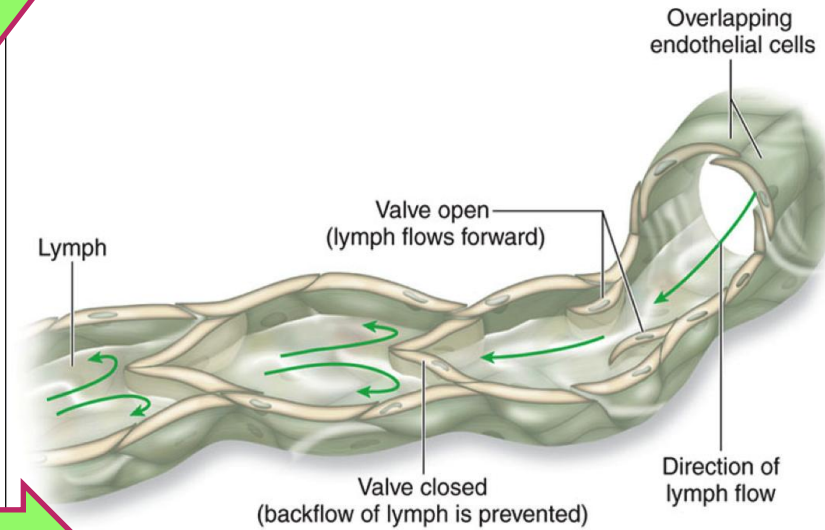
lymph movement occurs due to contraction and relaxation of smooth muscle, valves, and contraction of adjacent skeletal muscle





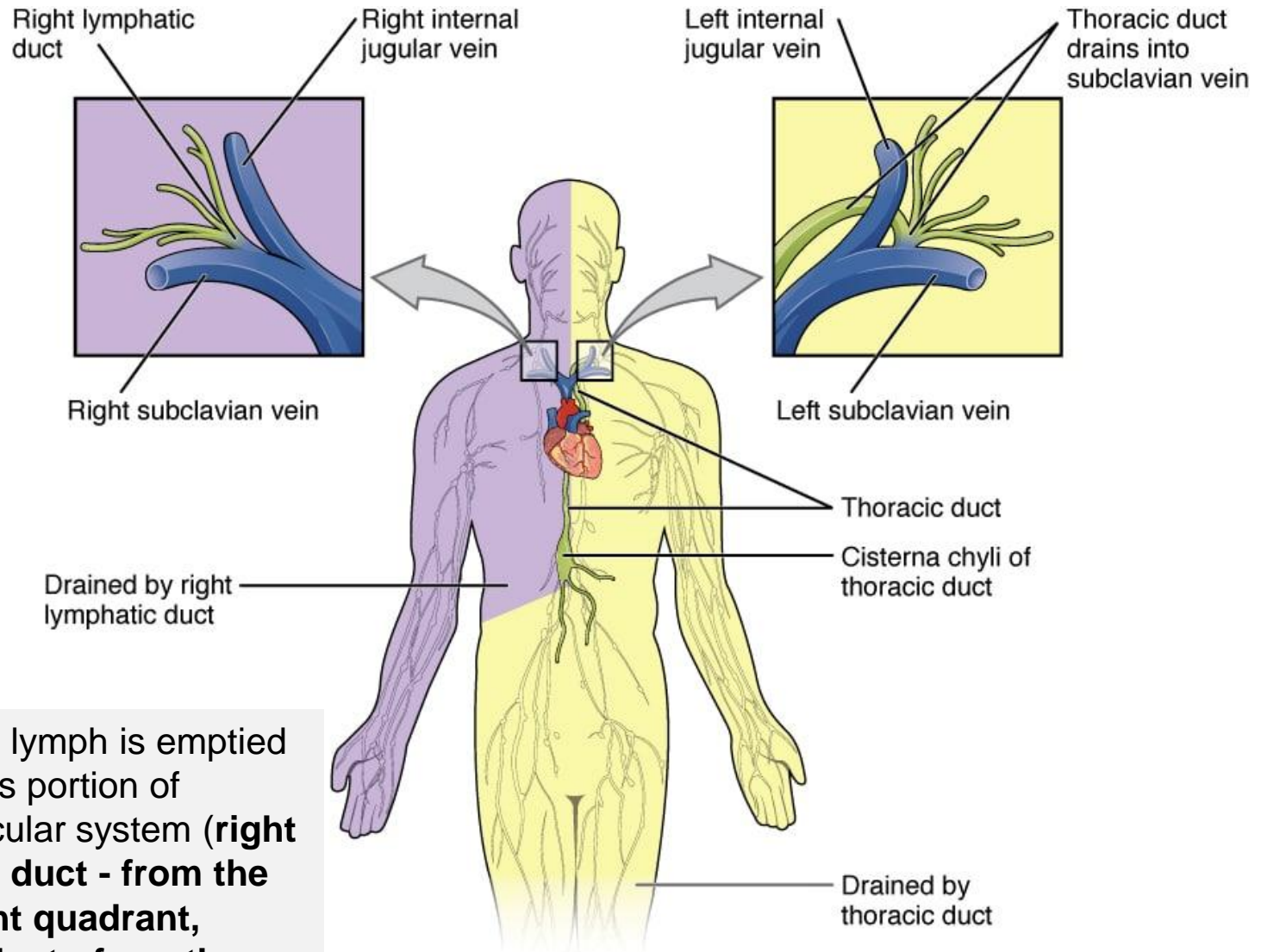
Blind-ended lymphatic capillaries collect the lymph from tissues - endothelium with intercellular clefts and anchoring filaments (but without fenestrae), and incomplete basal lamina.

Lymphatic vessels - possess closely spaced valves (prevent backflow of the lymph), basal lamina.



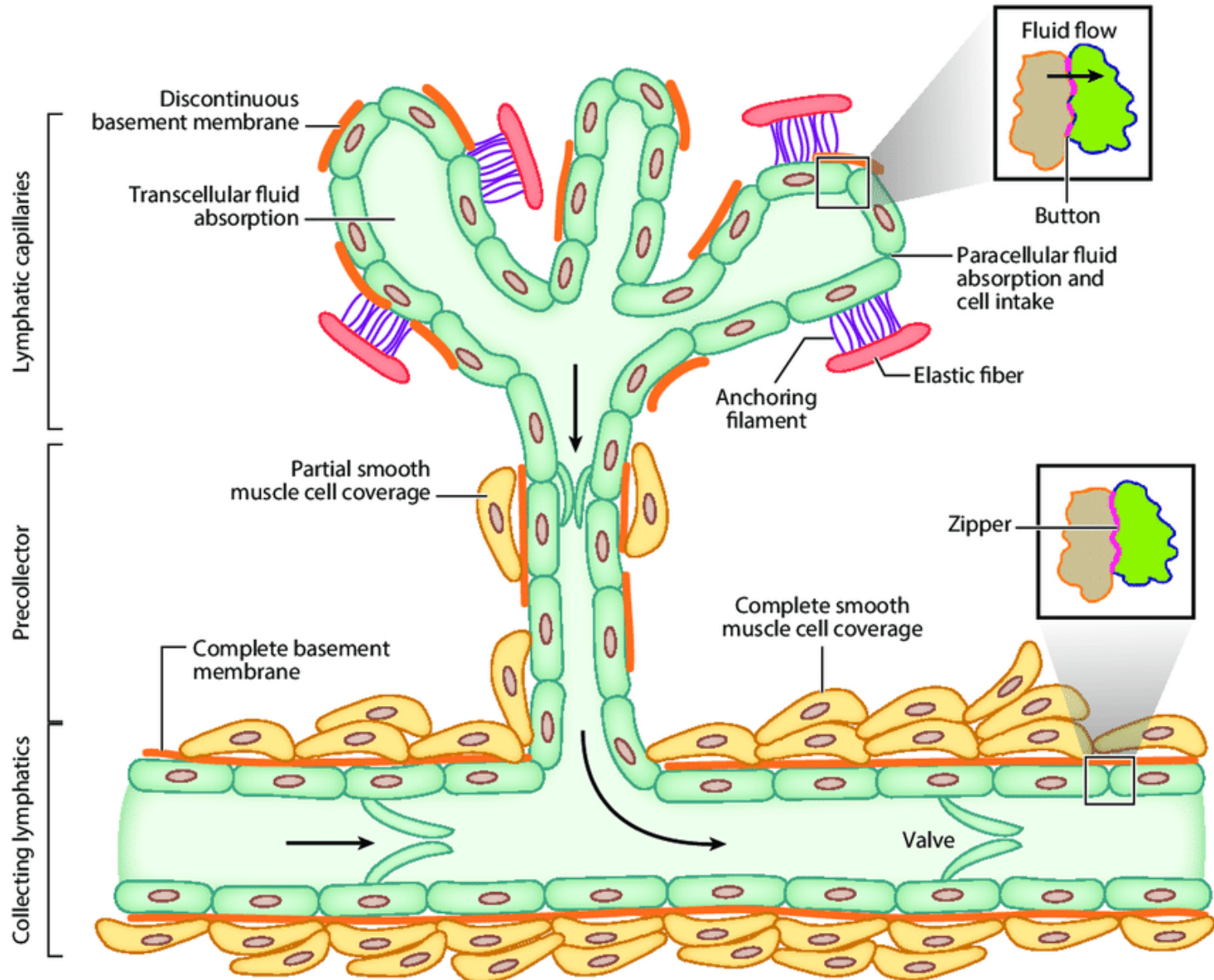
(a) Lymphatic vessel, longitudinal section

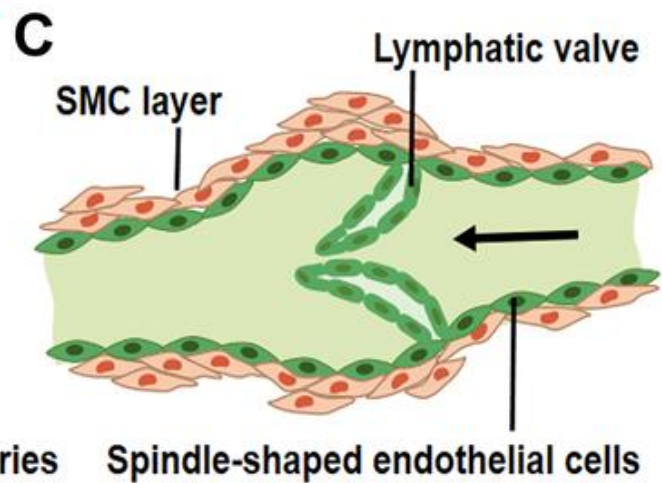
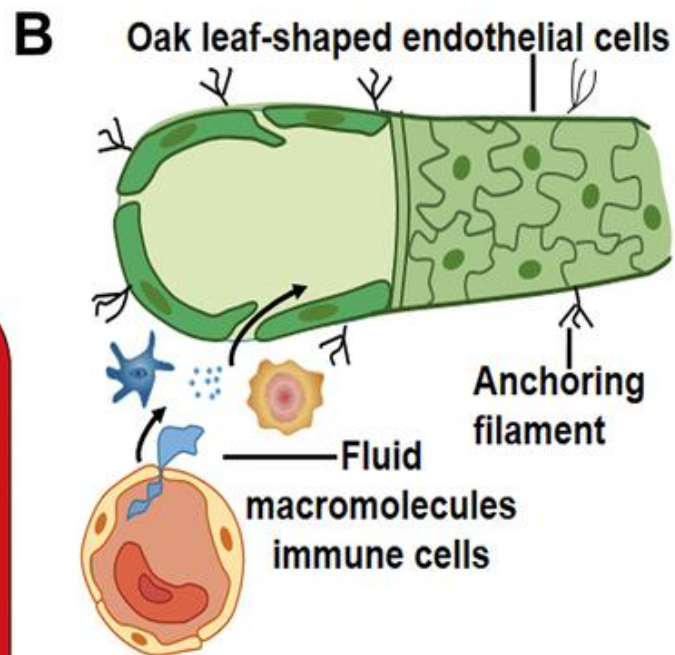
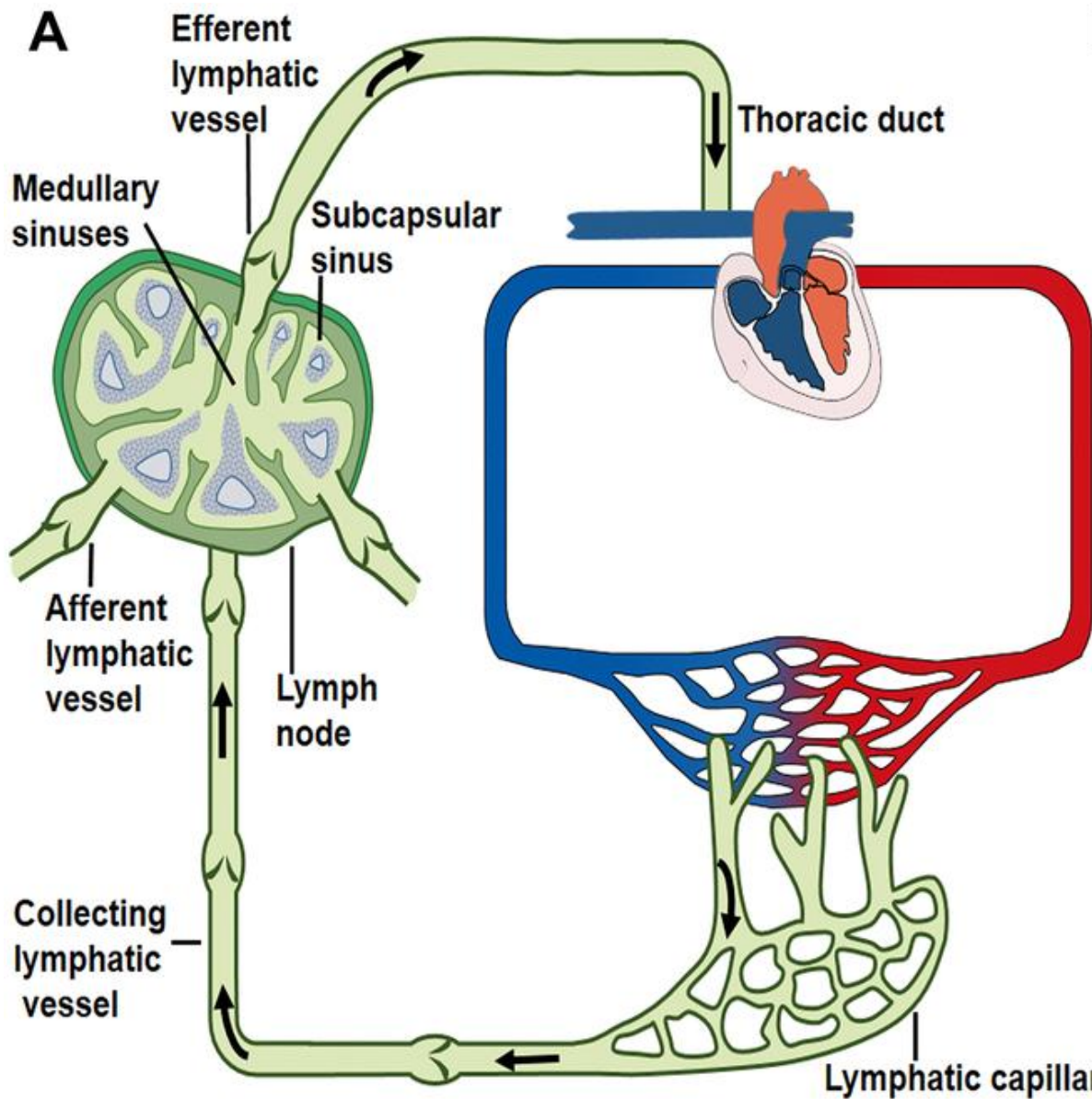
- two lymphatic ducts (**right lymphatic duct** and **thoracic duct**)



- from ducts lymph is emptied into venous portion of cardiovascular system (**right lymphatic duct - from the upper right quadrant, thoracic duct - from the almost all parts of body**).

Lymphatic vascular tree

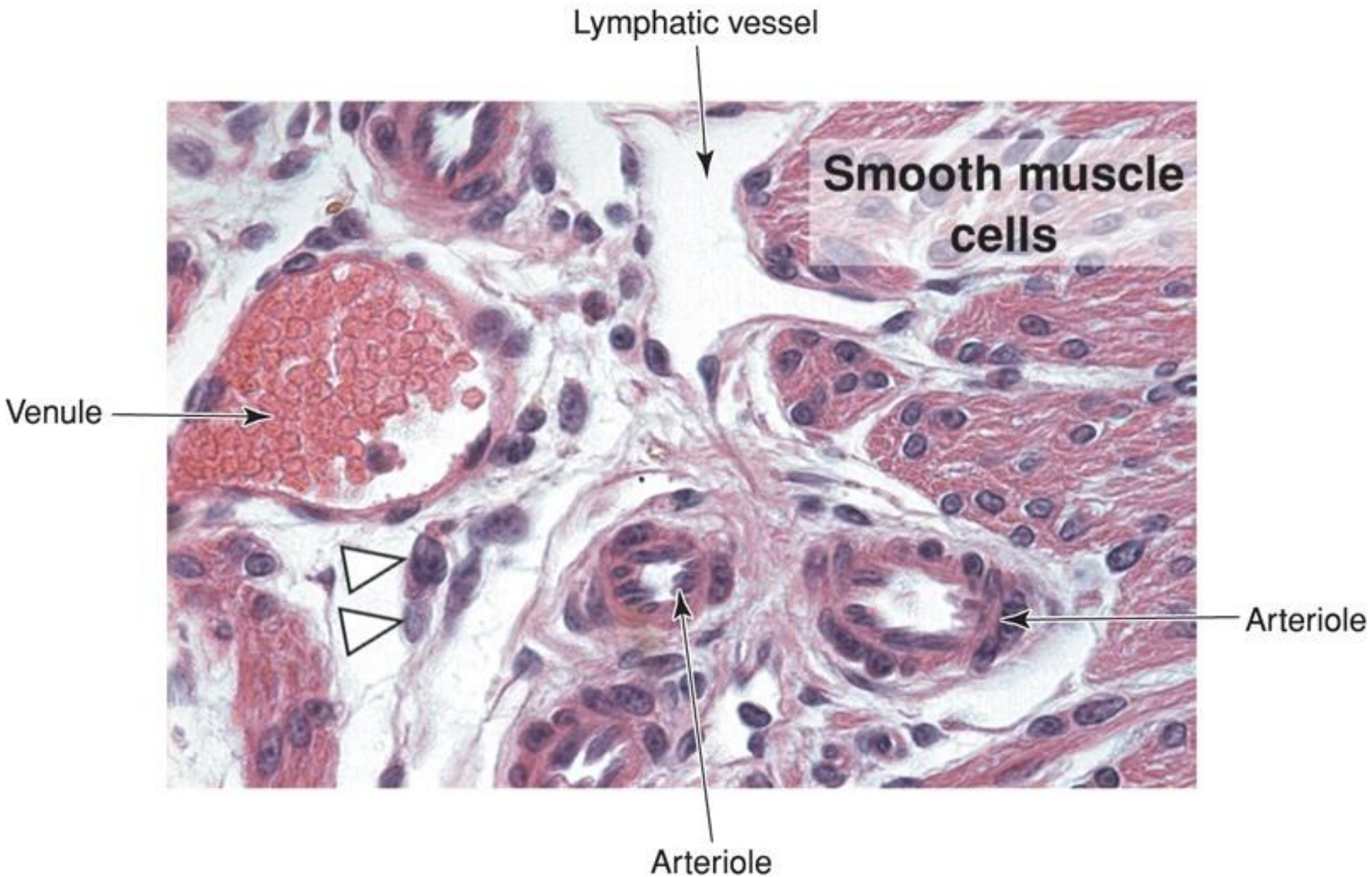


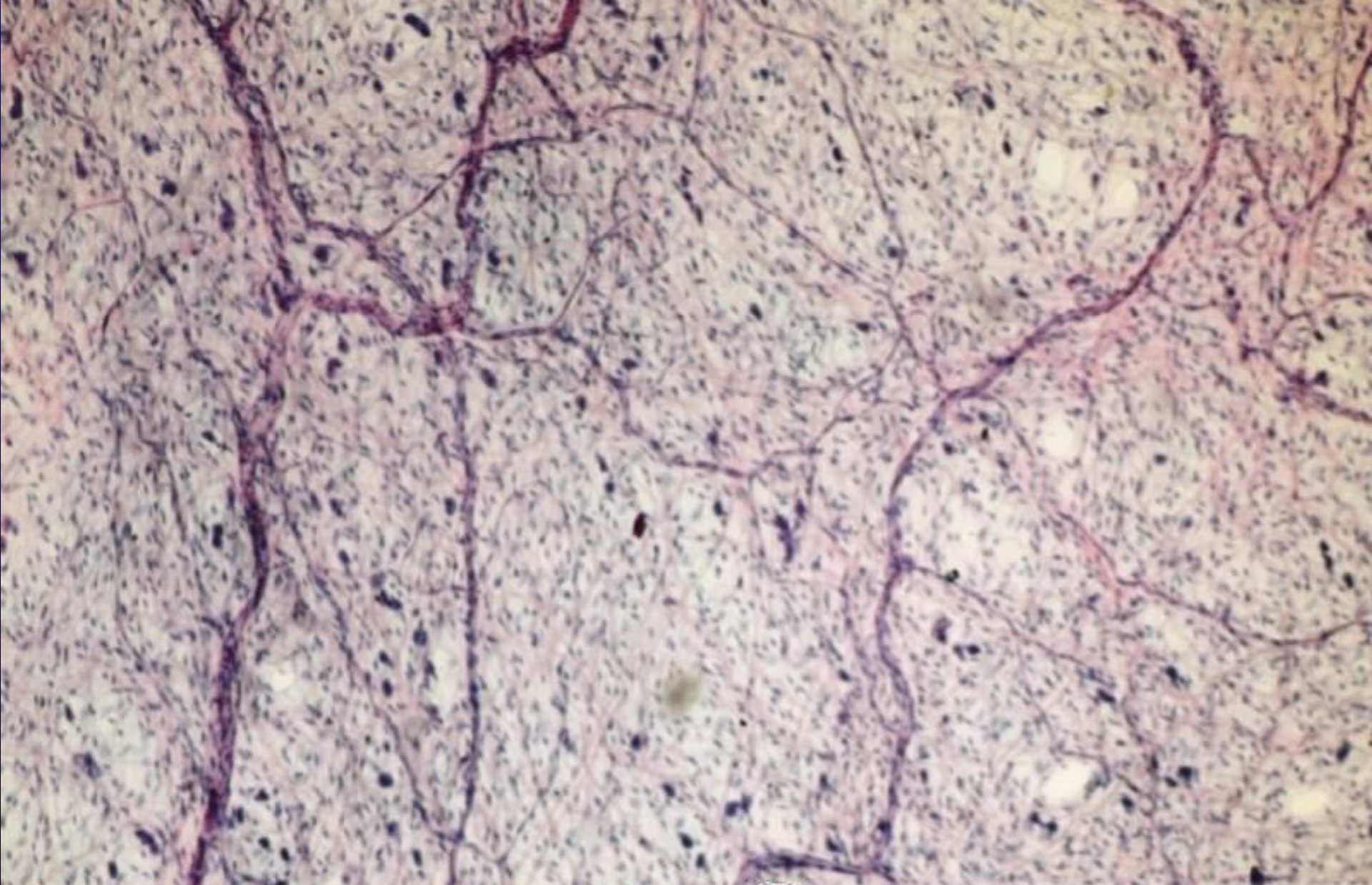




Lymphatic vessels. Visible valve

Arterioles, venules and lymphatic vessels within loose connective tissue



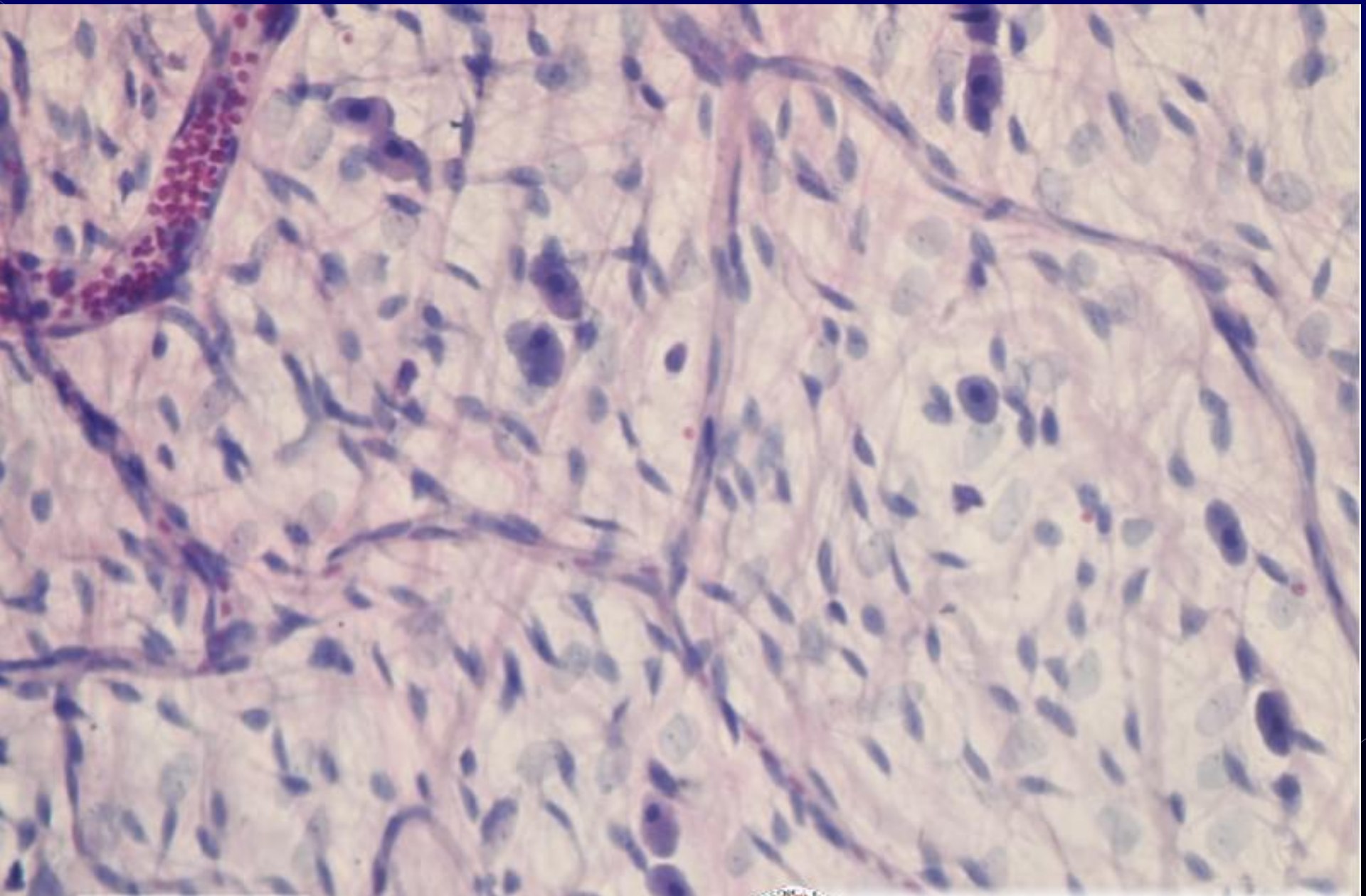


#28; 100x

Mesentery – capillary vessels



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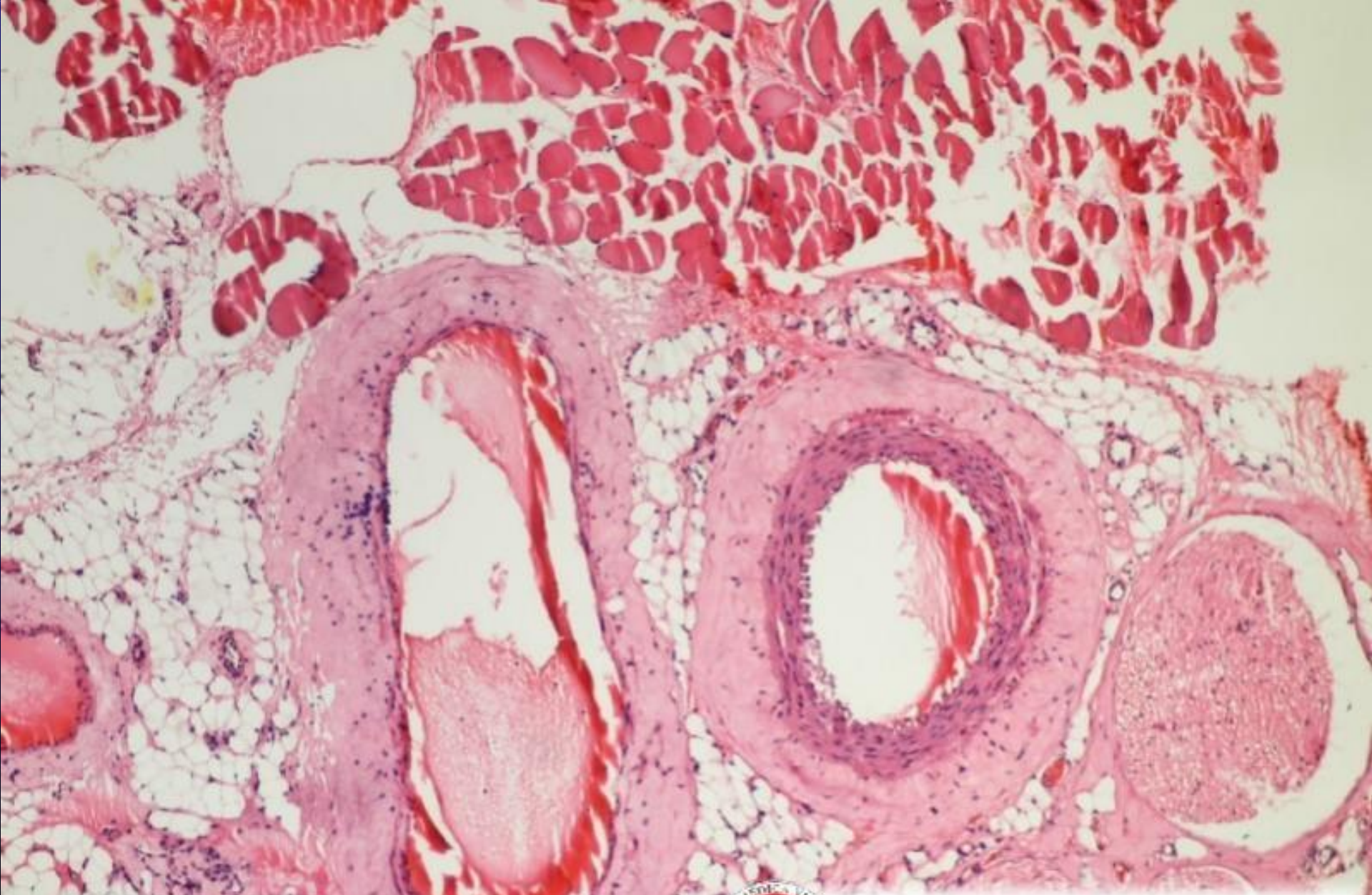


#28; 400x

Mesentery – capillary vessels



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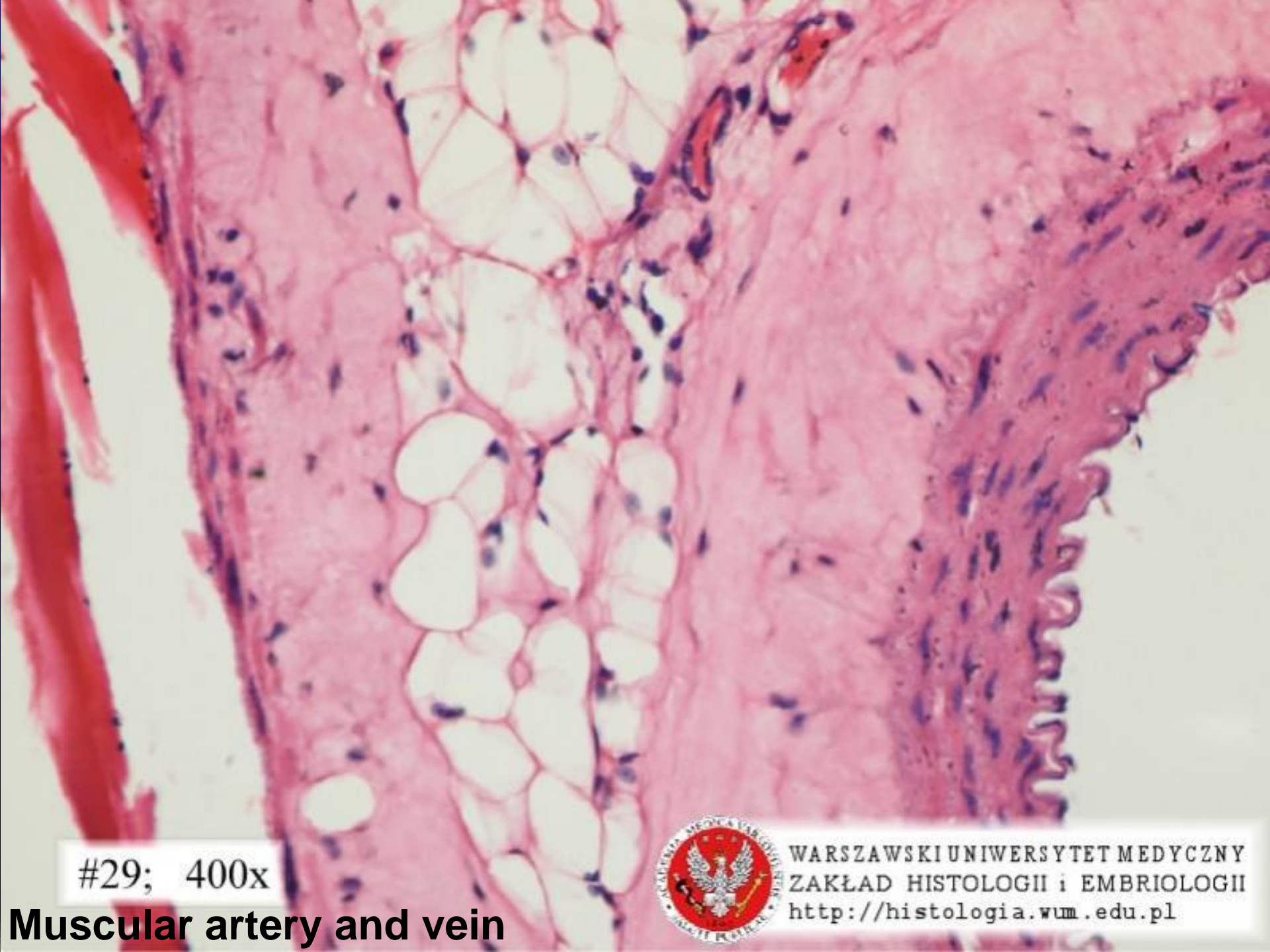


#29; 100x



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Muscular artery and vein

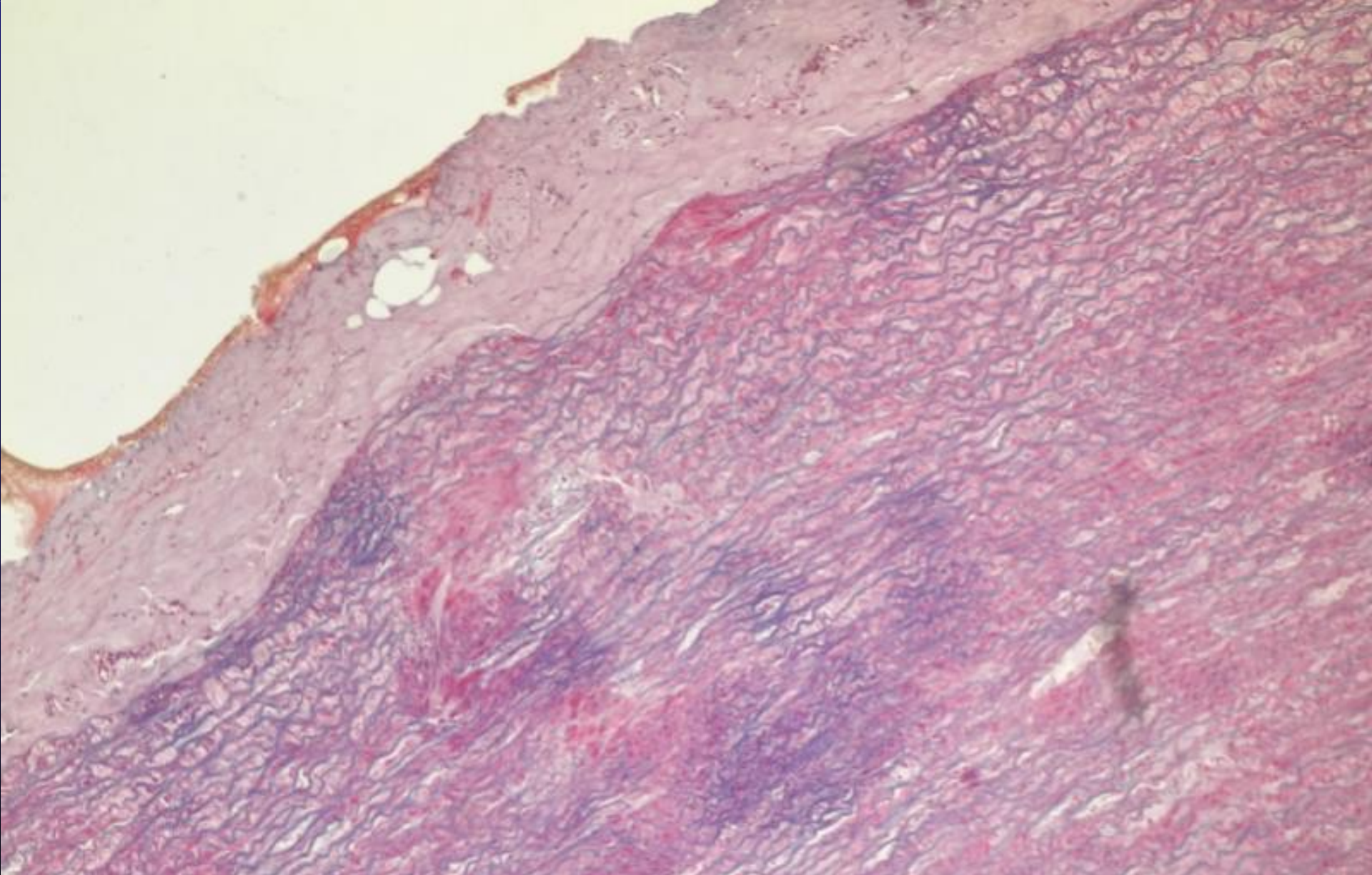


#29; 400x

Muscular artery and vein



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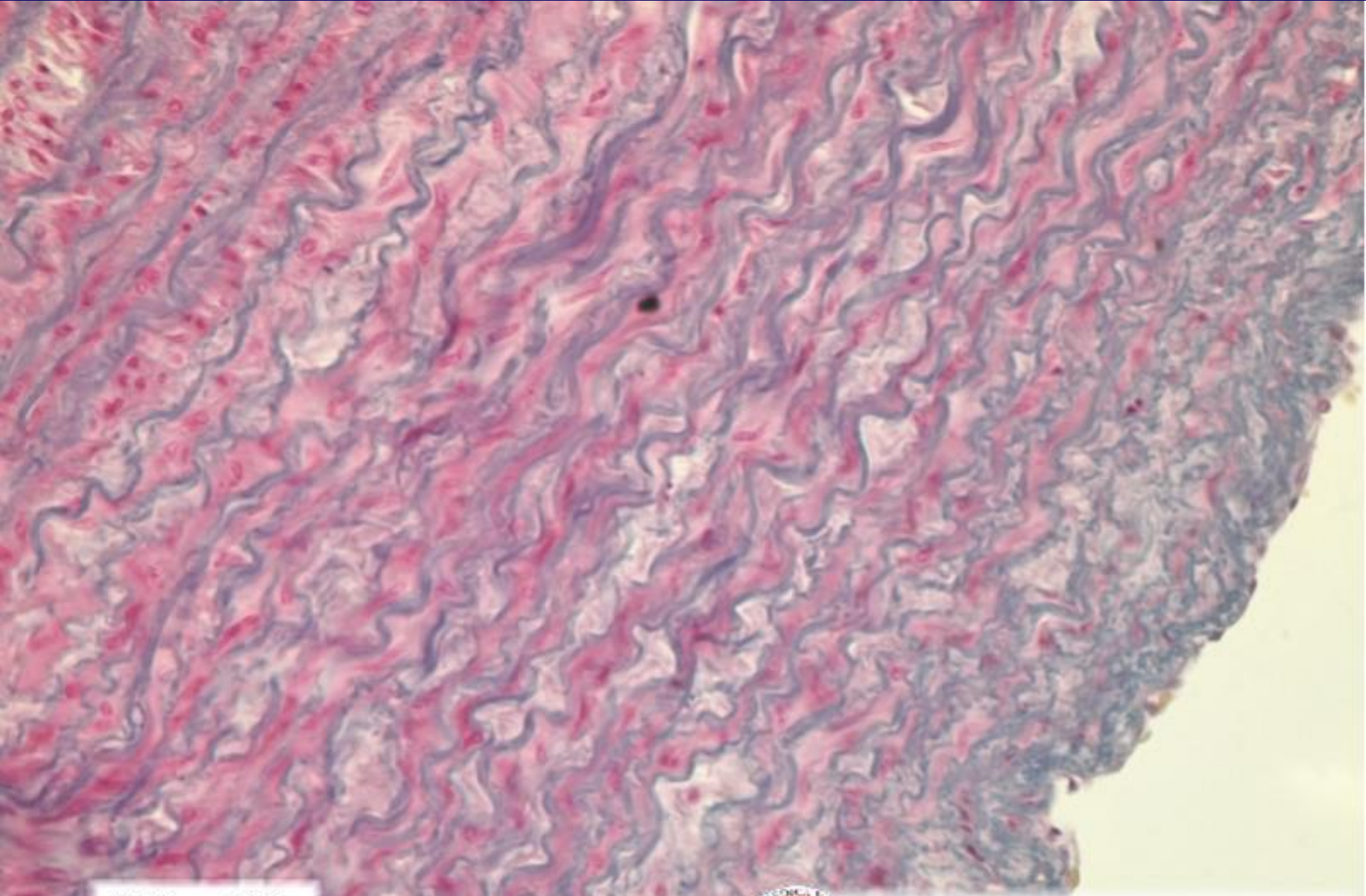


#30; 100x

Aorta stained with HE



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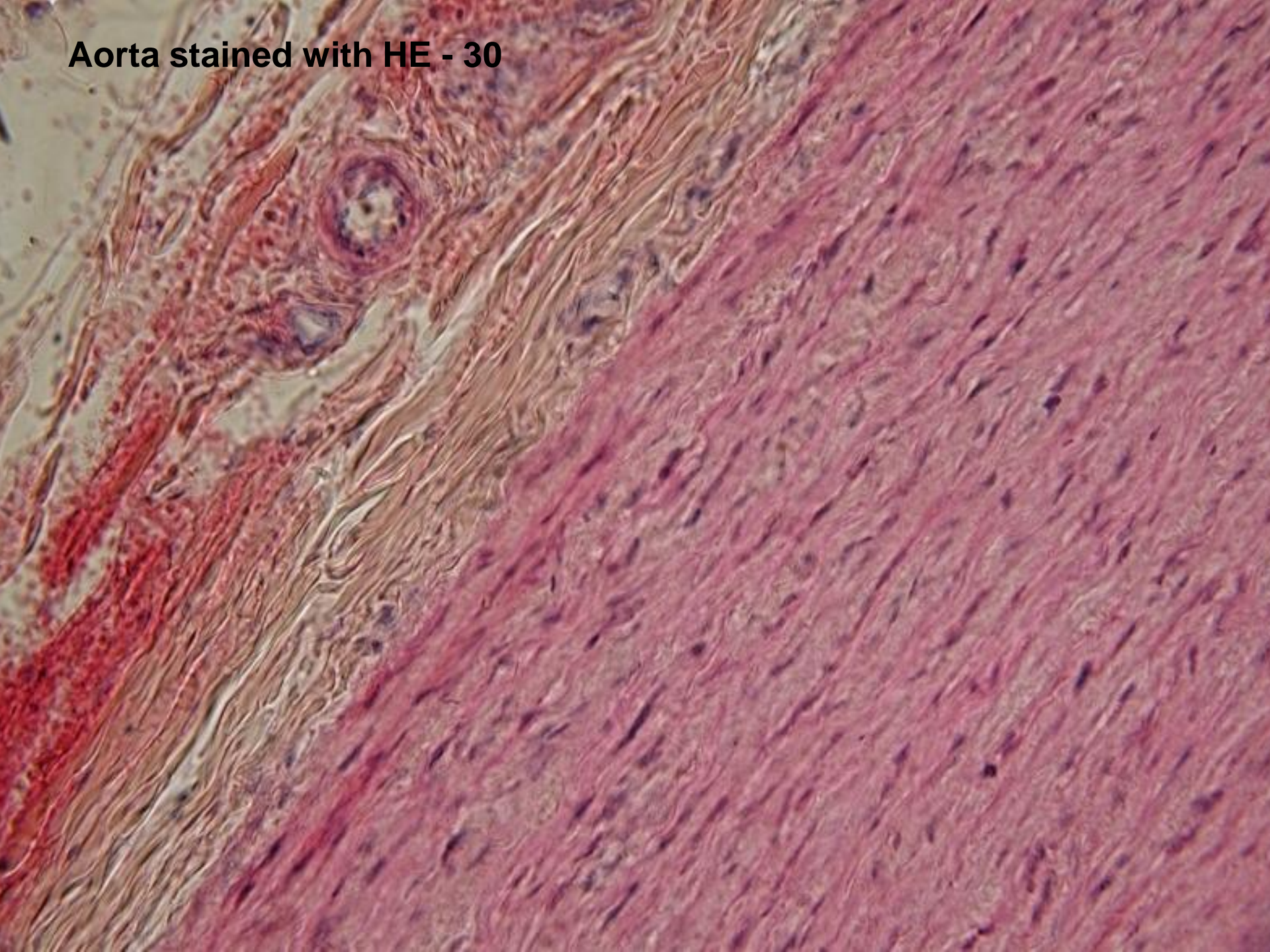
#30; 400x

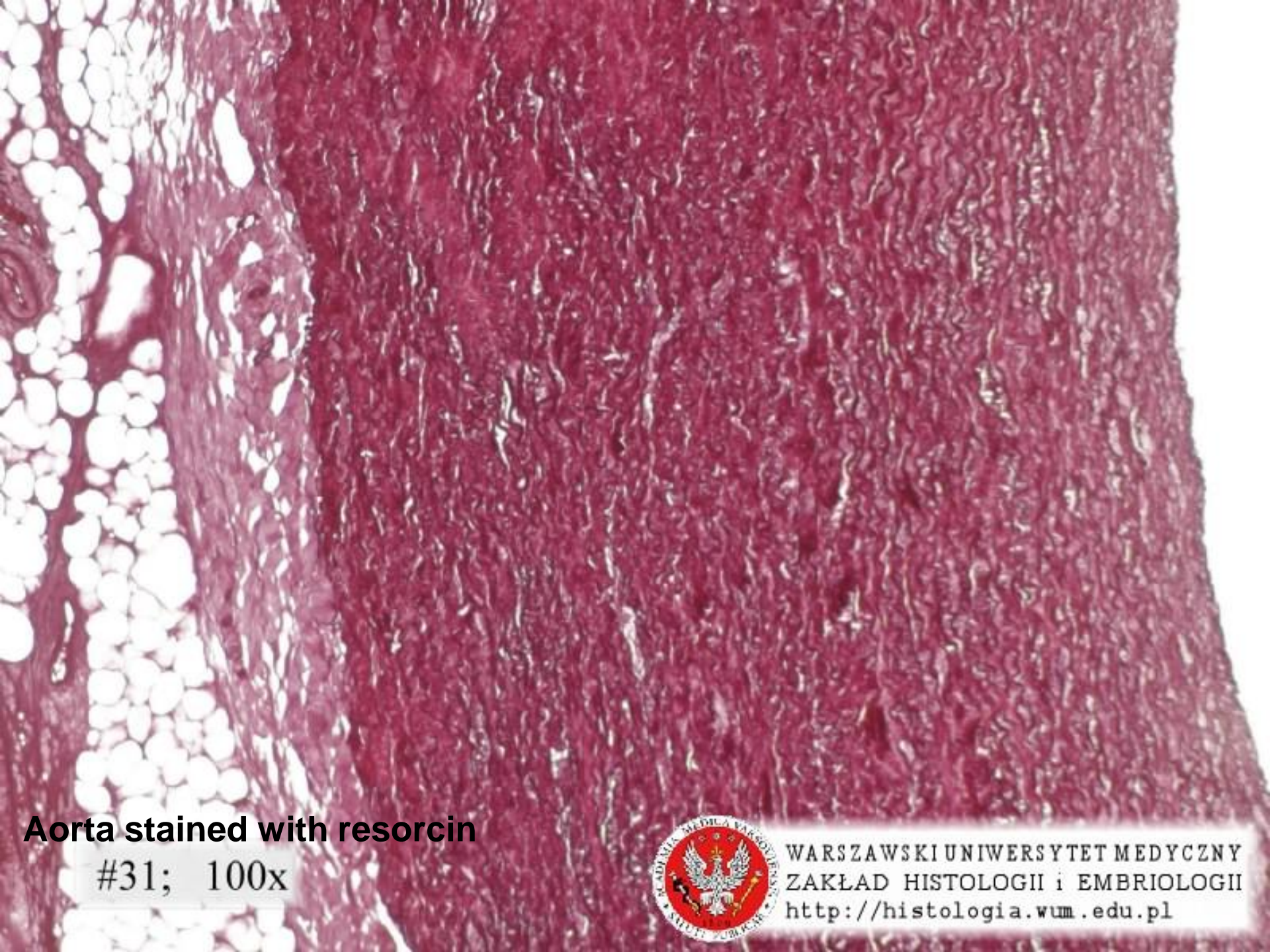
Aorta stained with HE



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Aorta stained with HE - 30





Aorta stained with resorcin

#31; 100x



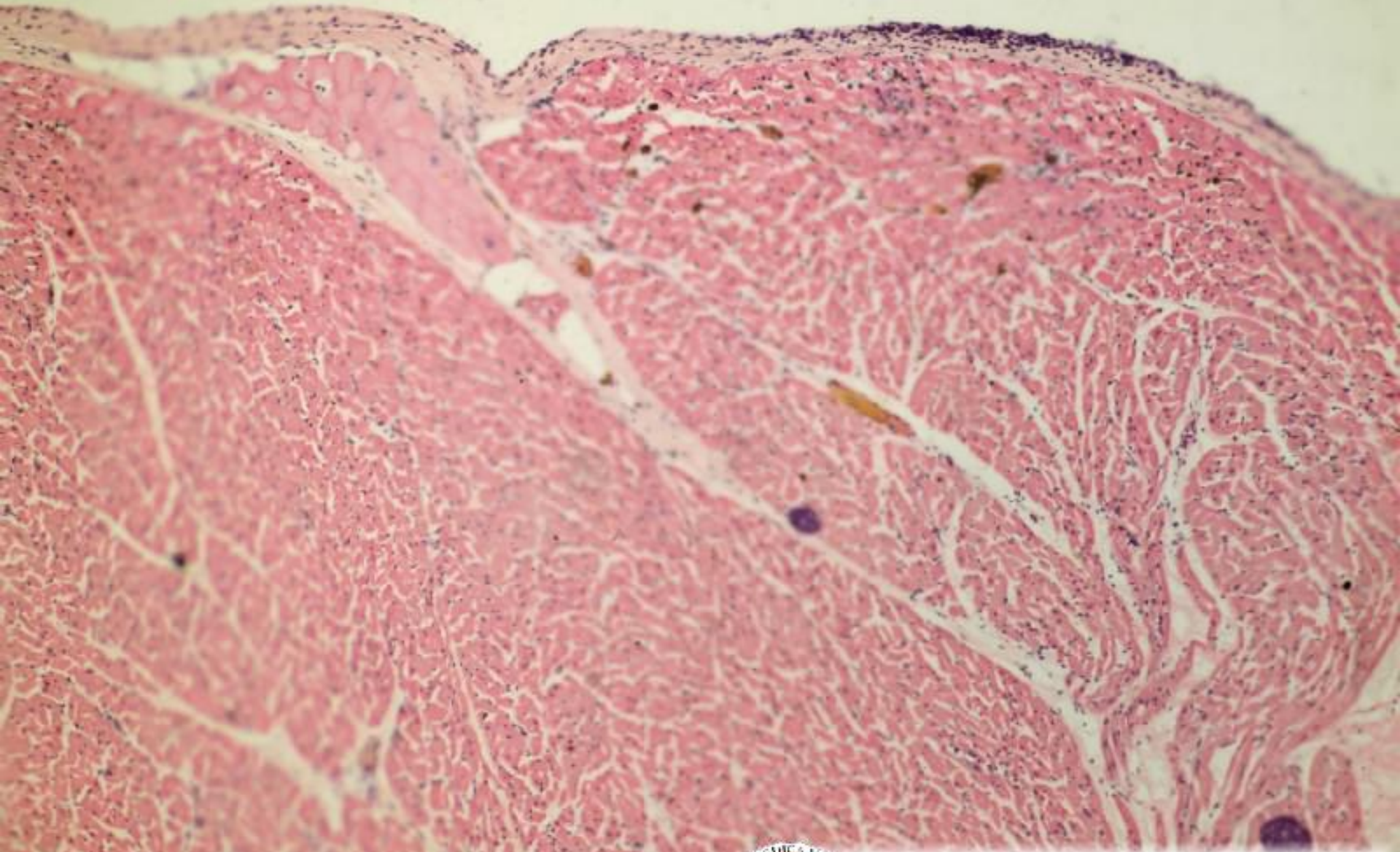
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**Aorta stained with
resorcin (elastic
membranes
and fibers)**

#31; 400x



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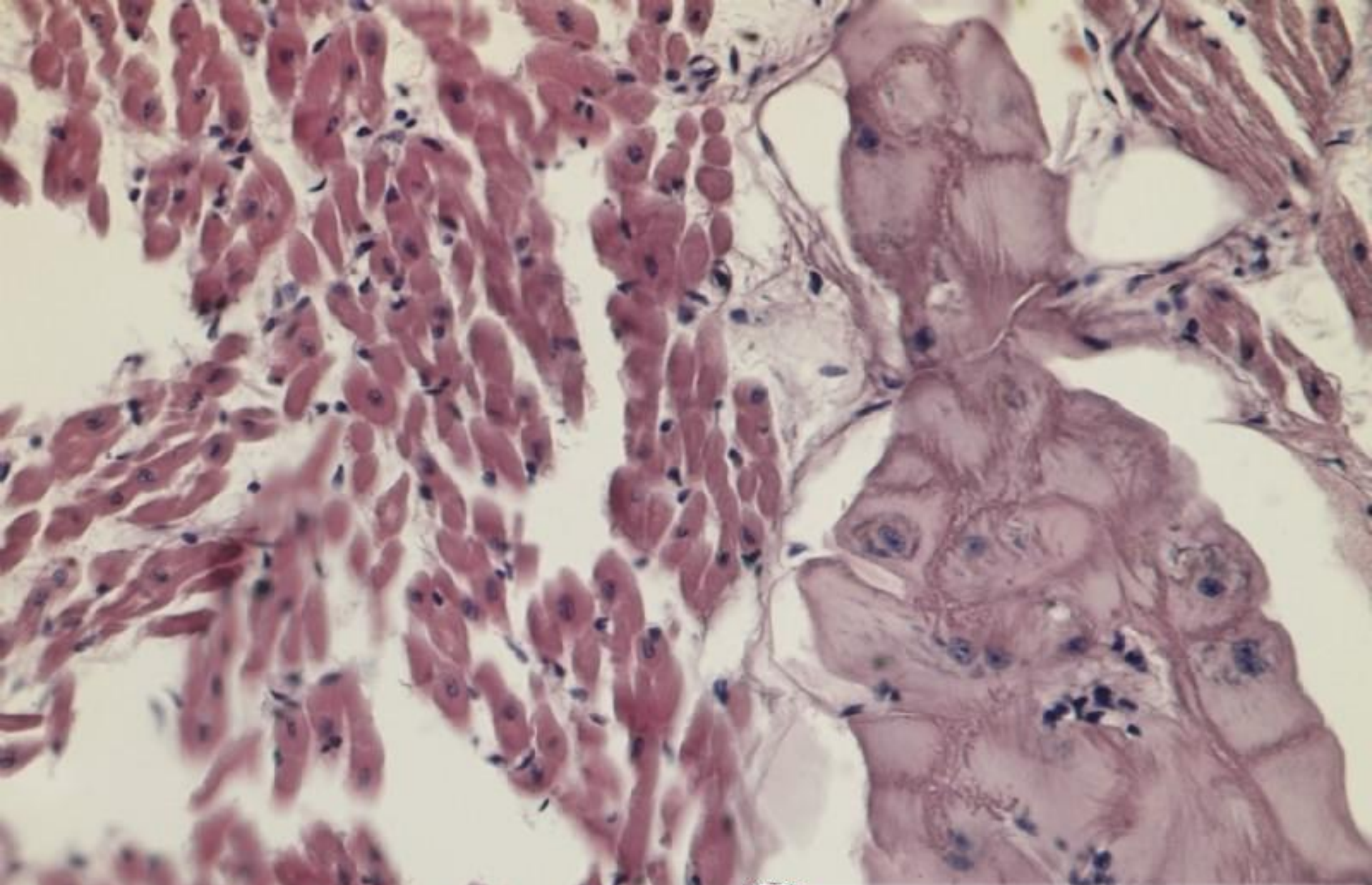


#33; 100x

Heart, Purkinje fibers (no. 33)



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#33; 400x

Heart, Purkinje fibers (no. 33)



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Figure 18.1b Generalized structure of arteries, veins, and capillaries.

