

Lecture

Cardiovascular system

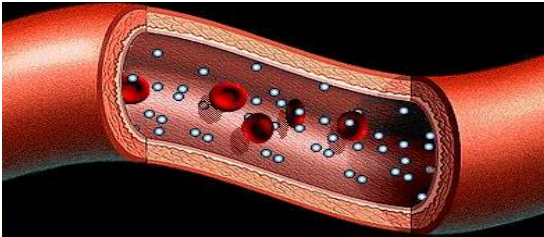
- Overall concept of blood circulation
- Vessels
- Arteries
- Microcirculation
- Veins
- Lymphatics
- Heart

Brno, May 2024

Cardiovascular system = part of circulatory system

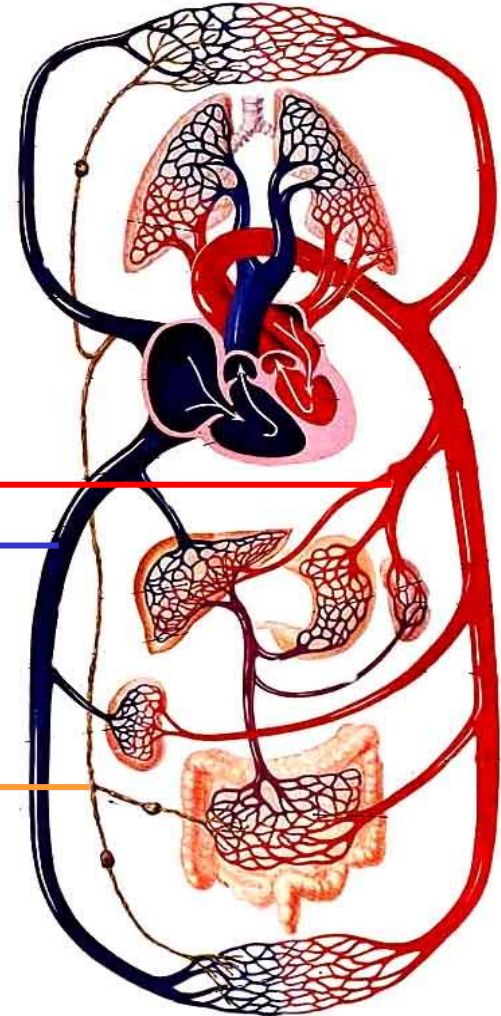
Circulatory s. = Closed tubular system

(carries fluids (blood, lymph) in tubes)



Blood cardiovascular

Lymphatic vascular system

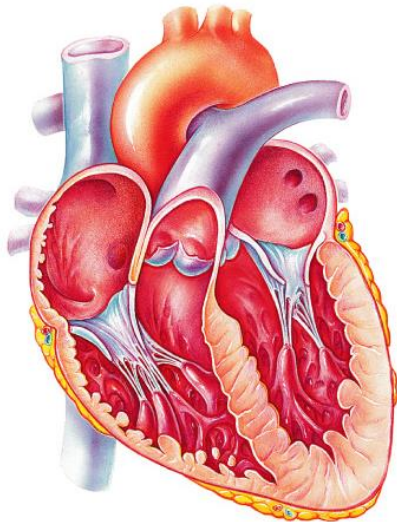


Cardiovascular system – overall composition

Heart

PUMP

- moves blood with all its elements through the body



Blood vessels

TUBES

- distribute the blood to the cells **throughout the body** and then back to the heart

Three major types

Arteries

- deliver blood from the heart to the capillaries

Capillaries

- intimate with body cells – place of exchange between blood and tissues

Veins

- carry blood from body to the heart

Blood vessels – several different flavours

Veins

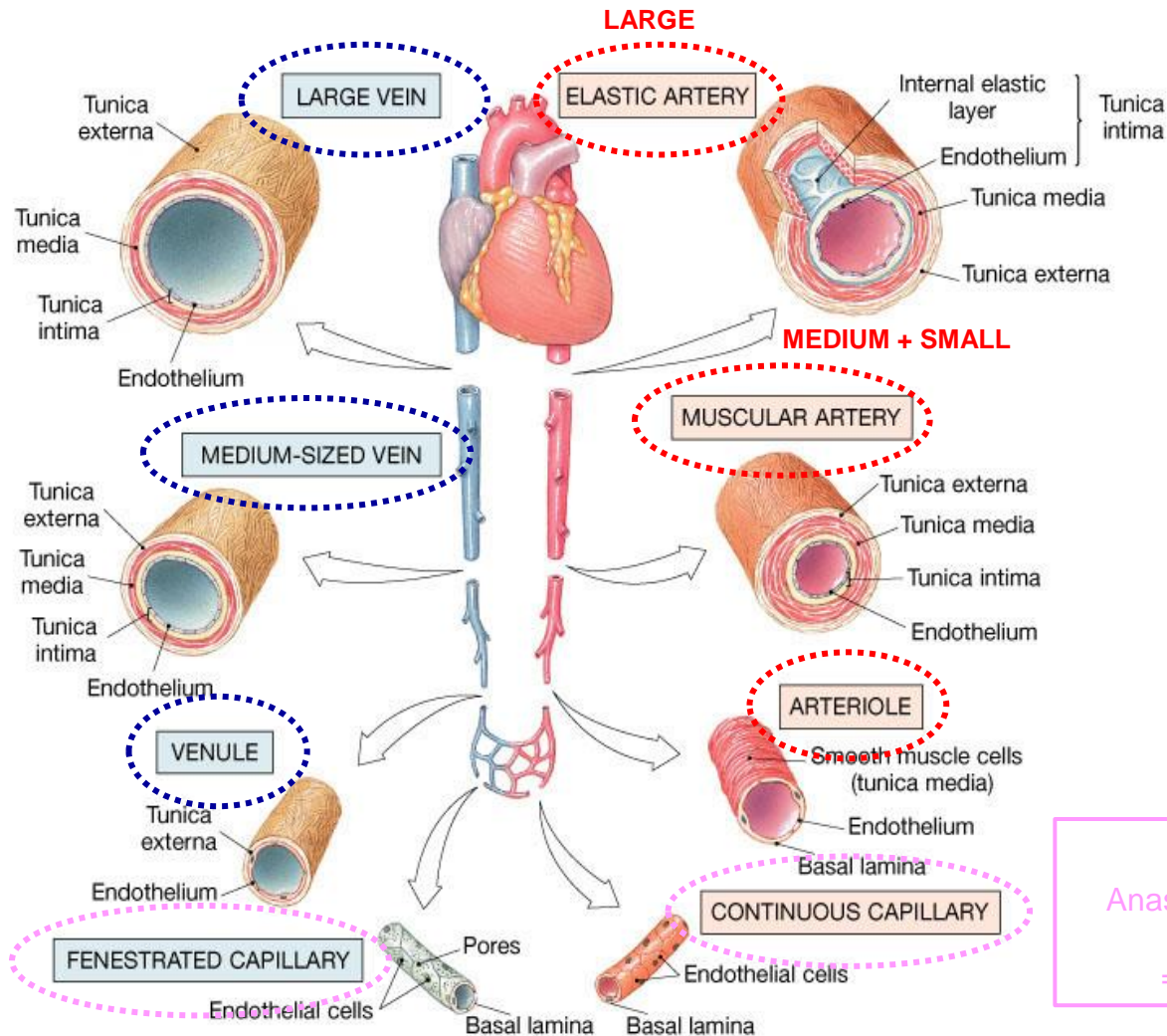
ALWAYS return the blood to the heart
(contain about 2/3 body's blood at any given time)

Arteries

ALWAYS carry blood from the heart to the periphery

Macrovasculature – diameter >0.1 mm

Microvasculature – <0.1 mm

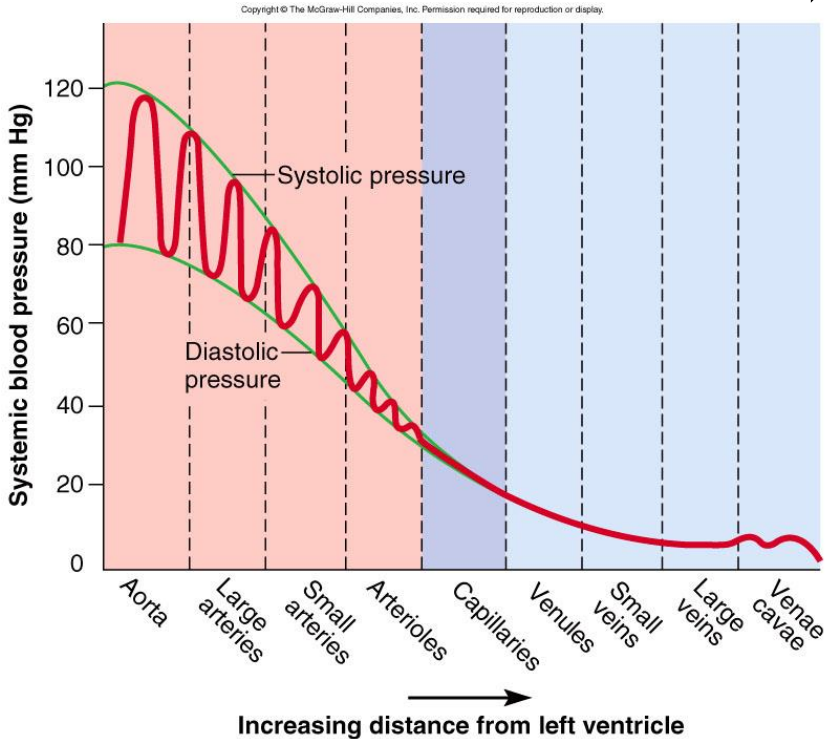


Capillaries

Anastomosing tubules among arteries and veins
= microvascular bed

Blood vessels – flow of blood

Pulsatile to continuous



Due to specific morphologies of the vessels

Vessel type	Diameter (mm)	Blood velocity (mm/sec)
Aorta	25	1 200 (systolic)
Arterioles	0.02-0.05	15
Capillaries	0.005-0.009	0.4
Venules	0.02	5
Inferior vena cava	30	80

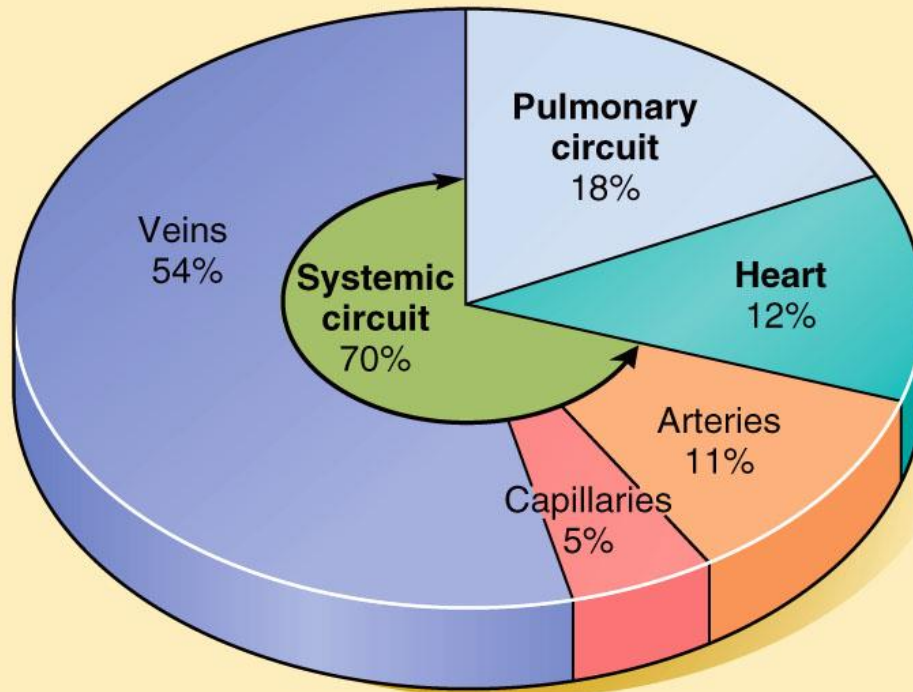
For example

- At ventricular diastole:**
- the semilunar valves are closed
 - no blood enters the arteries
 - the blood moves forward due to the action of arteries

...reflected by uneven distribution of blood

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Distribution of Blood



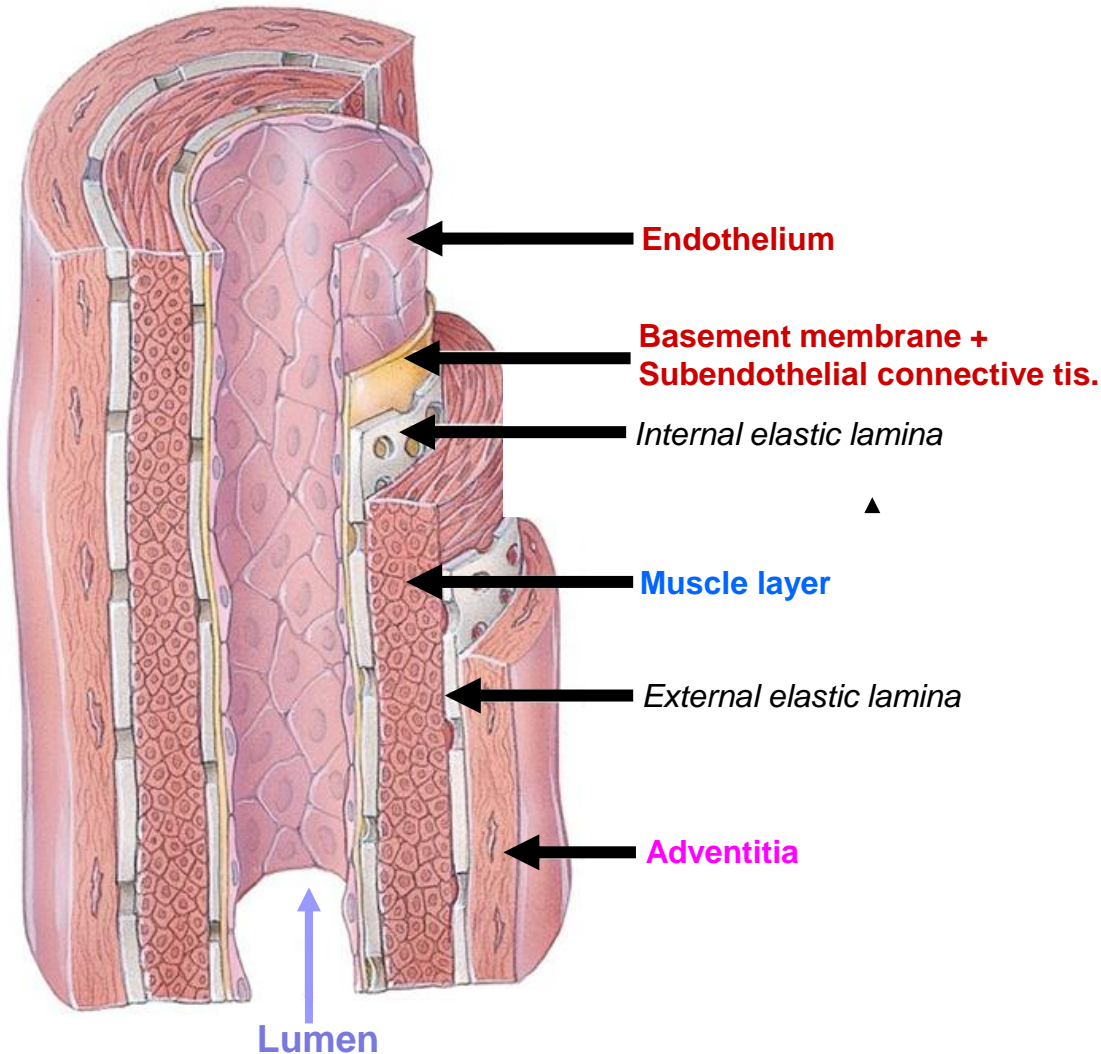
65 – 70% in veins

- Reservoir
- Lumens are larger than in corresponding arteries

Capillaries

~ 100 thousand km (estimate)
&
only 5% of blood volume
&
largest surface area (~ 600 m²)
&
most of the cells are no farther than 50 μ m from a capillary.

Blood vessels – common building plan (three-layered)



Tunica intima

Endothelial cells:

- polygonal, squamous, elongated
- covered by negatively charged glycocalyx (0.5 μm)
- provide repellent surface for cell elements
- glycocalyx - binding site for various regulators
- regulate permeability
- secrete regulators (e.g. interleukins,

Tunica media

- mainly smooth muscle (circularly arranged in layers)
- collagen and elastic fibers (lamellae), reticular fibers
- proteoglycans
- strengthen the vessels
- provide vasomotion

Tunica externa

- connective tissue (collagen 1 + elastin)
- home for vasa vasorum and nerve fibers
- continuous with stroma of the surrounding tissues

Arteries

Several categories according to their: **size + structure + function**

Large = conducting = elastic artery

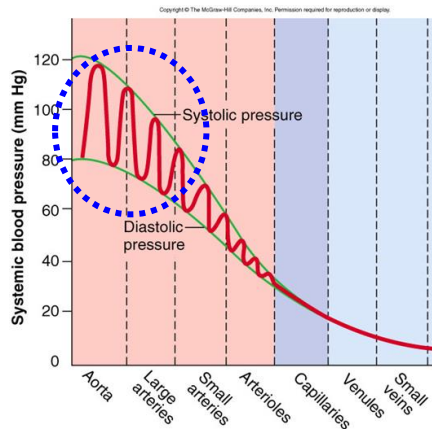
(aorta, common carotid, subclavian a., common iliac a., pulmonary trunk)

Medium-sized = distributing = muscular artery ($D > 1 \text{ mm}$)

(brachial, ulnar, femoral, renal, ...)

Small artery ($D = 0.1 - 1 \text{ mm}$)

Arteriole ($D < 0.1 \text{ mm}$)



Large = elastic = conducting arteries

Conducting

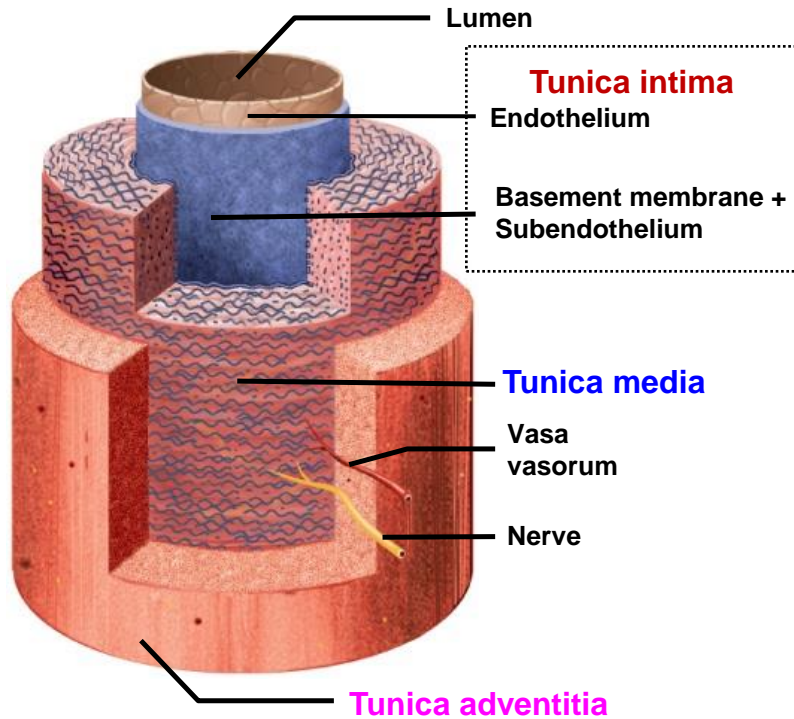
- their major function is to transport blood away from the heart

Elastic

- they absorb and store the contractile energy of the left ventricle and transform the pulsatile flow of blood into smooth out
- during ventricular contraction (systole), the elastic laminae of conducting arteries are stretched and reduce the pressure change
- during ventricular relaxation (diastole) ventricular pressure drops to a low level but the elastic rebound of conducting arteries helps to maintain arterial pressure
- as a consequence, arterial pressure and blood flow decrease and become less variable as the distance from the heart increases

Large = elastic = conducting arteries

Relatively thin wall as compared to their wide lumen (1/10 of the vessel diameter).



Endothelium

- elongated cells - along the long axis

Subendothelial layer

- loose connective tissue
- contains many fine longitudinal elastic fibres - these gradually merge into the elastic components of t. media
- some smooth muscle cells near the boundary with t. media - longitudinally arranged
- place of atherosclerotic changes

Internal elastic lamina

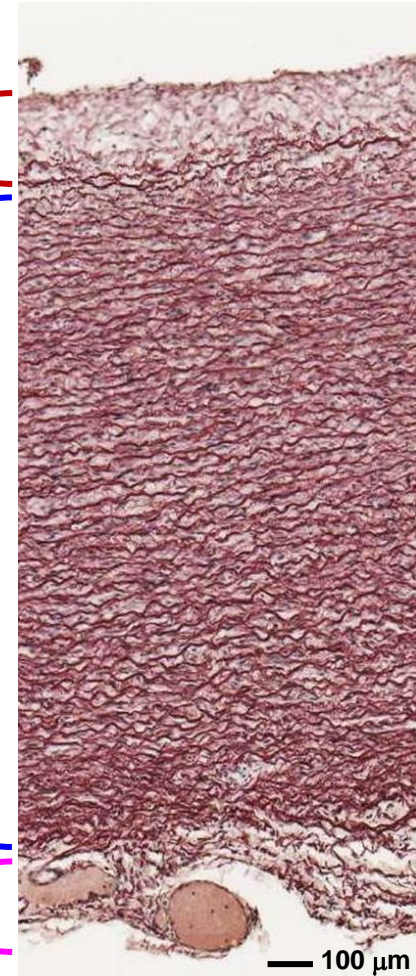
- not clearly demarcated

- elastic fibers arranged circularly as discontinuous fenestrated membranes about 2.5 μm thick - about 50 lamellae
- smooth muscle cells - circularly oriented, interspersed between elastic membranes

- relatively thin
- loose connective tissue
- some elastic fibers – longitudinally arranged, next to the t. media
- vasa vasorum and lymphatics (some into t. media)
- nerves

0.15 mm

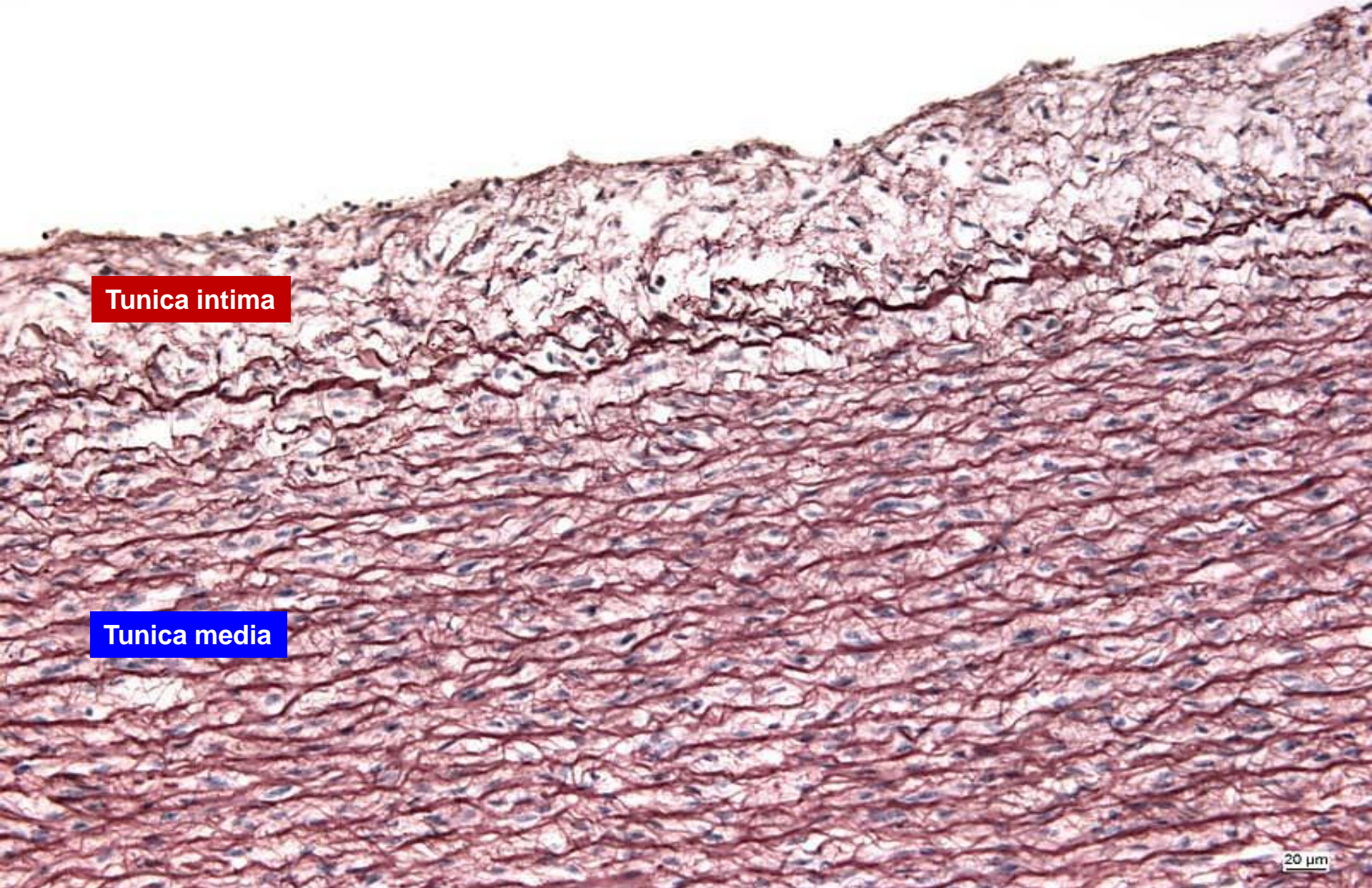
2 mm



Large = elastic = conducting arteries

Tunica intima

Tunica media

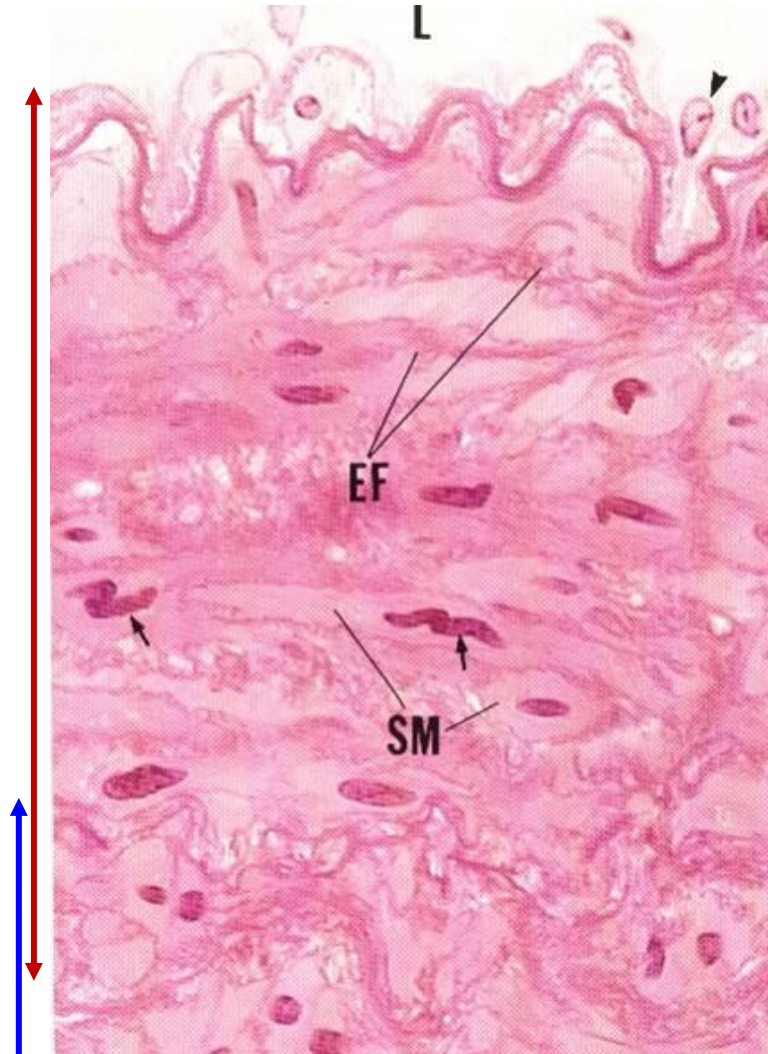


Large = elastic = conducting arteries

Monkey
H & E
x540

Tunica intima

Tunica media

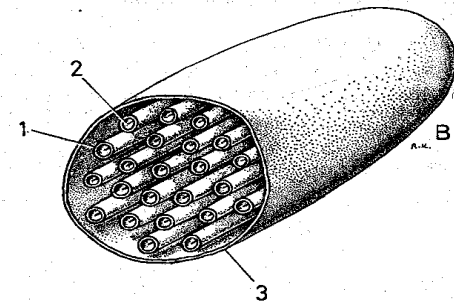
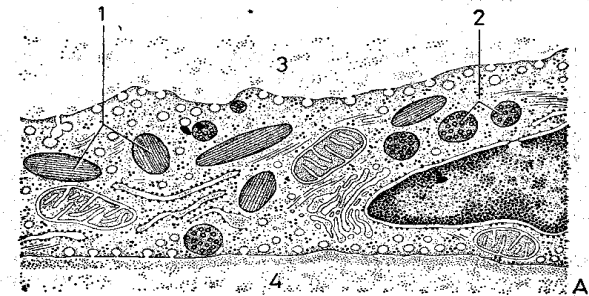


transition

Artery - Endothelium

Weibel-Palade bodies

- organelles that are unique to endothelial cells
- contain von Willebrand factor (activates coagulation factor VIII) + P-selectin



Arteries - Atherosclerotic changes

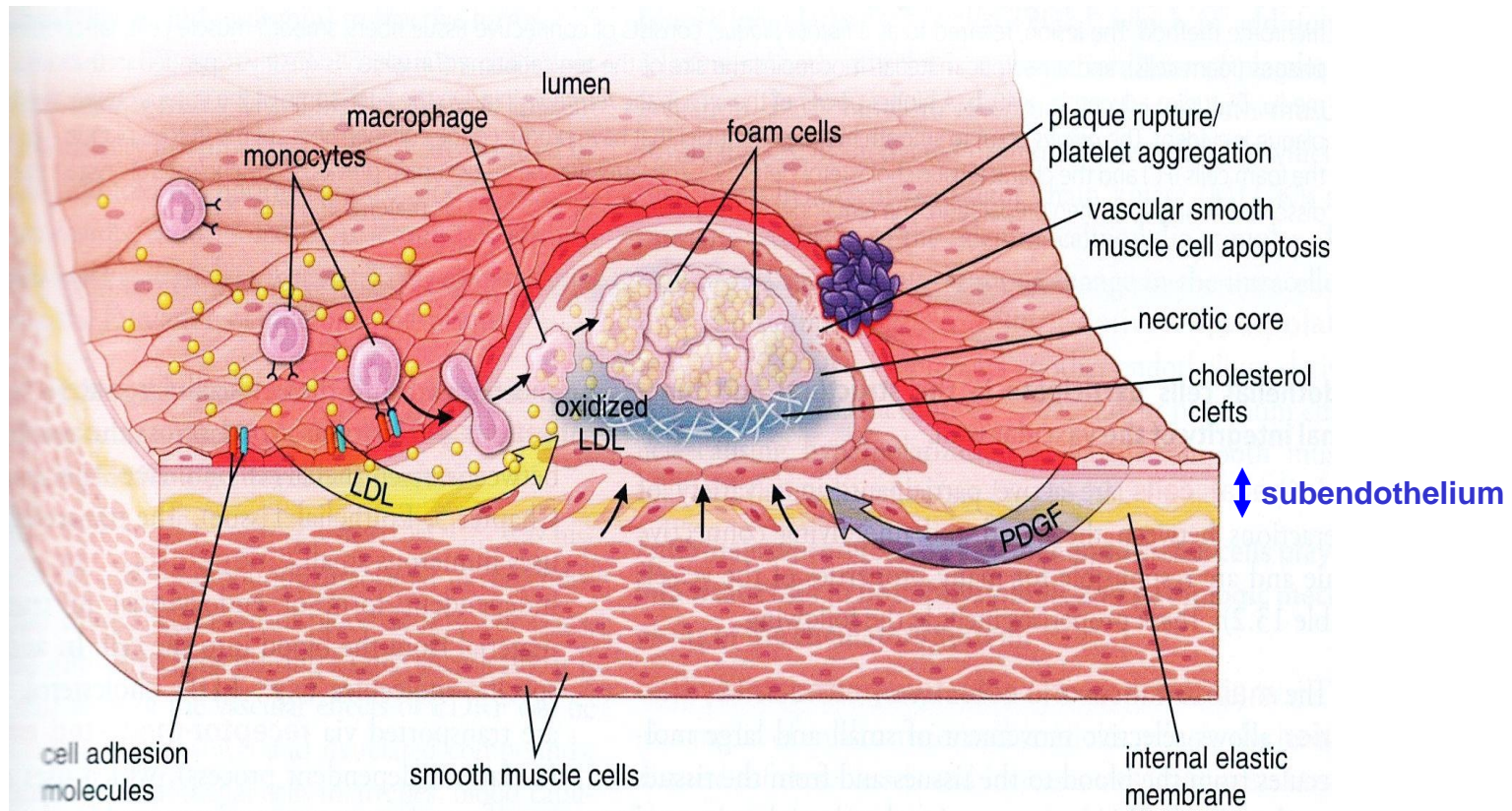
Endothelial injury
(upon predisposing factors)

Production of ROS

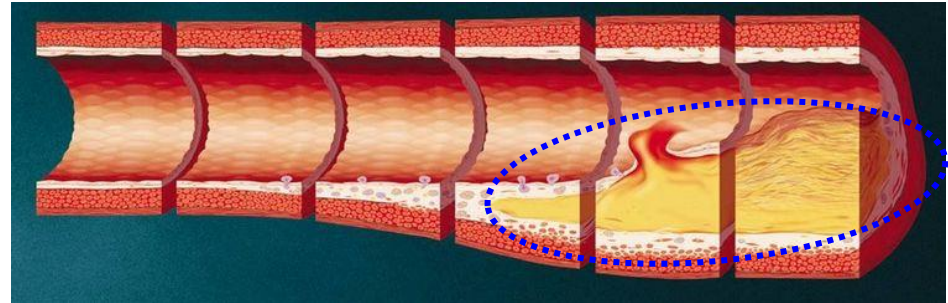
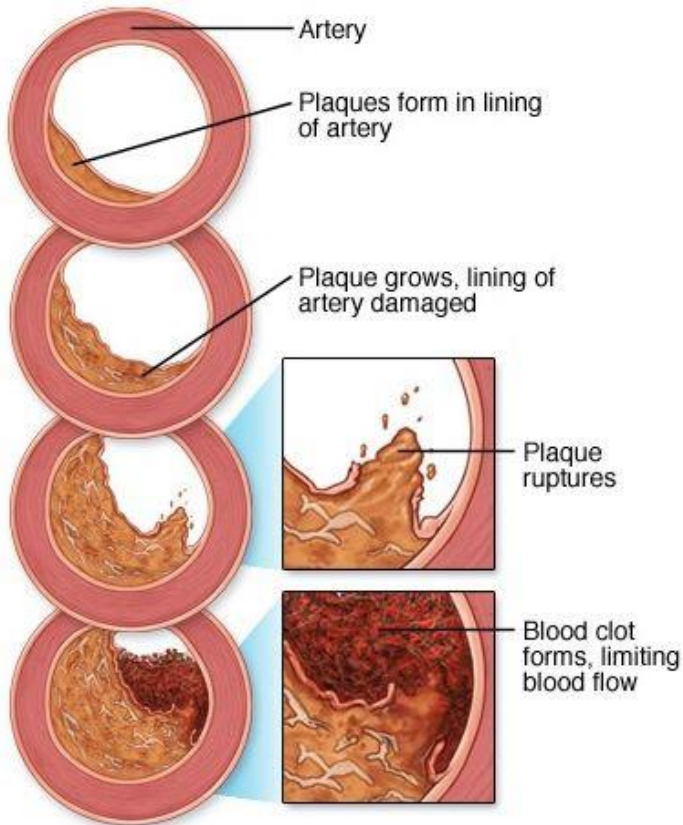
Oxidizing of LDL

Entry of monocytes
(conversion to foam cells)

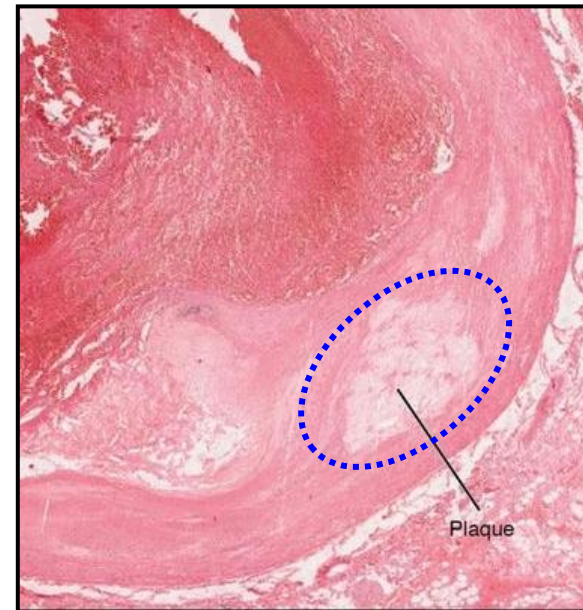
Plaque formation
(necrosis + lipid accumulation)



Arteries - Atherosclerotic changes



Atheromatous plaque



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Artery clogging

Muscular arteries = distributing arteries

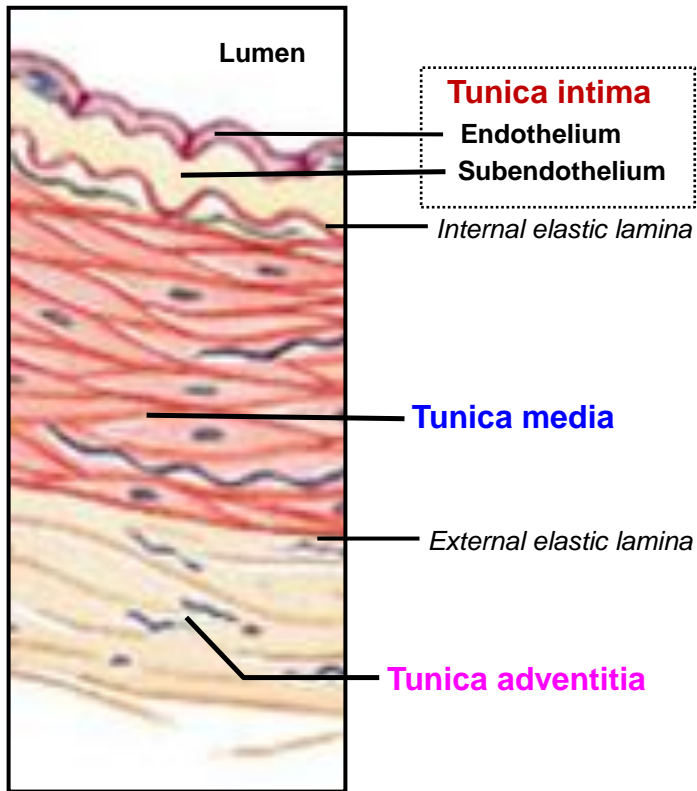
Distributing

- distribute blood to specific destinations/organs
- size varies from centimeter down to just visibility by unaided eye

Muscular

- they regulate the perfusion of different parts of the body under physiological conditions

Muscle arteries = distributing arteries



Muscular artery

Endothelium

- elongated cells along the long axis
- well developed adhesion, tight, and gap junctions
- Glycocalyx

Subendothelial layer

- thickness increases with age
- loose connective tissue
- many fine longitudinal elastic fibres
- some smooth muscle cells

Internal elastic lamina

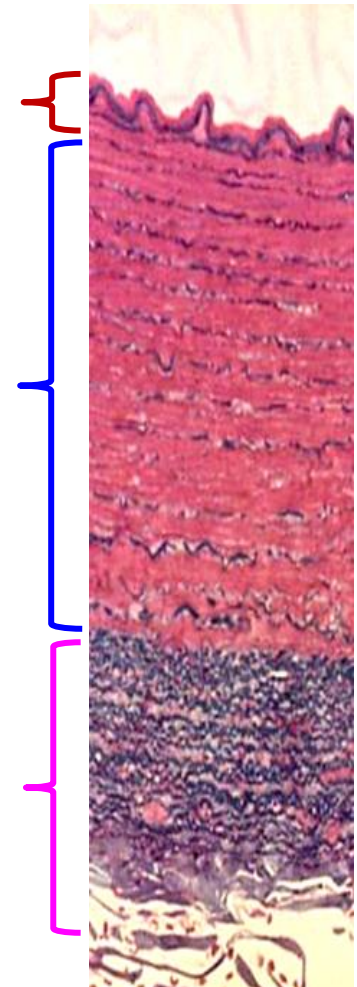
- well developed

- very thick
- concentrically arranged smooth muscle cells
- up to 50 layers of smc
- ECM with elastic, collagen and reticular fibers
- GAP junctions between smc (coordination)

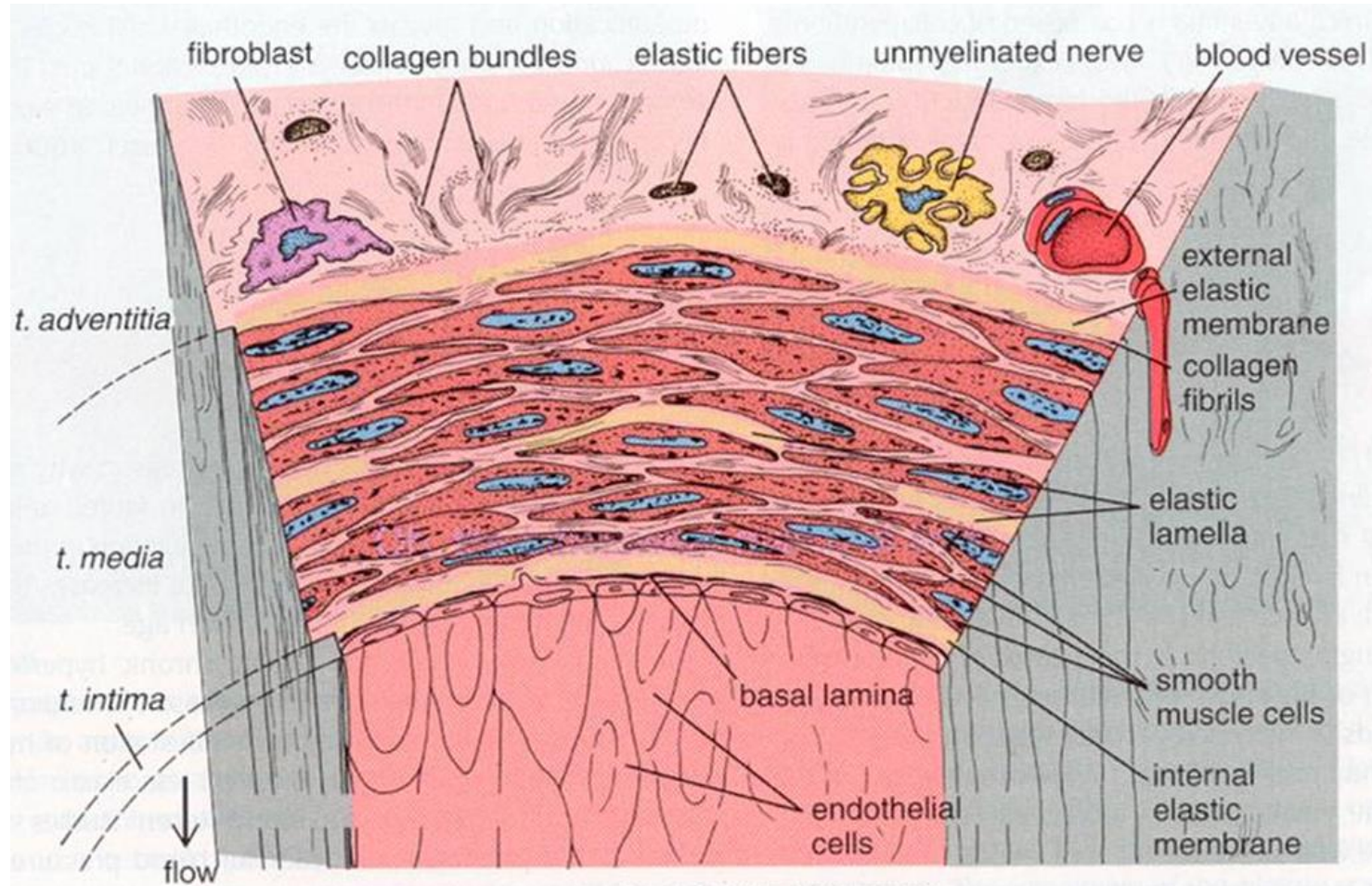
External elastic lamina

- well demarkated only in large caliber arteries

- relatively thick (~ 1/2 of the tunica media)
- collagen and elastic fibers
- some fibroblasts and adipocytes
- vasa vasorum and lymphatics (some into t. media)
- nerves – efferent – maximal in small caliber arteries

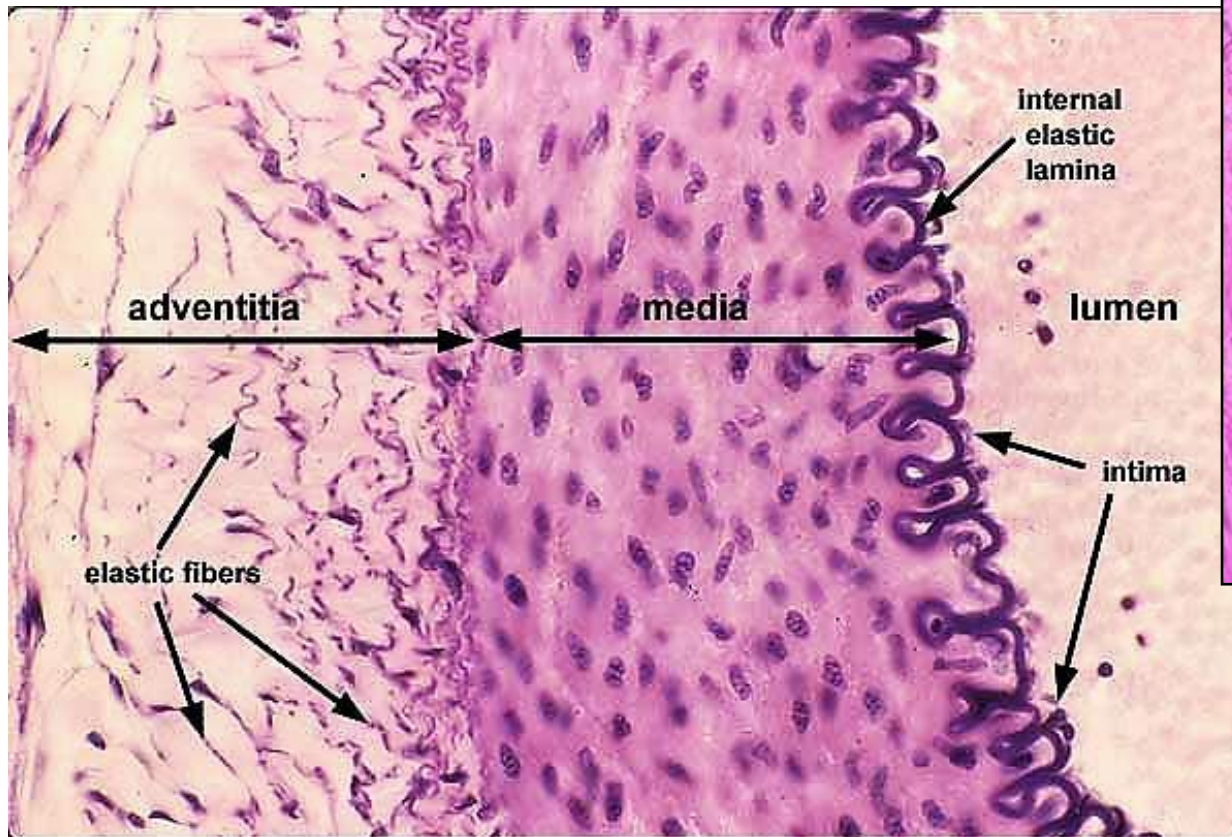


Muscular arteries = distributing arteries

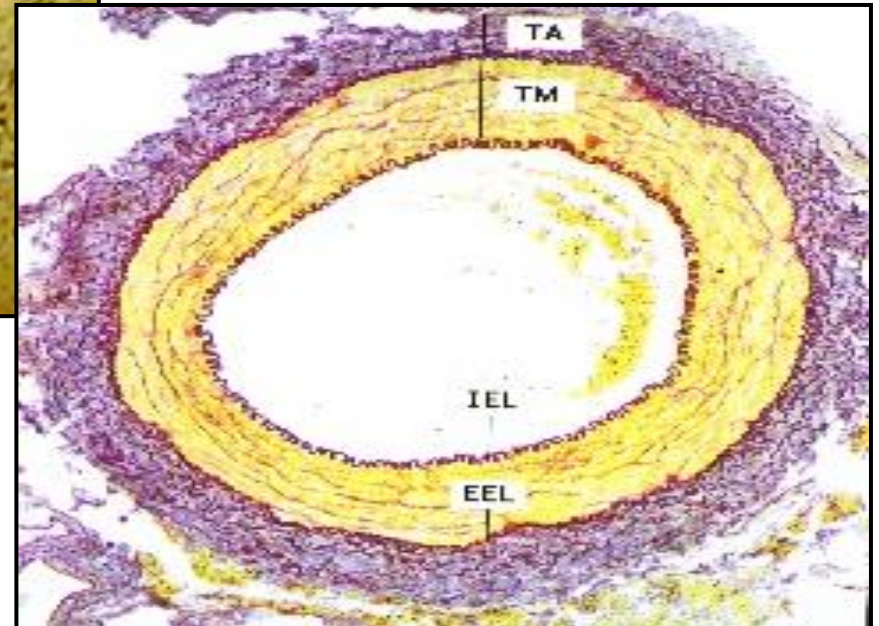
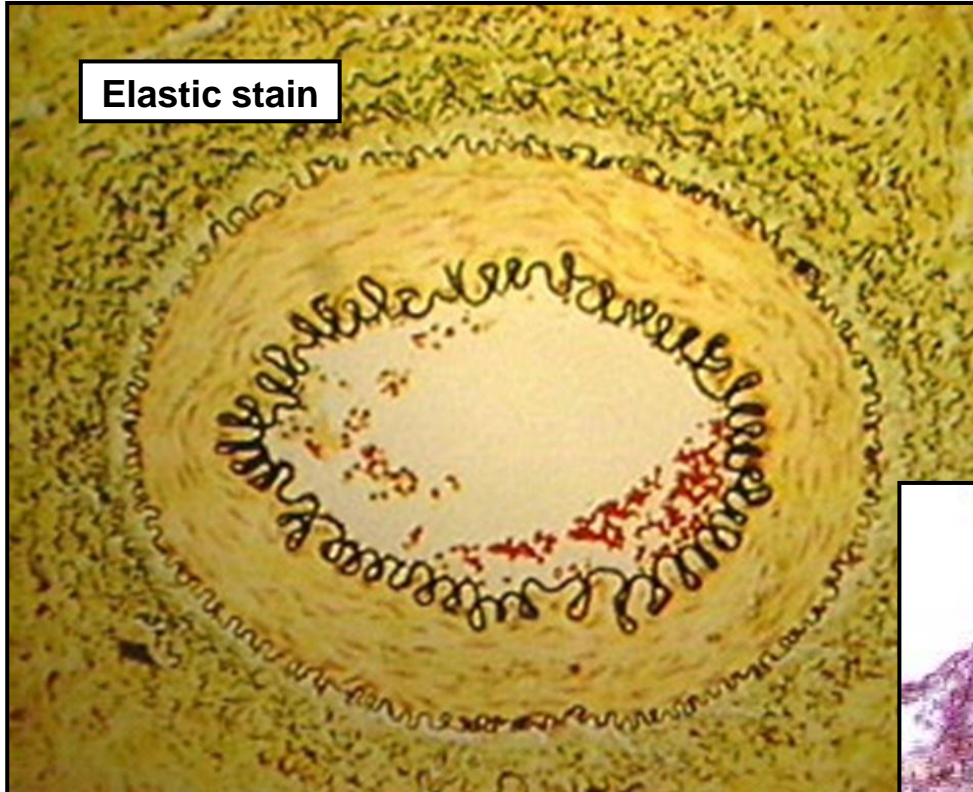


Muscle arteries = distributing arteries

Undulation - Artefact
(due to postmortem contraction of smooth muscle cells)

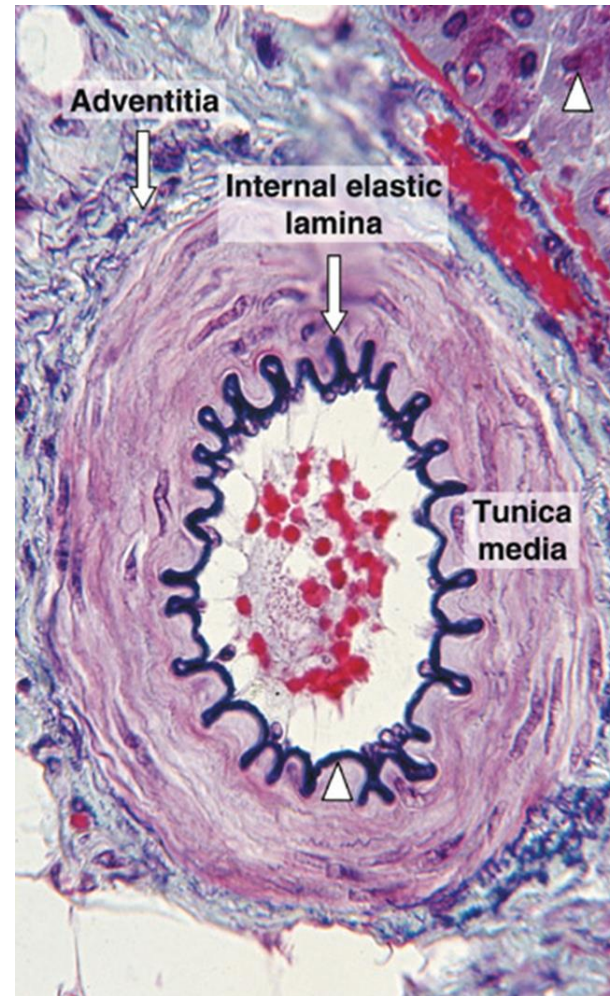
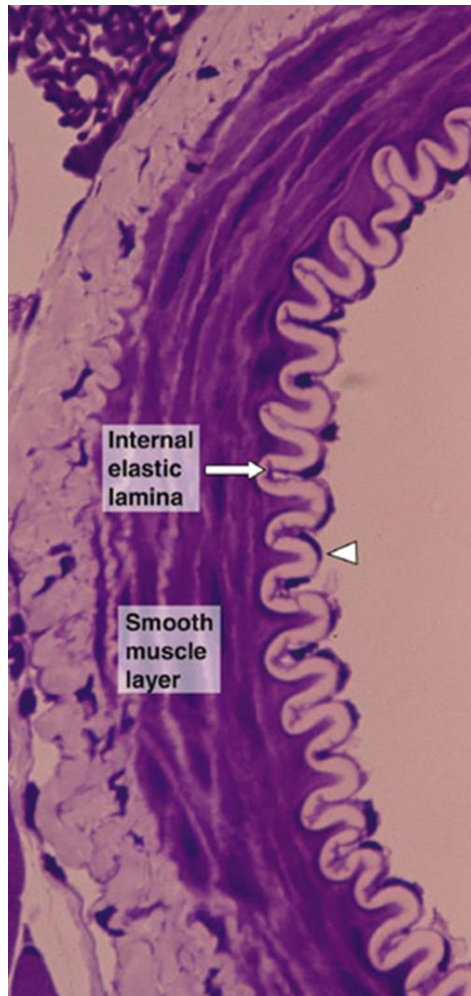


Muscle arteries = distributing arteries

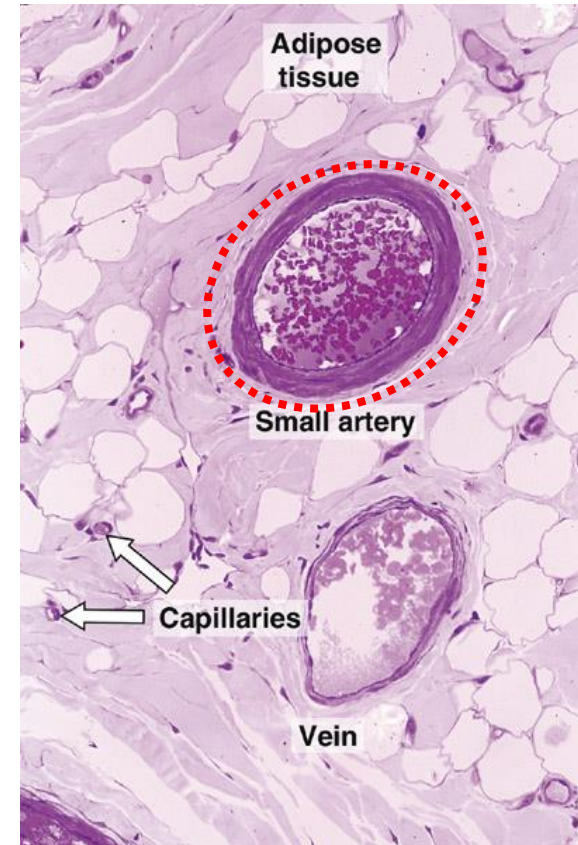
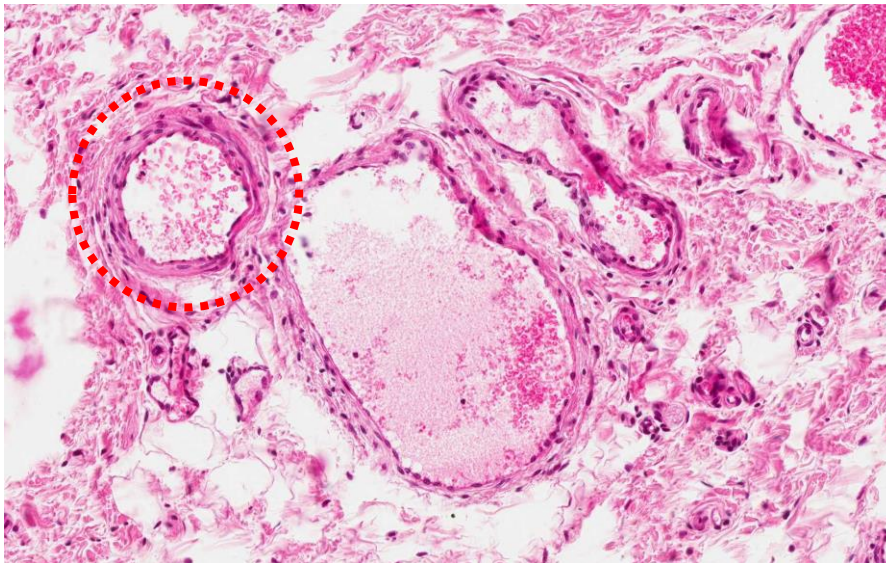
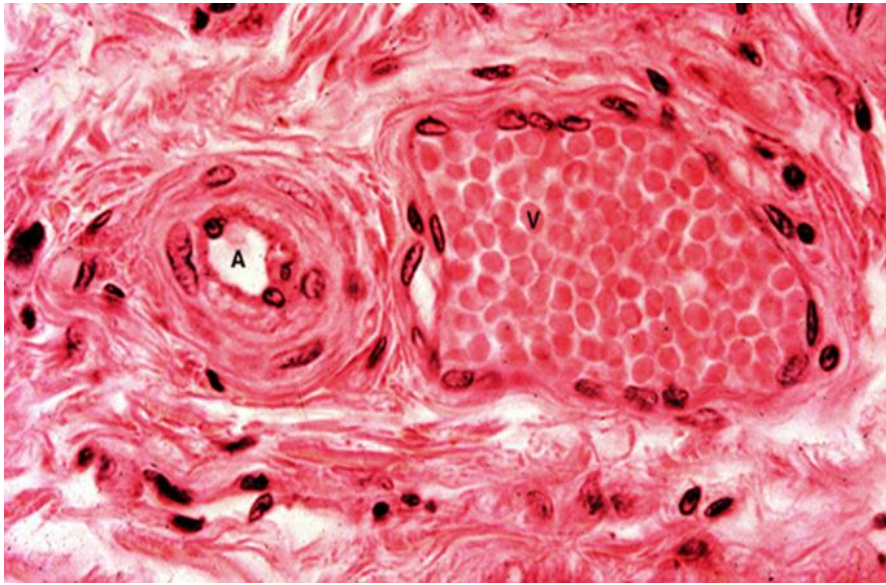


Muscle arteries = distributing arteries – *small sized*

- **peripheral resistance vessel** (along with arterioles)
- *internal elastic lamina* is clear x *external elastic lamina* is not distinguished
- the **tunica media** contains 3 to 10 layers of smooth muscles



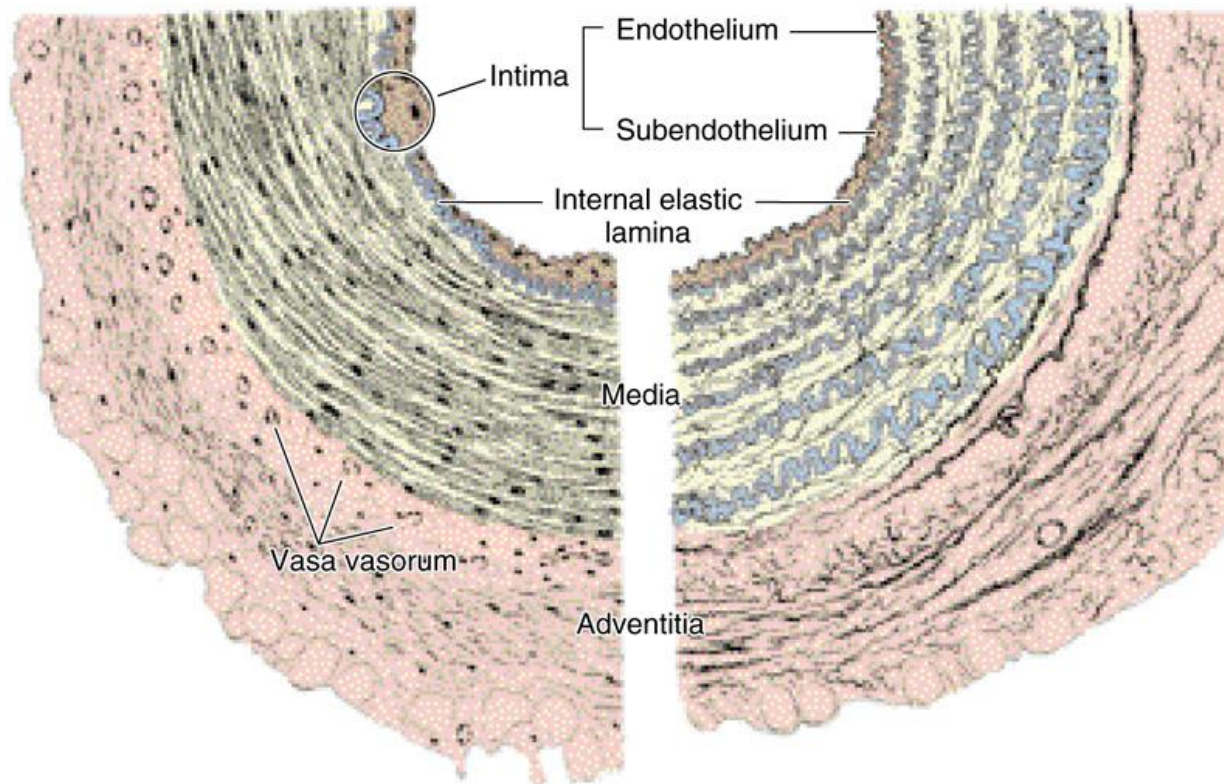
Muscle arteries = distributing arteries – *small sized*



Muscle arteries x Elastic arteries

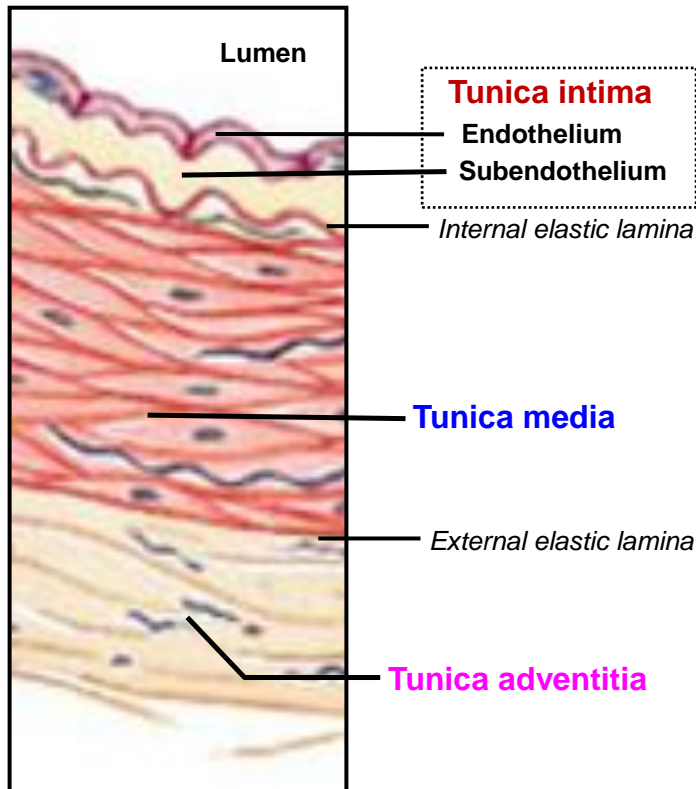
Smooth muscle cells predominate in their media

Elastic elements predominate in their walls



Arterioles

- **peripheral resistance vessel** (along with small-sized arteries)
- part of the **microcirculation** (terminal circulation)
- internal diameter < 0.1 mm
- they regulate the flow of blood through capillary bed



Muscular artery

Endothelium

- elongated cells along the long axis

Subendothelial layer

- non-developed

Internal elastic lamina

- non-developed

- thin (still the major part of the wall)

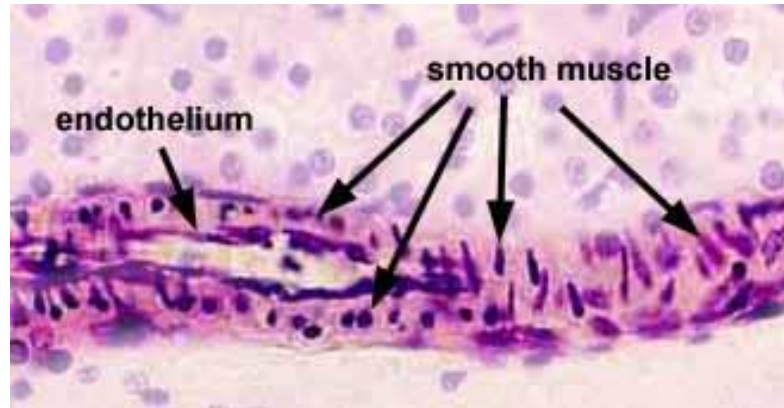
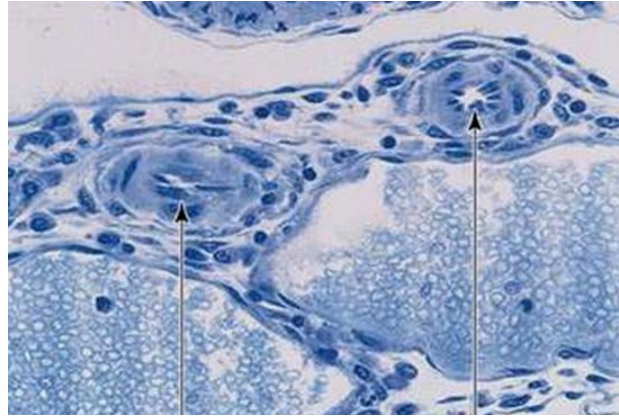
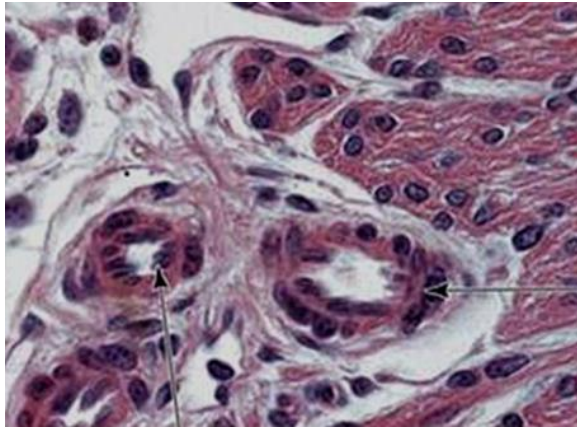
- 1 to 2 layers of smooth muscle cells

External elastic lamina

- non-developed

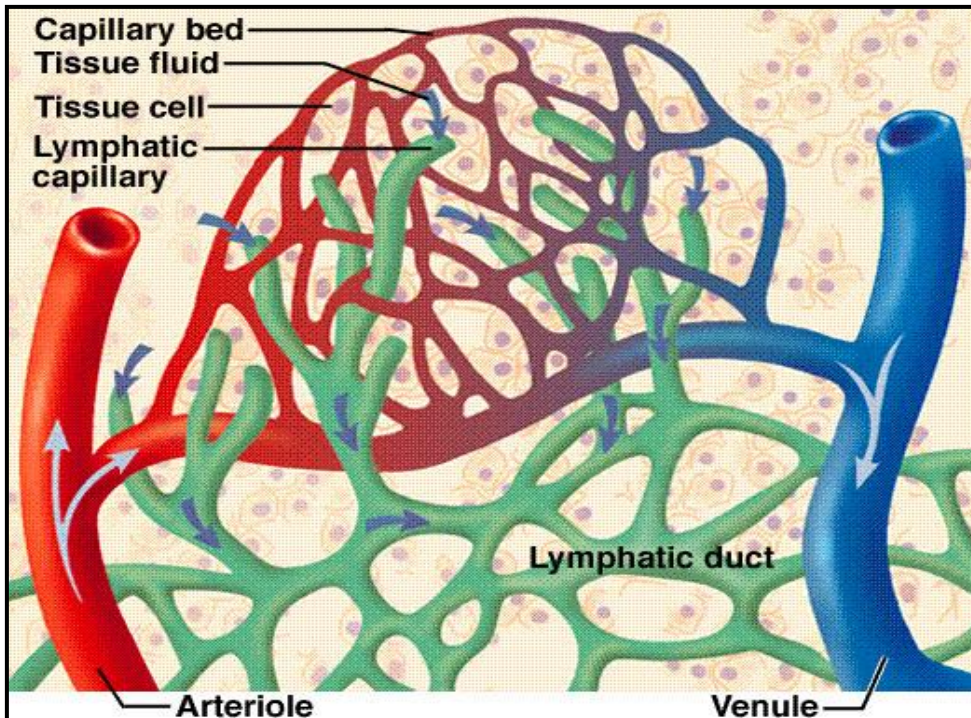
- reduced to only sheath of collagen fibers
- NO vasa vasorum

Arterioles



Capillaries

- are the site where materials carried in the blood are unloaded and other materials are loaded into the blood
- are the **thinnest, simplest, largest, longest, and most widely distributed** functional unit of the blood vascular system
- are inserted between arterial and venous limbs of the circulation
- branch extensively to form elaborate networks, the extent of which reflects the activity of an organ or tissue
- are the largest part of the **microcirculation** (along with **arterioles** and **venules**)



The total length of all the capillaries of the human body =

about 100 000 km

The total cross-sectional area of capillaries =

about 800 x
greater than of the aorta

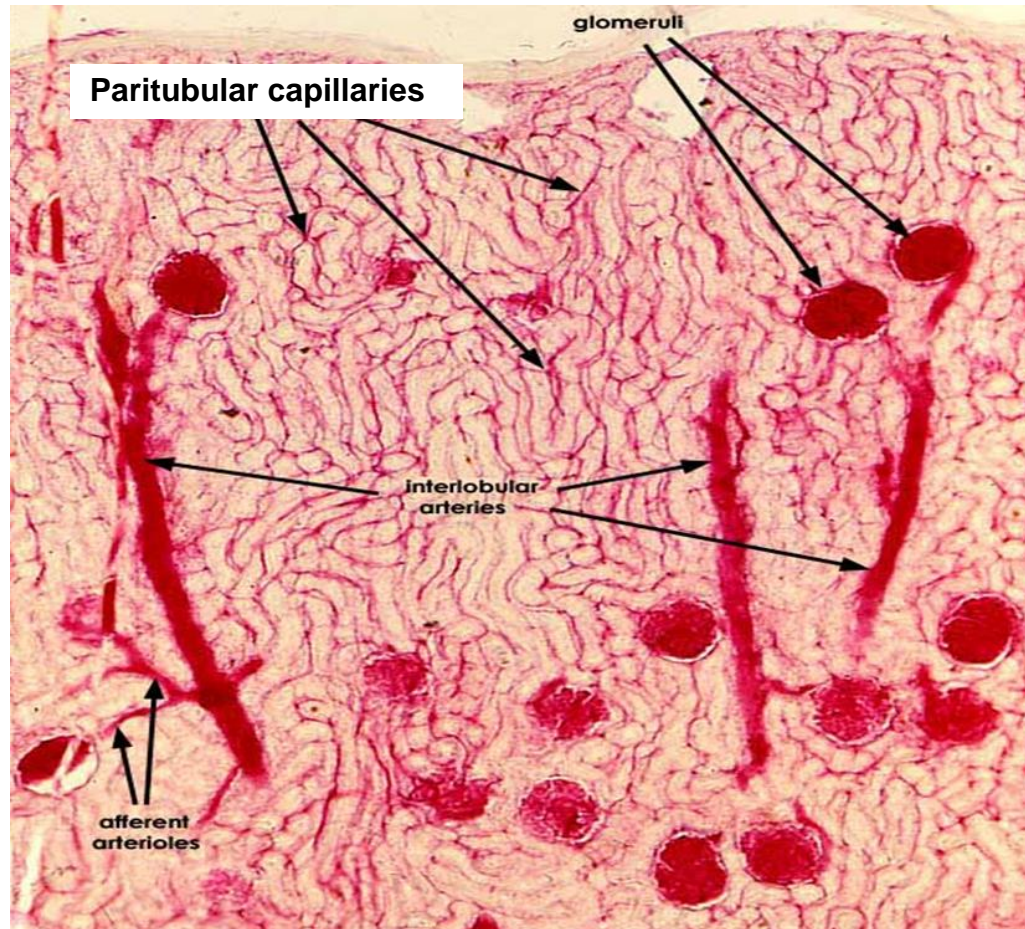
Maximal distance of tissue cell from the capillary =

about 50 μm

The length of the capillaries usually varies between

about 0.25 and 1 mm

Capillaries

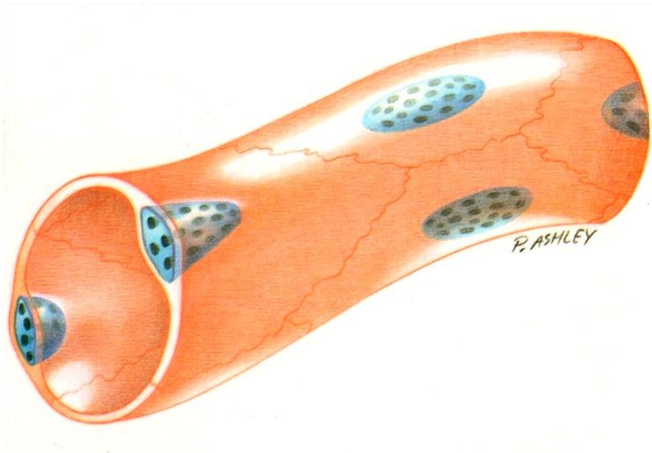


Extensive vasculature of renal cortex (perfused by red dye)

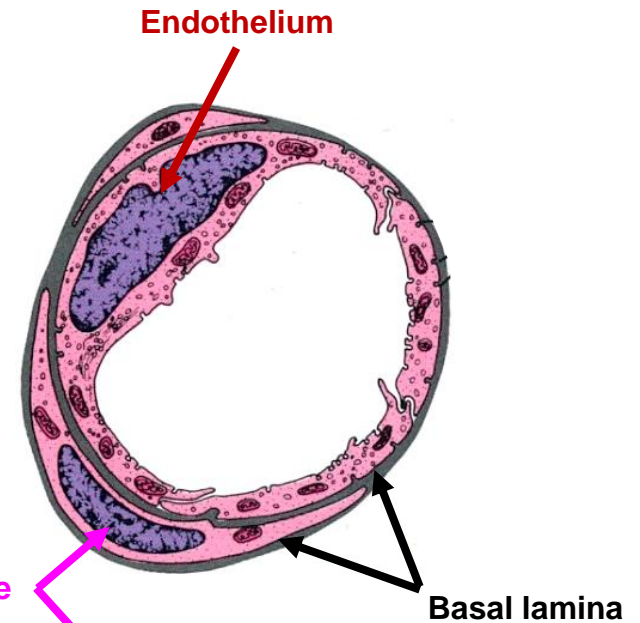
Scarse in: tendons, ligaments

Absent from: cartilage, epidermis, cornea

Capillaries



average diameter about $8 \mu\text{m}$



Capillary wall

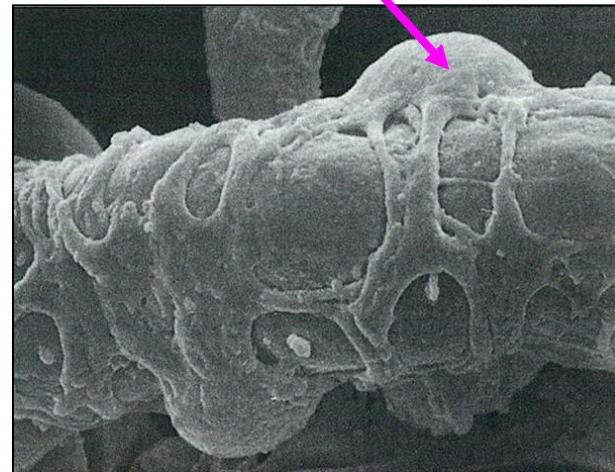
Endothelium

- single layer, squamous
- serrated (wavy) cell borders
- zonulae occludentes + desmosomes + GAP junctions

Basal lamina

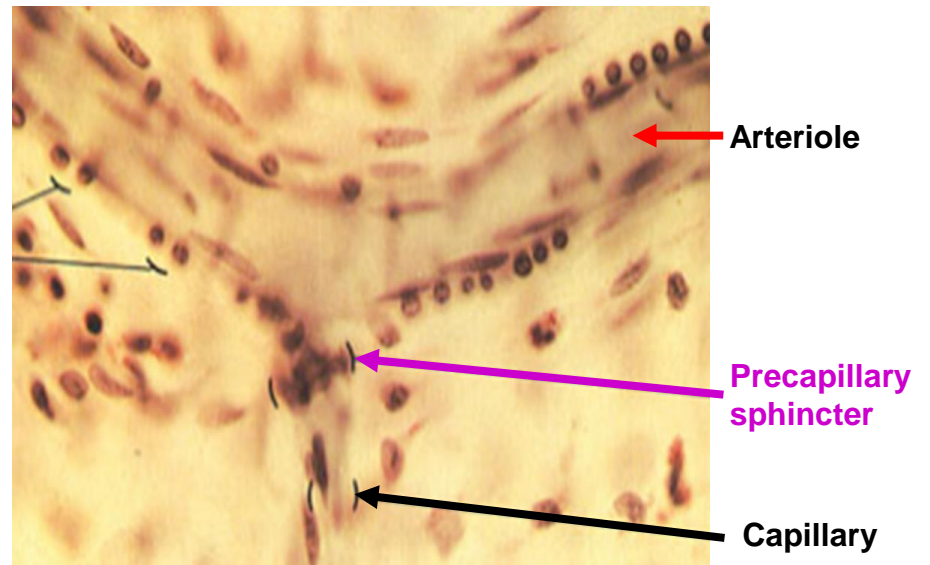
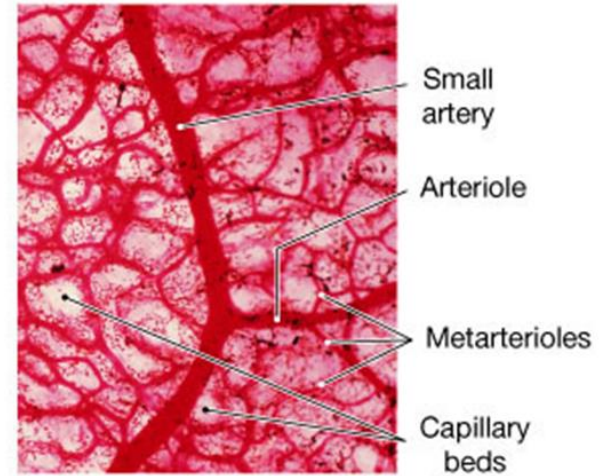
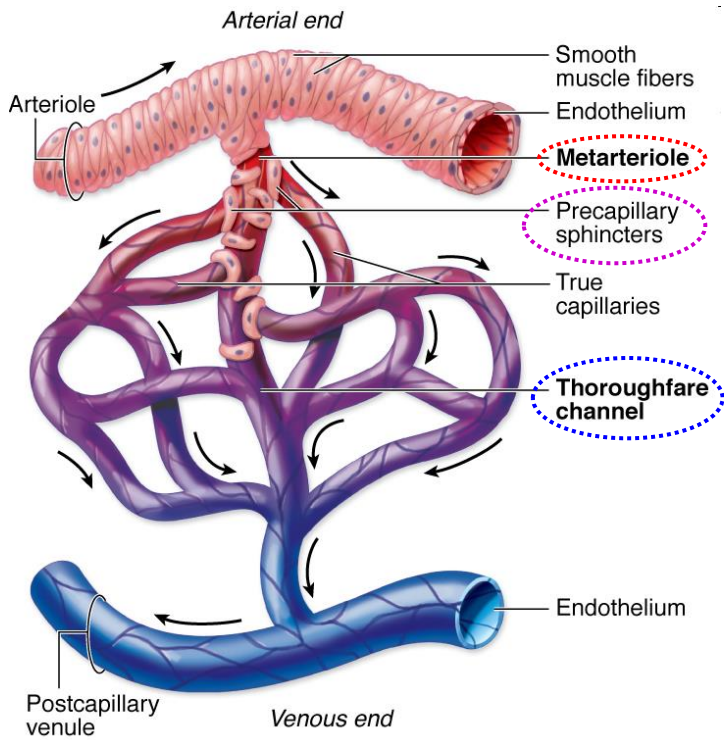
„Envelope“

- pericytes (+ reticular fibers and macrophages)



Capillaries

Only about 25 - 50 % of capillary volume is actively moving (containing) blood under normal conditions.



Rabbit mesentery (H+E; 600x)

Capillaries – Regulation of blood flow

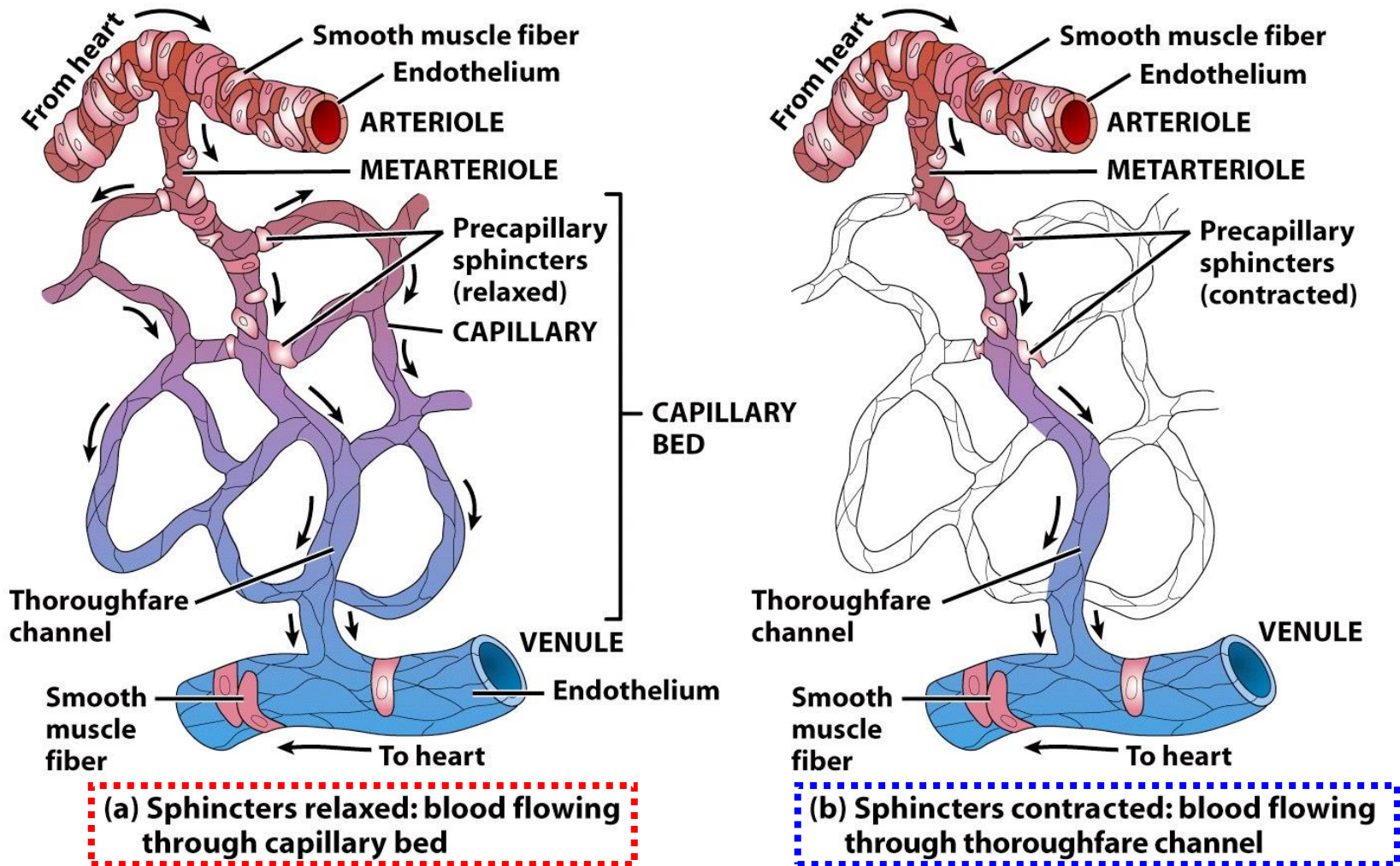
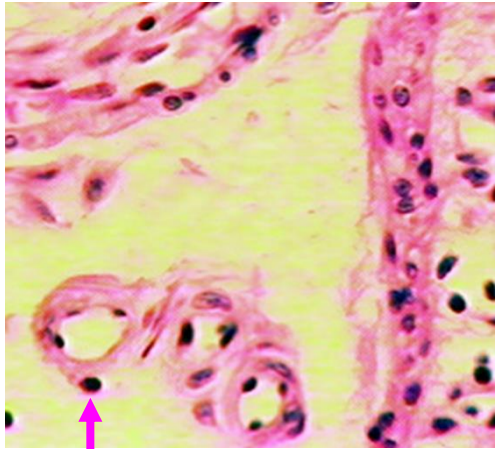
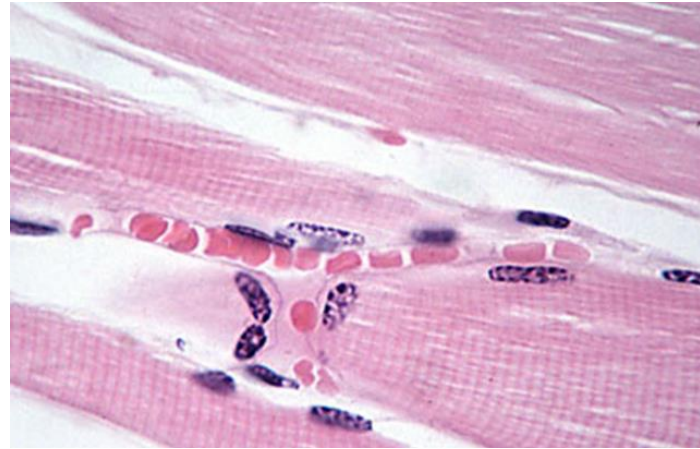


Figure 21-3 Principles of Anatomy and Physiology, 11/e
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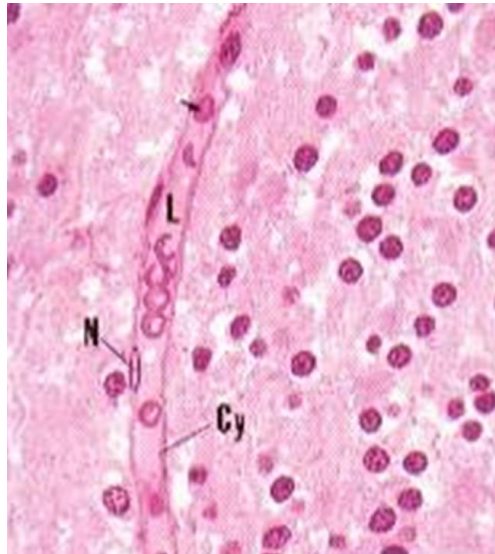
Capillaries



Pericyte



Striated muscle

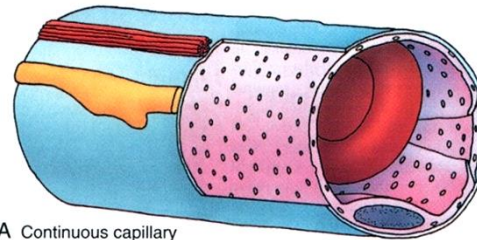


Cerebellum (monkey)

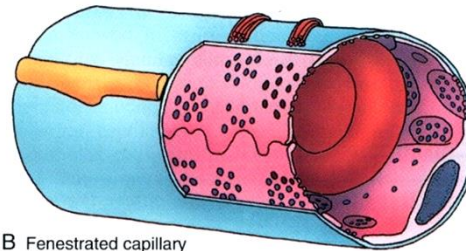
Capillaries

According to the integrity of the endothelium and basement membrane – by TEM:

- **Continuous capillary**
- **Fenestrated capillary**
- **Sinusoidal**



A Continuous capillary

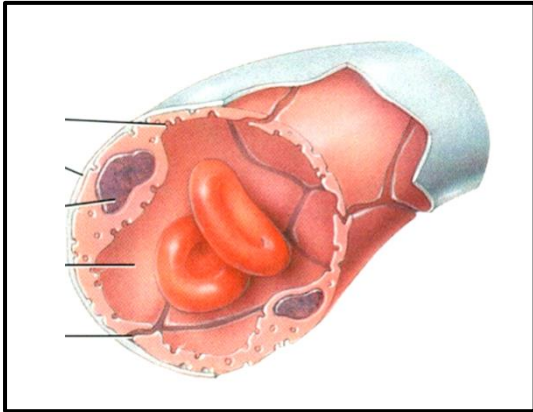


B Fenestrated capillary



C Sinusoidal (discontinuous) capillary

Capillaries - Continuous

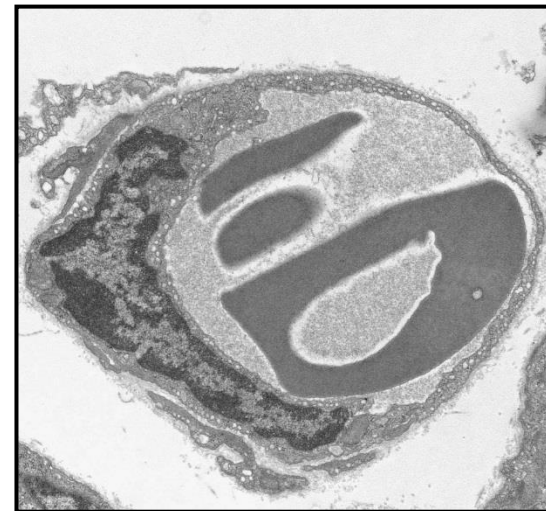
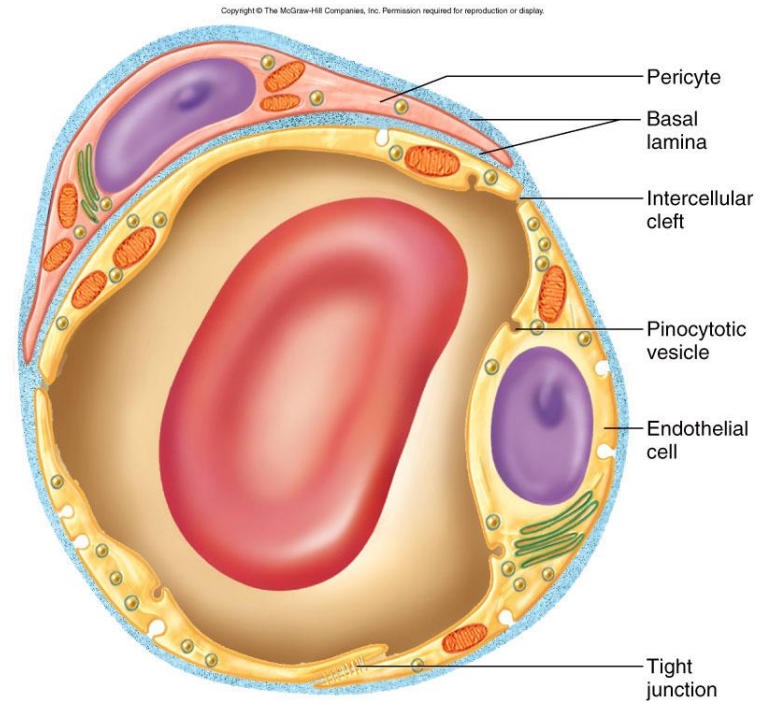


How ?

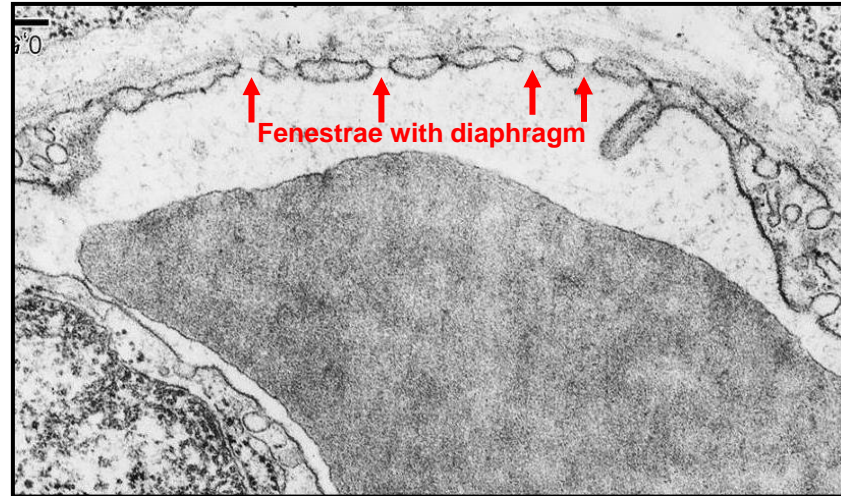
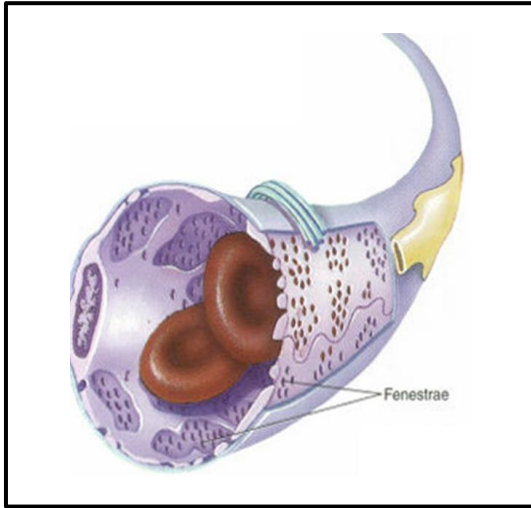
- non-interrupted lining
- no defects in the wall (endothelium + basal lamina)

Where ?

- most common type
- muscle, connective tissue, nerve tissue (blood-brain barrier), exocrine glands



Capillaries - Fenestrated

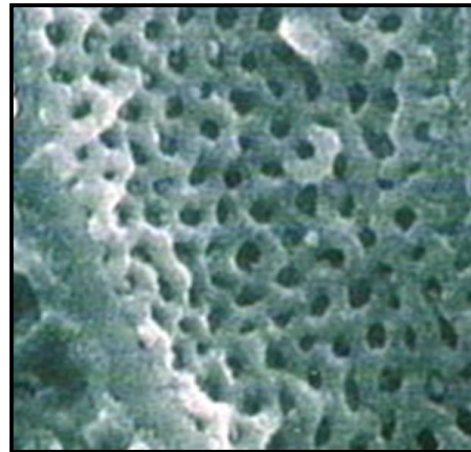


How ?

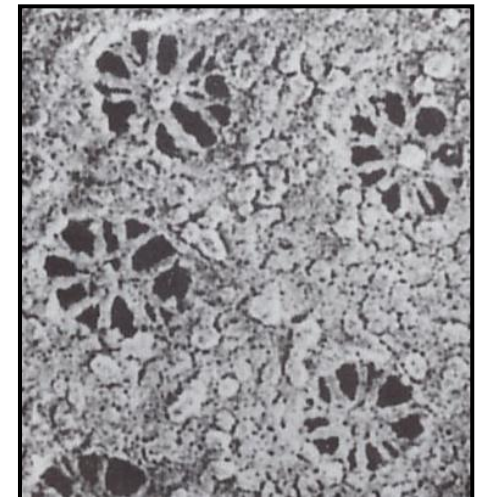
- endothelial cells perforated (diameter ~60-80 nm; diaphragm 4-6 nm)
- continuous basal lamina

Where ?

- in tissues where rapid interchange of substances occurs between the tissue and the blood
- intestinal mucosa, some endocrine glands, pancreas, choroid plexus, ciliary body, ...
- kidney glomeruli (no diaphragm over fenestrae)

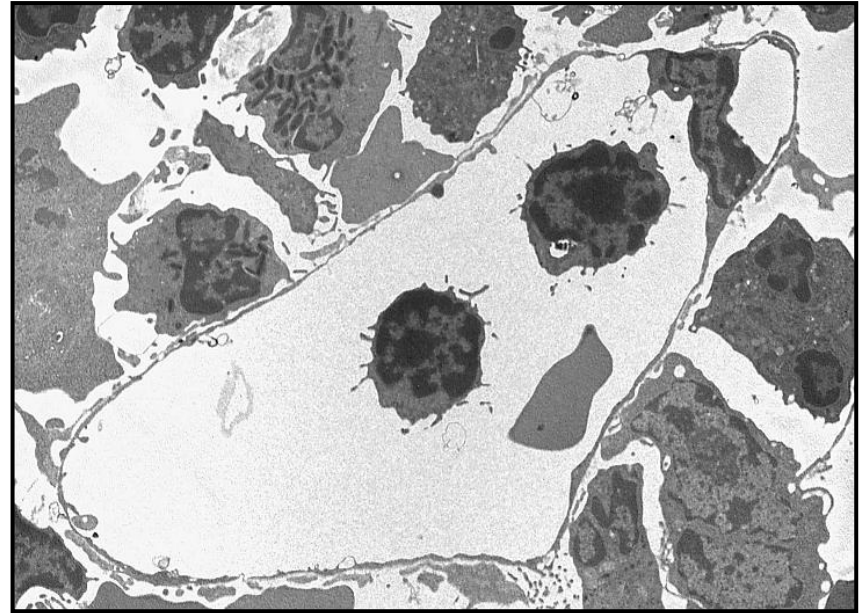


Fenestrated capillary - kidney



Diaphragm

Capillaries – Sinusoidal - Discontinuos

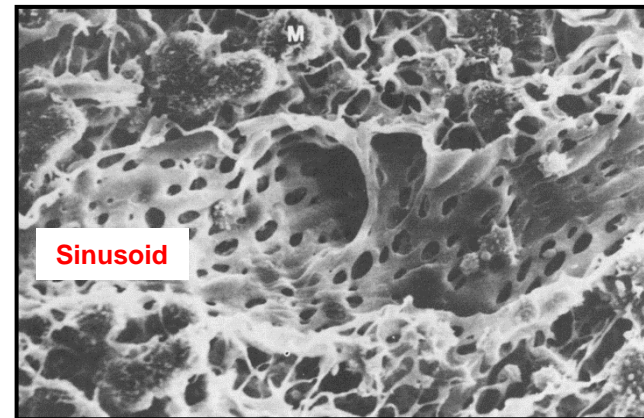


How ?

- enlarged diameter (up to 40 μm)
- endothelial cells with large pores without diaphragm
- large clefts between endothelial cells
- discontinuous basal membrane (or even absent)
- pericytes are absent (macrophages instead)

Where ?

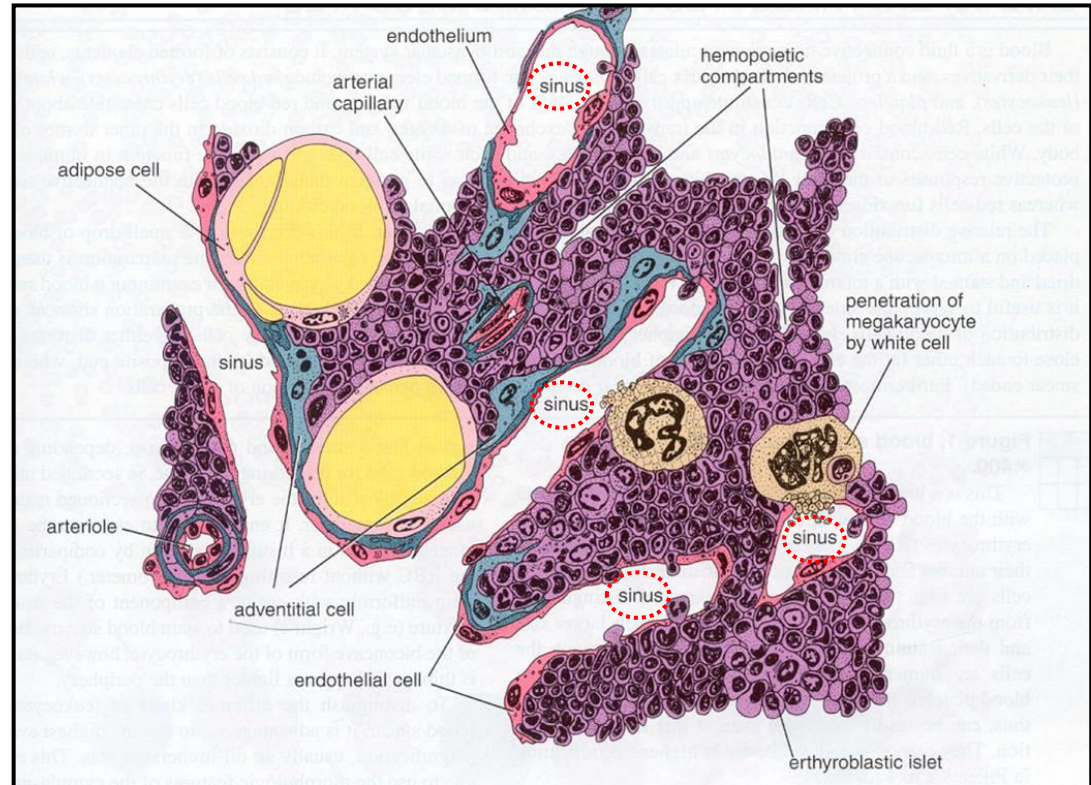
- liver (pores 100 nm)
- hematopoietic regions (bone marrow)
- endocrine glands (adenohypophysis, islets of Langerhans)



Capillaries – Sinusoidal - Discontinuuos



Bone marrow



Blood vessels – several different flavours

Veins

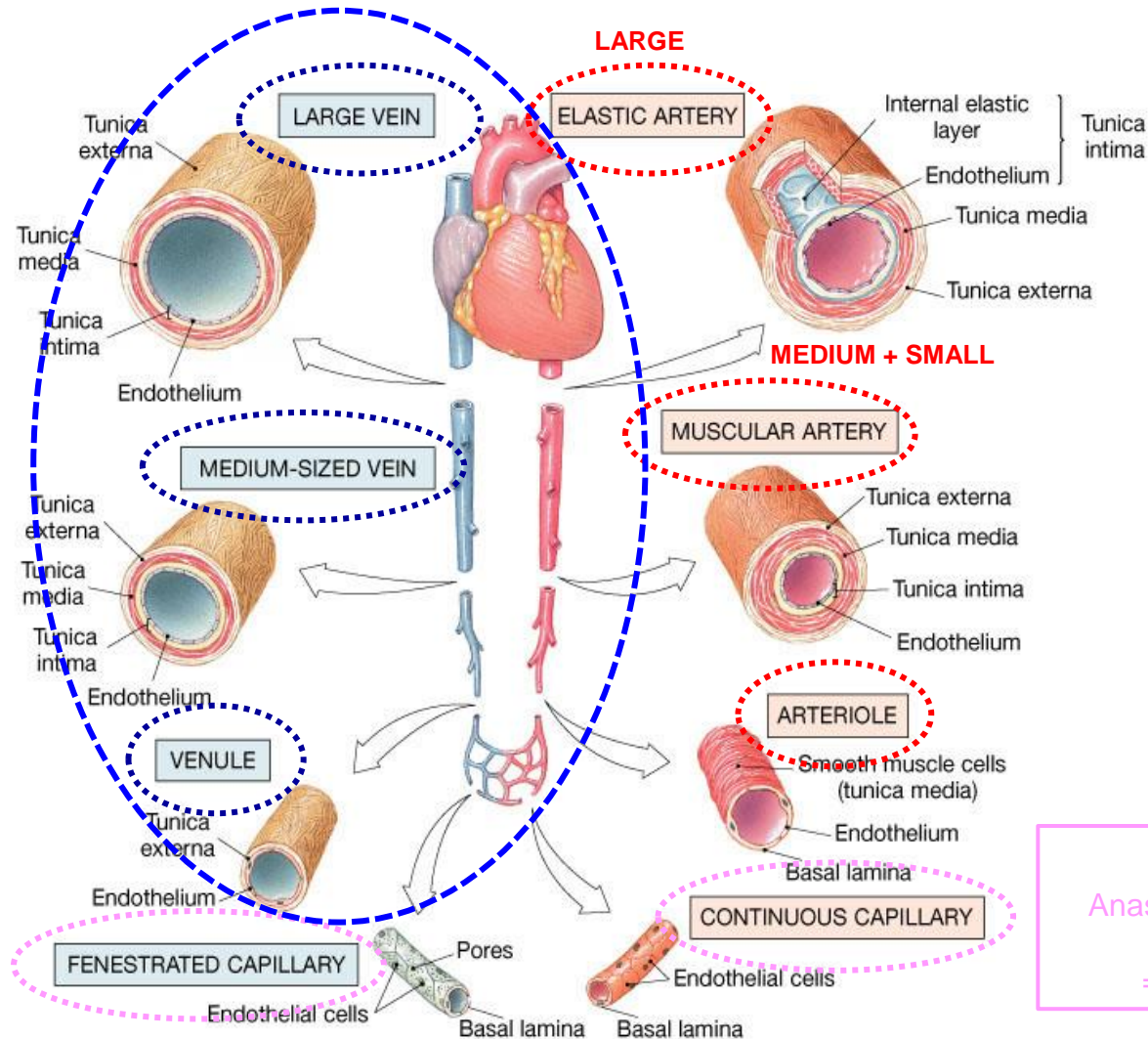
ALWAYS return the blood to the heart
(contain about 2/3 body's blood at any given time)

Arteries

ALWAYS carry blood from the heart to the periphery

Macrovasculature – diameter >0.1 mm

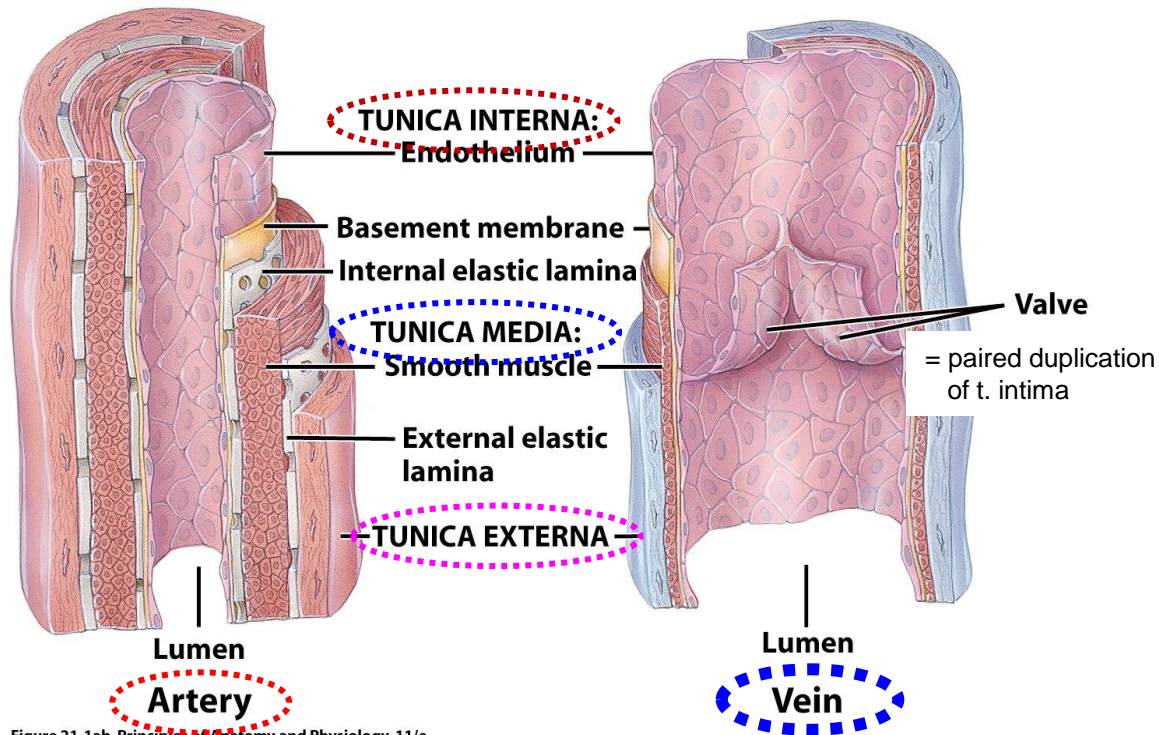
Microvasculature – <0.1 mm



Capillaries
Anastomosing tubules among arteries and veins
= microvascular bed

Veins – capacitance vessels

- they function as blood reservoir - greater capacity for blood containment than arteries due to **thinner wall**
- **lower blood pressure** (10 mm Hg with little fluctuation)
- **valves aid skeletal muscles in upward blood flow** (typically in lower limbs – veins with diameter > 2 mm)



General features

Endothelium

- very thin

Subendothelial layer

- very thin

Internal elastic lamina

- missing or only very thin

- relatively thin (except for lower limbs)
- Little bundles of smooth muscle cells
- collagen fibers – considerable amount

External elastic lamina

- non-developed

- well developed – thickest layer
- often with longitudinally arranged bundles of smooth muscle cells
- robust vasa vasorum (often penetrate deep to t. media)

Three layered building plan

Veins – Categories according to their diameter

Postcapillary venules

- endothelial cells + some pericytes
- receive blood from capillaries
- more porous than capillaries
- larger diameter than capillaries (15-20 μm)

Collecting & Muscular venules

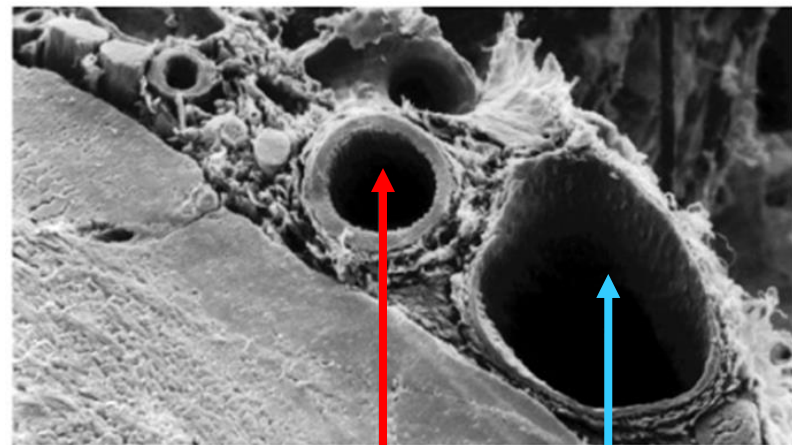
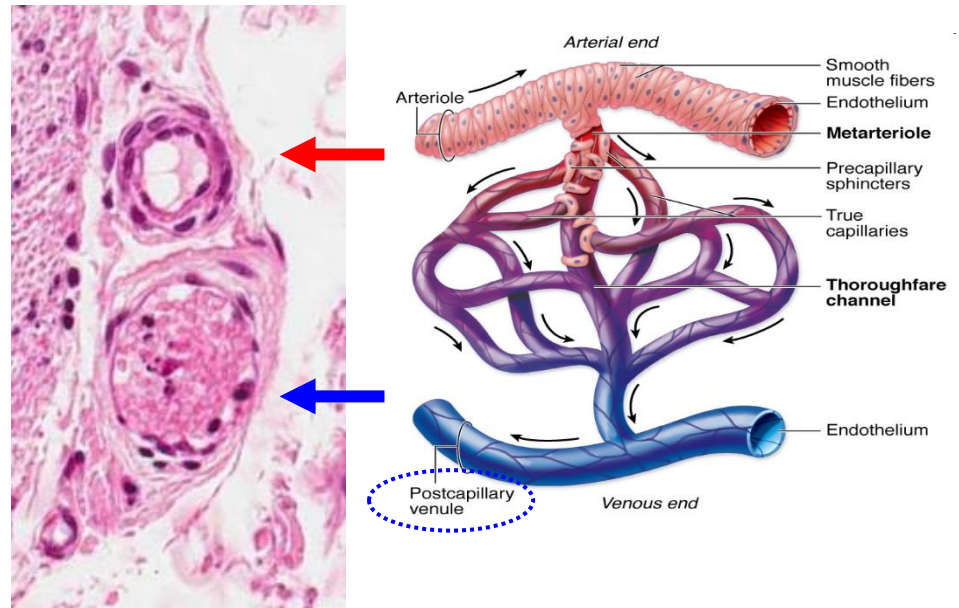
- increasing number of contractile cells
- tunica media is defined in muscular venules

Small- & Medium-sized veins

- most have individual names
- run parallel with corresponding arteries
- many have valves

Large veins

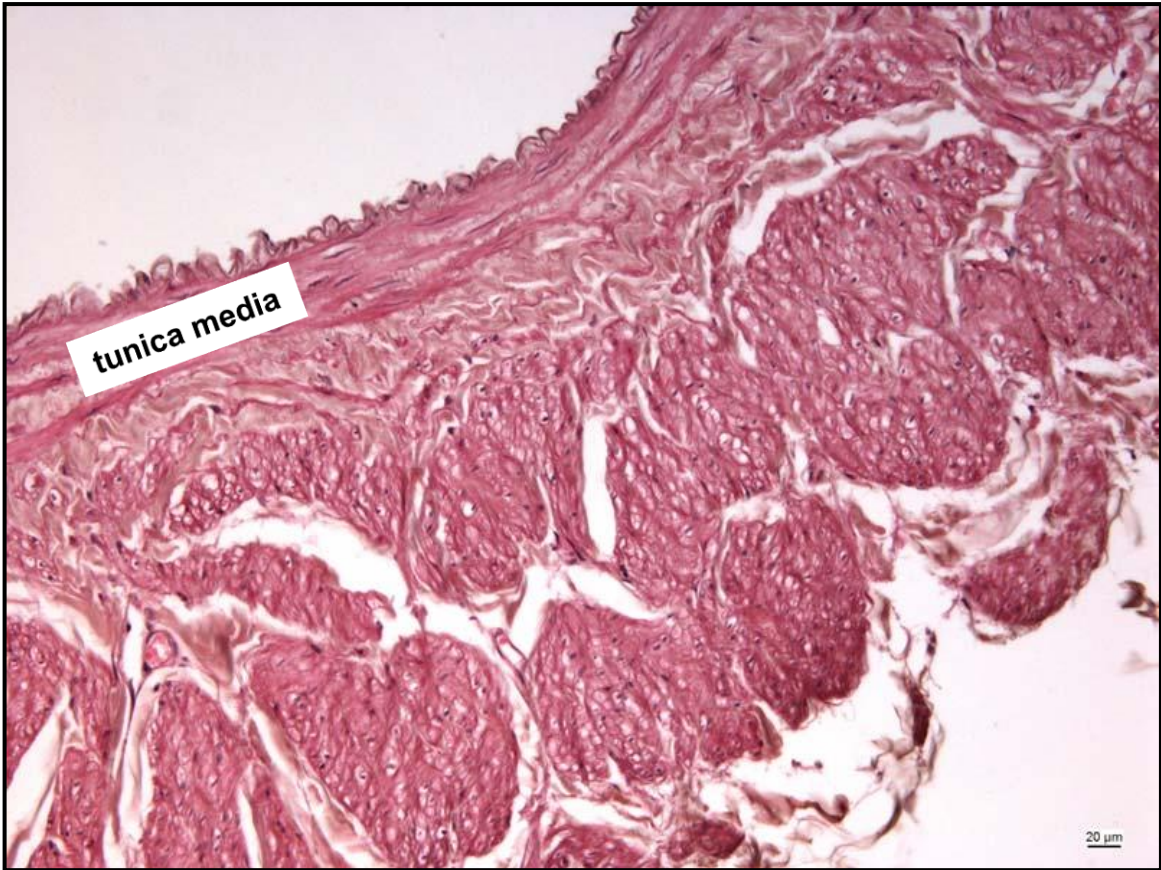
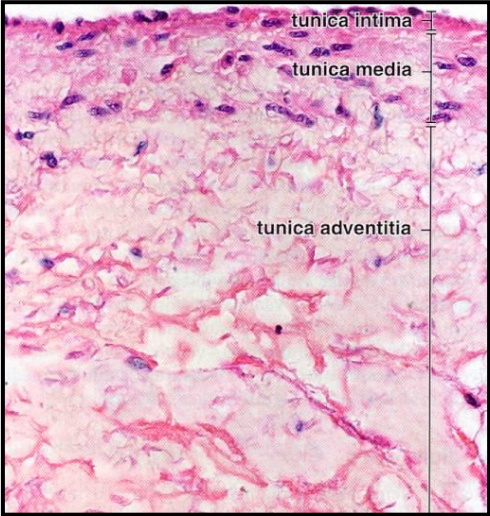
- close to the heart
- (*v. cavae, pulmonary veins, internal jugular veins*)
- paired with elastic arteries
- diameter > 10 mm
- with valves
- t. media is thin (muscle cells+connective tissue)
- thick t. externa (with longitudinal bundles of SMC; myocardial sleeves)



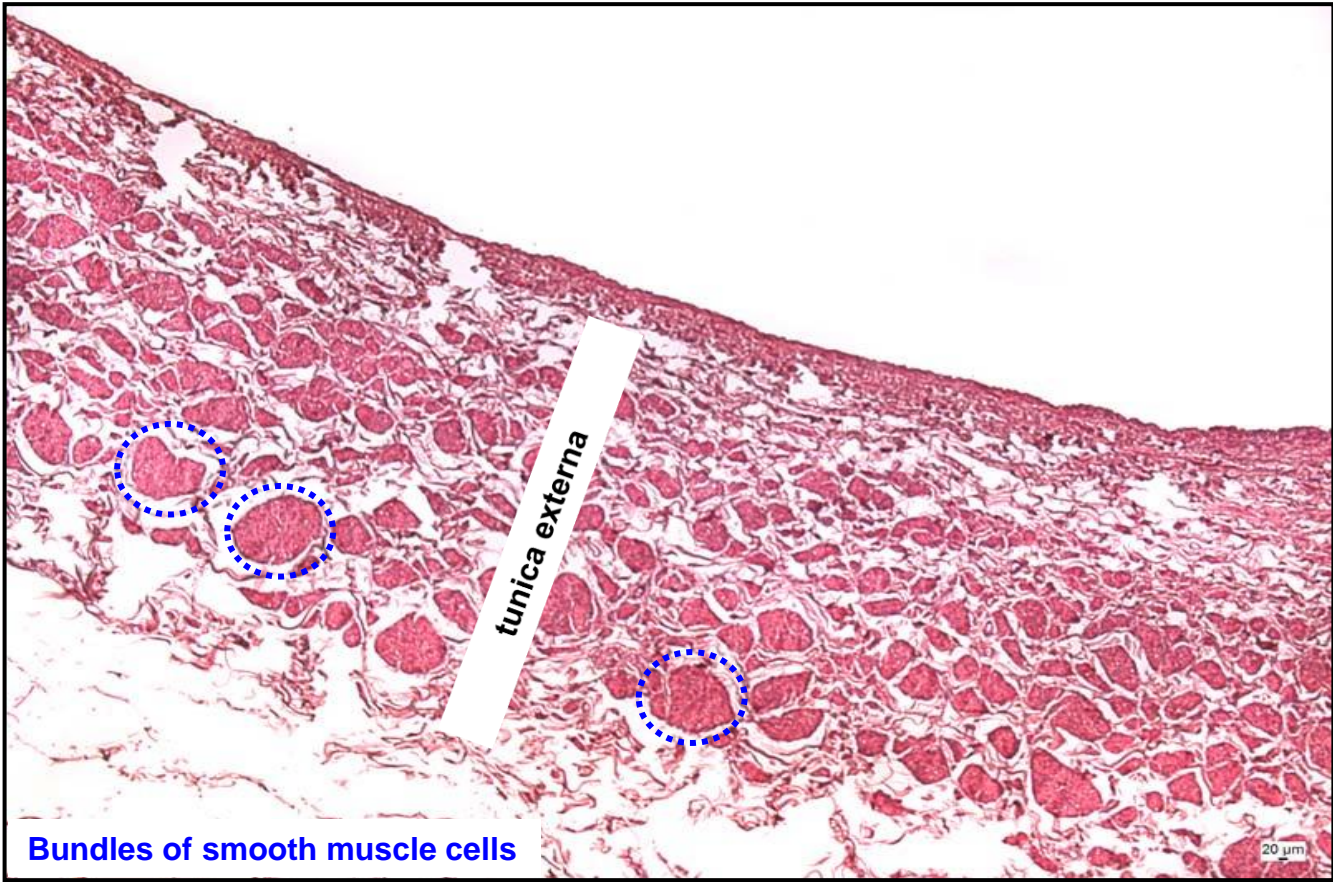
Artery

Vein

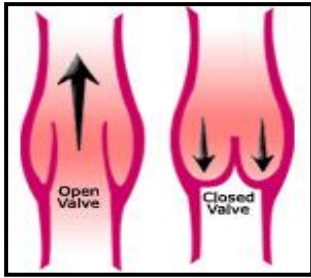
Veins – Middle-sized



Veins - Large



Vena cava

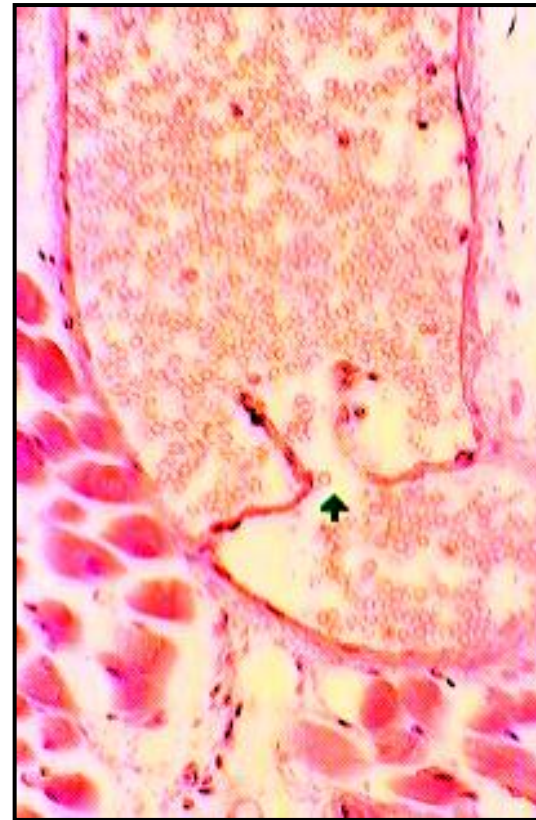


Veins – Valves

- bag-like protrusion of tunica intima, which prevent the blood flow from running to opposite direction
- only in the veins that has low position or far away from heart



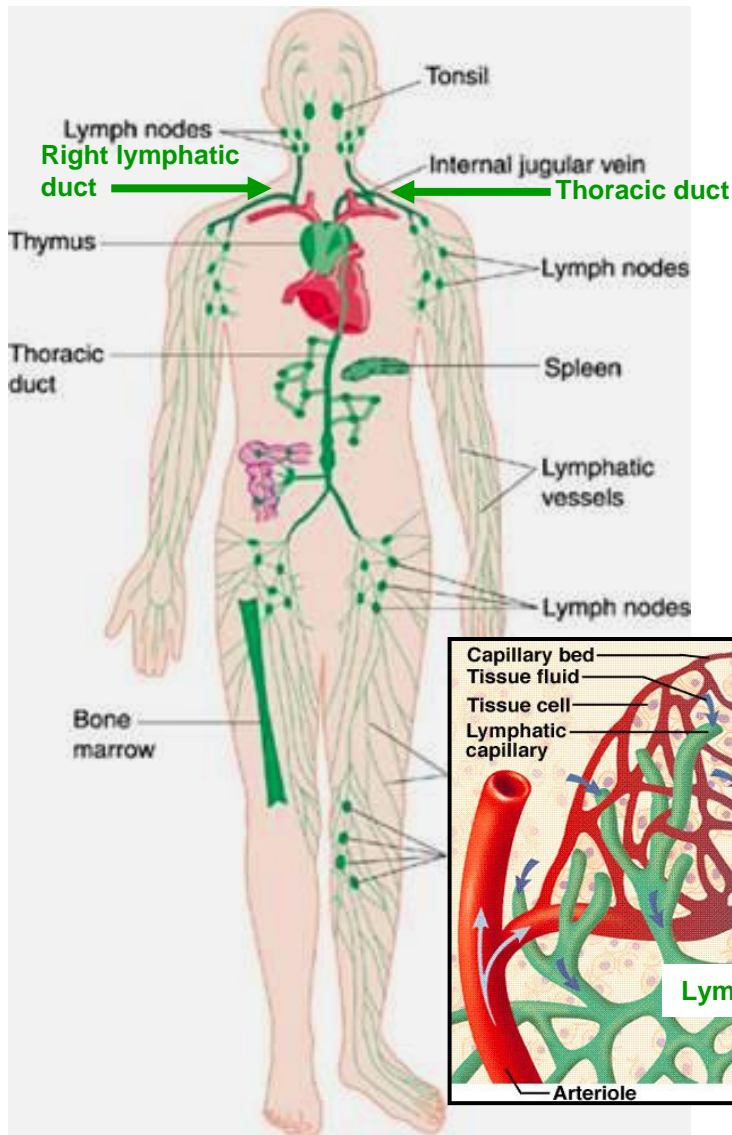
Appearance of internal surface



Histological view

Lymphatic vessels

- return fluid from tissues to the circulatory system
- depend on skeletal muscles to move fluid

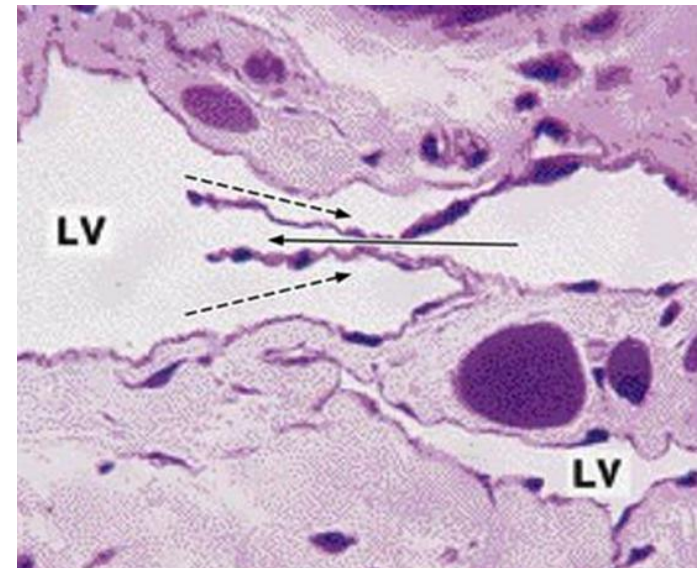
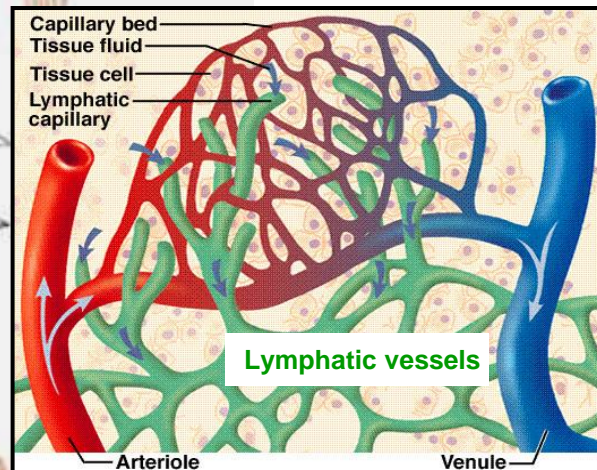


Lymphatic capillaries

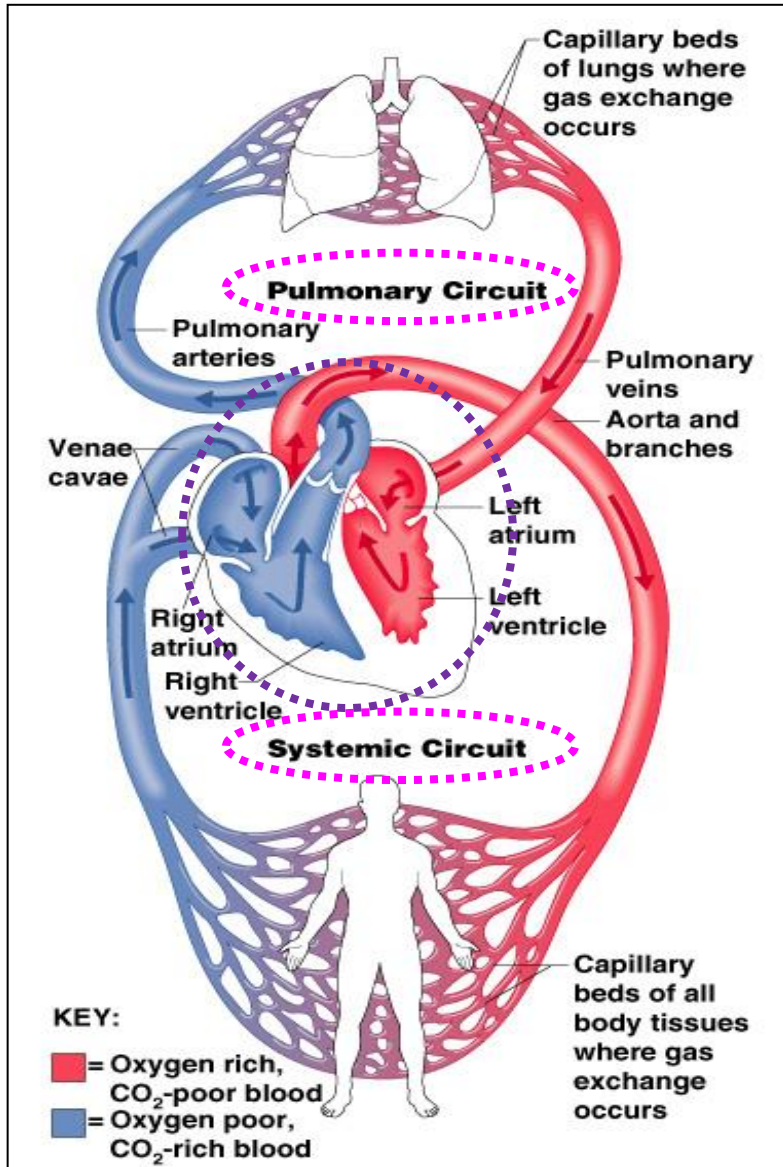
- blunt ended
- very simple structure
- endothelial cells + fine reticular fibres of circular orientation
- the basal lamina is not developed

Lymphatic vessels and ducts

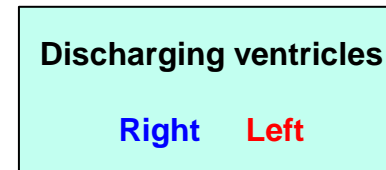
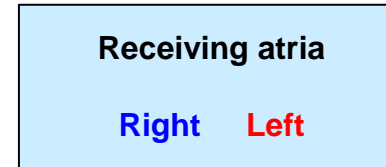
- thin walled tubes
- resemble veins in their structure (intima+media+adventitia)
- have valves



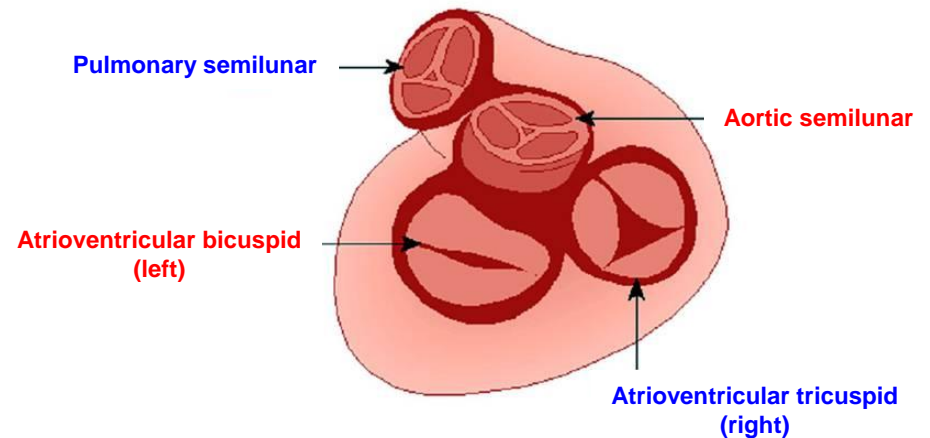
Heart - Anatomy



- a hollow organ that contracts rhythmically
- it functions as a pump
- it is composed of two sets of chambers:

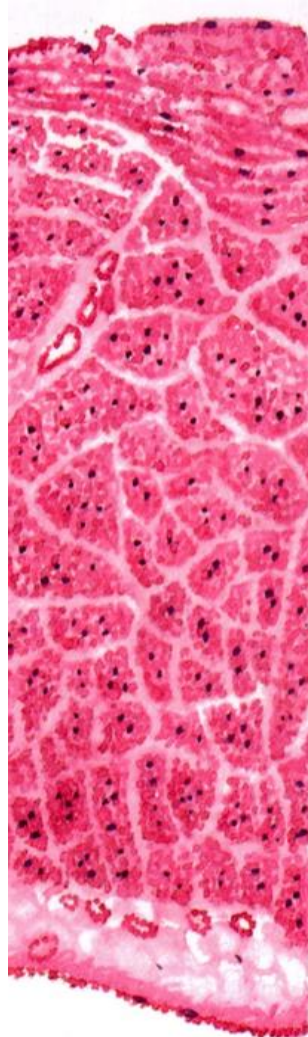


- it is equipped by four valves (blood can travel in only one direction)



Heart - Wall

inner surface



Endocardium

- endothelium
- subendothelial layer
- subendocardial layer

Myocardium

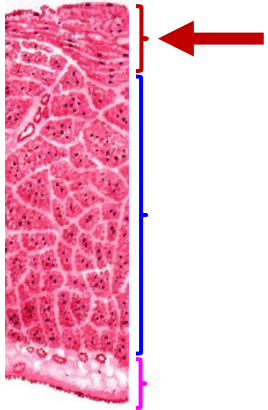
Epicardium

- mesothelium
- submesothelial layer

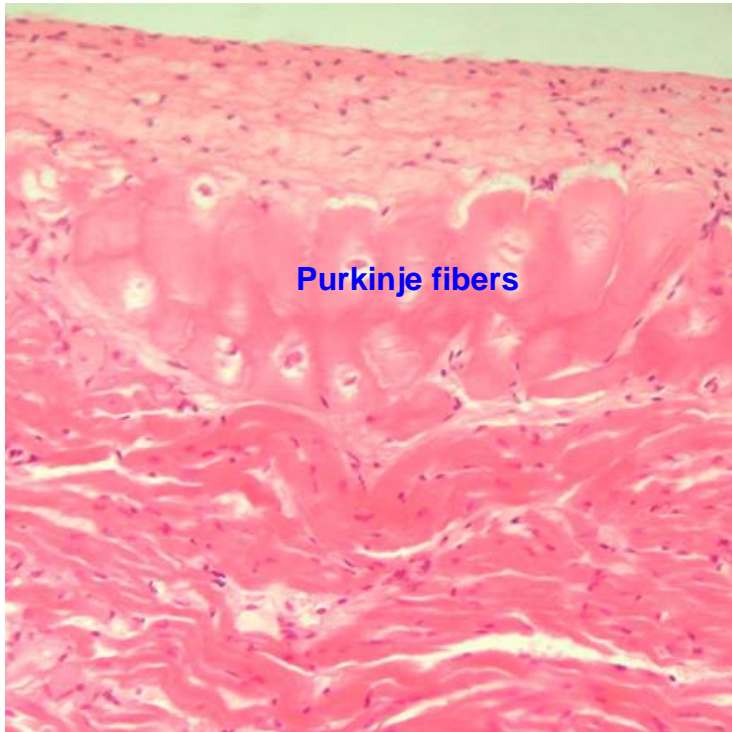
outer surface

inner surface

Heart - Endocardium



- is continuous with the tunica intima of the large vessels entering and leaving the heart
- the endocardium of the left half of the heart is not continuous with the one on the right half as it is separated by a heart septum
- valves are derivatives of endocardium



Purkinje fibers

Endothelium

- with continuous basal membrane

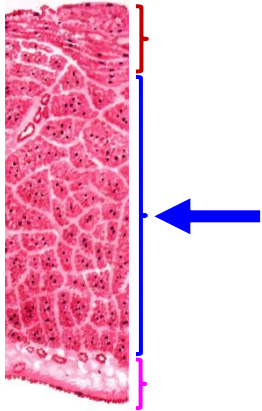
Subendothelial layer

- connective tissue
- collagen, elastics, solitary smc, small blood vessels, nerves

Subendocardial layer

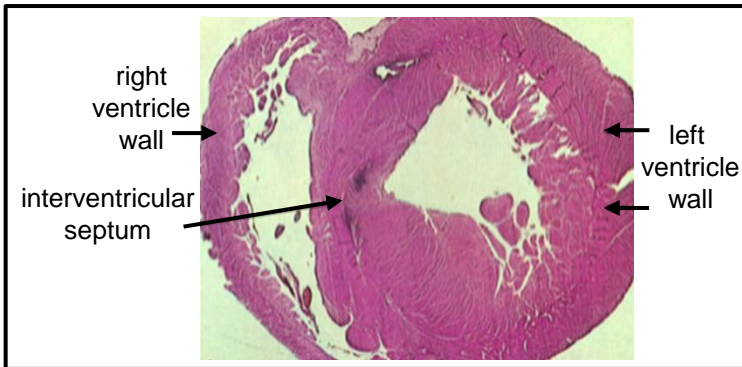
- loose connective tissue
- continuous with endomysium of the myocardium
- nerve fibers, vessels, **impuls-conducting system**

inner surface

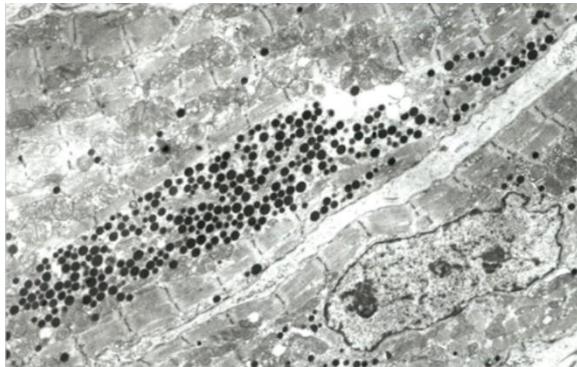


Heart - Myocardium

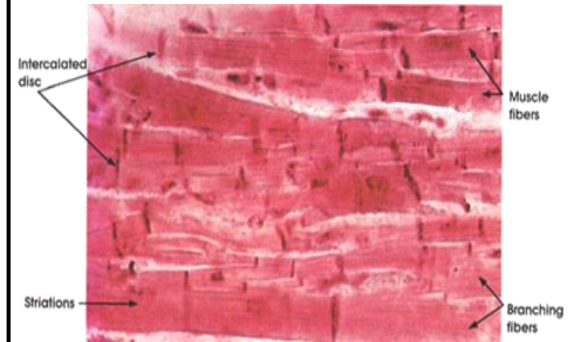
- its thickness varies in different parts (thickest – left ventricle; thin in atria)
- has rich blood supply (many capillaries)
- has no regenerative capacity
- muscle fibers are arranged circularly around chambers
- masses of connective tissue in between the muscles – **cardiac skeleton** (anuli fibrosi in valves, trigonum, septum membranaceum)



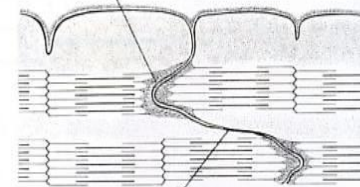
Atrial natriuretic peptide
(endocrine function of contractile cells; acts on kidney)



Intercalated discs

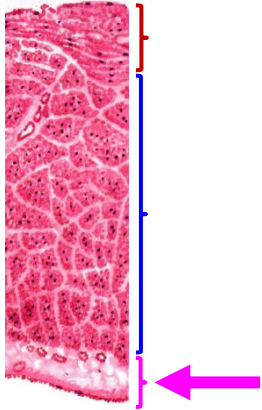


Transverse portion (myofibrillar junctions, desmosomes, and gap junctions)



Longitudinal portion (contains large gap junctions)

inner surface



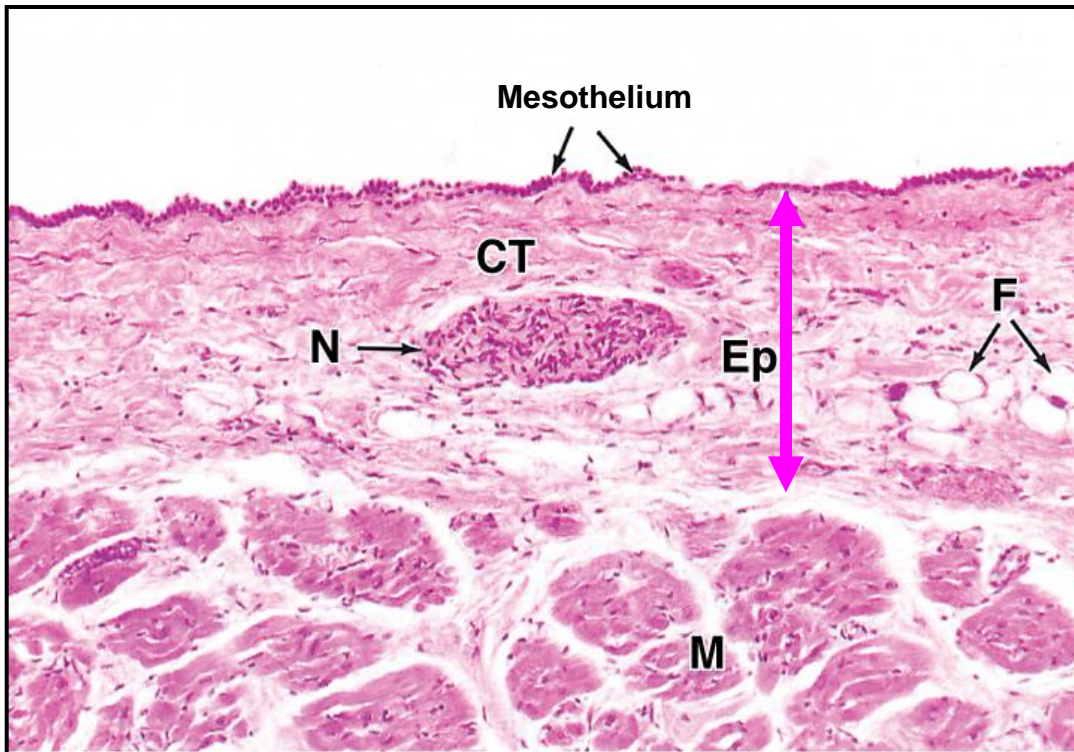
Heart - Epicardium

- represents visceral layer of the **pericardium**

Pericardium

Fibroserous sac enveloping heart

- mesothelium with basal lamina (faces epicardium)
- fibrous layer (dense connective t. with vessels and nerves)



Mesothelium

- simple squamous epithelium
- basal lamina
- secretes pericardial fluid

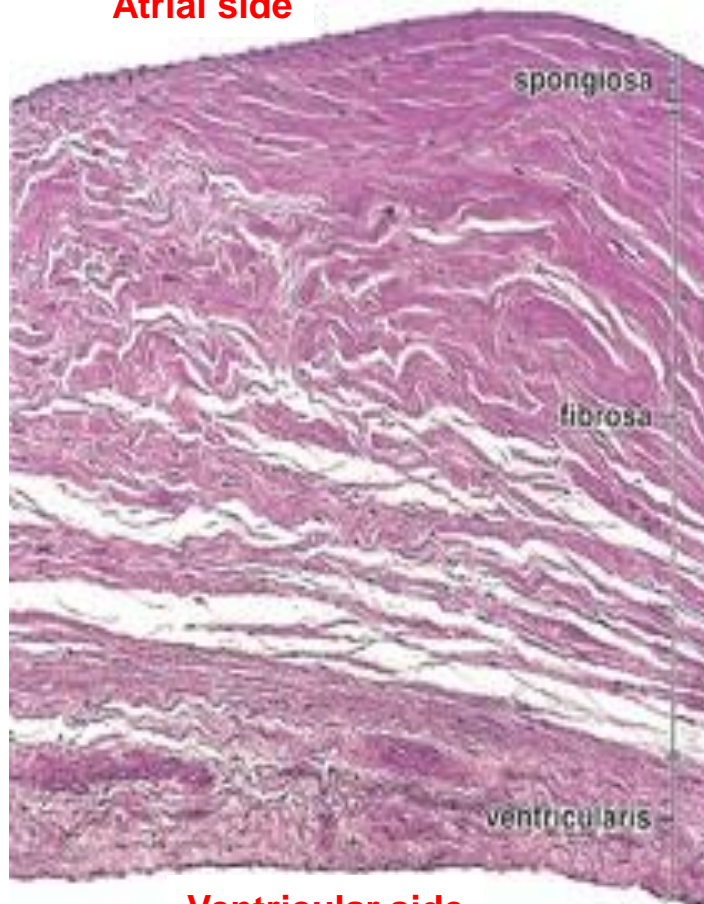
Submesothelial layer

- loose connective tissue
- elastic fibers
- nerves
- blood and lymphatic vessels
- home of coronary vessels
- adipocytes (high in obese individuals)

Heart - Valves

- composed of connective tissue layers covered by **endothelium on each side**

Atrial side



Ventricular side

Spongiosa

- loose collagen

Fibrosa

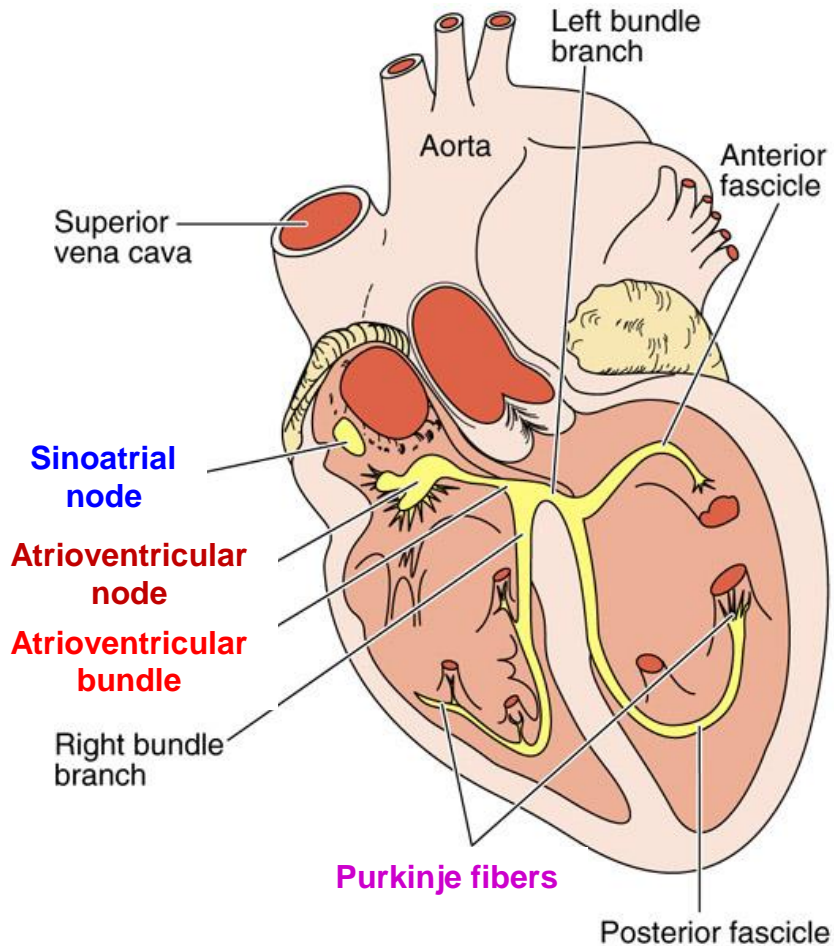
- dense core of connective tissue

Ventricularis

- dense connective tissue with many elastic and collagen fibers

Heart – Conducting system

- **specialty modified cardiac muscle cells** (non-contracting, less myofibrils, abundant GA junctions)
- **generate and conduct impulses of heart contraction to various parts of myocardium**
- **assure proper succession of beat of atria and ventricles**



Sinoatrial node (node of Keith-Flack)

- it lies on the medial wall of the right atrium near the entrance of the superior vena cava
- **PRIMARY PACEMAKER**

Atrioventricular node (node of Aschoff and Tawara)

- it runs on the right side of the interatrial septum
- **SECONDARY PACEMAKER**

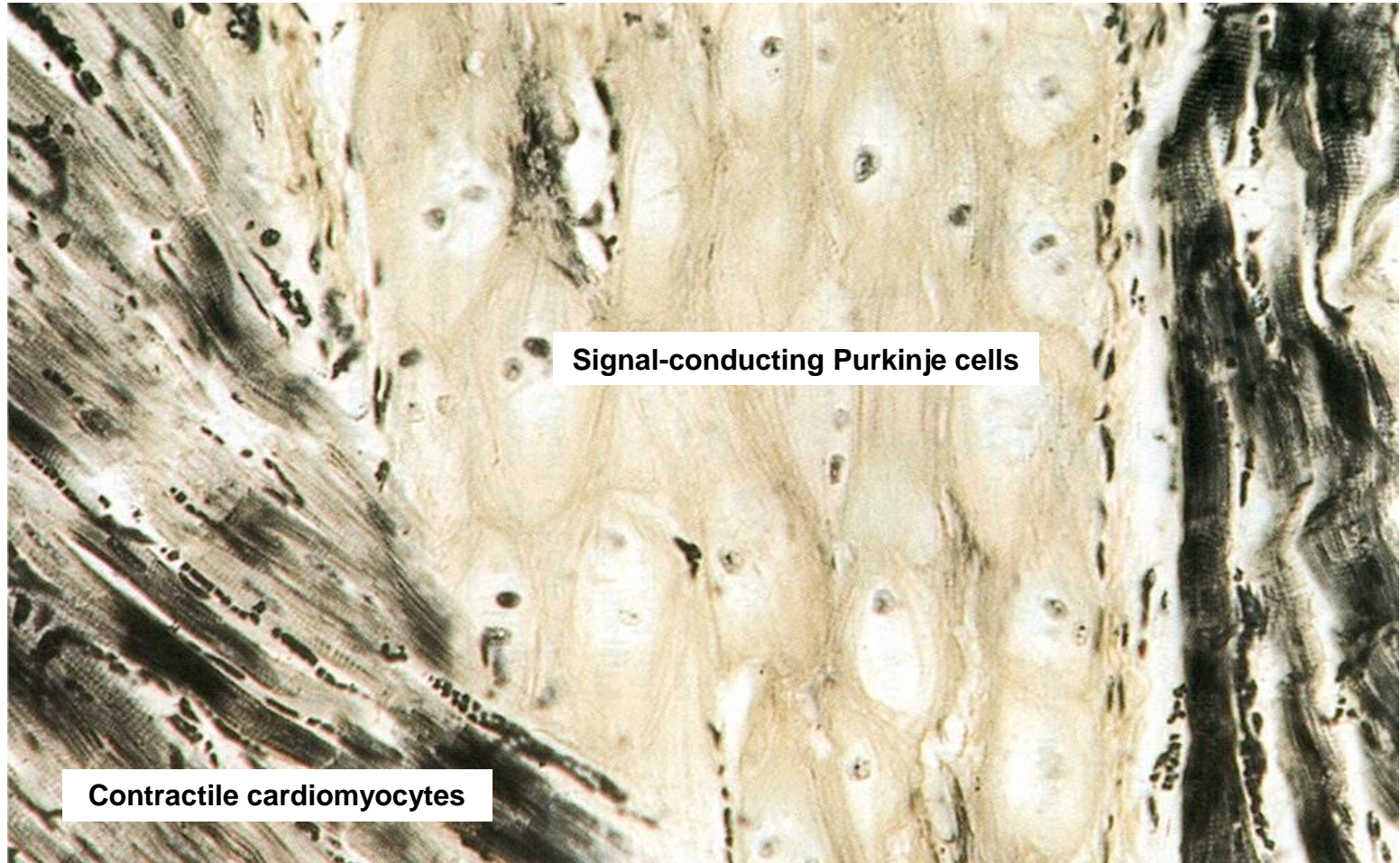
Atrioventricular bundle (bundle of His)

- it divides into 2 branches (for the left and right ventricles)

Purkinje fibres

- terminal ramifications of the AV bundle

Heart – Conducting system

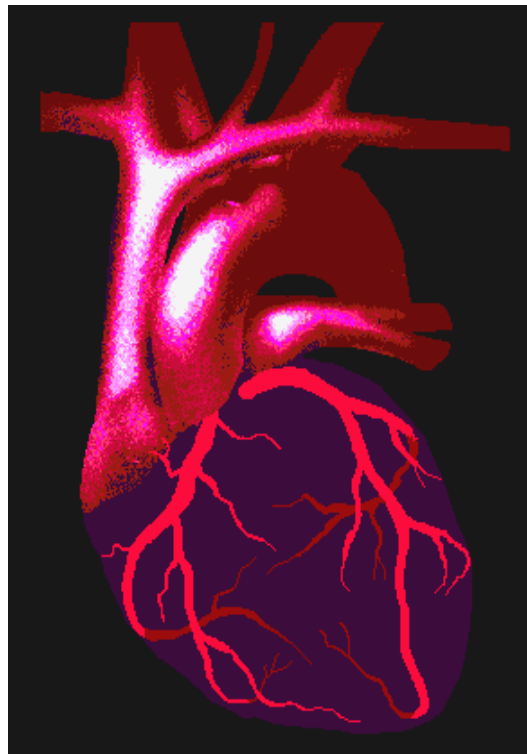


Signal-conducting Purkinje cells

Contractile cardiomyocytes

Heart – Coronary circulation

- blood in the heart chambers does not nourish the myocardium
- the heart has its own nourishing circulatory system: Coronary **arteries** & **veins**
- 5-7% of blood flows through the coronary arteries
- blood empties into the right atrium via the coronary sinus



Thank you for your attention !

**Questions and comments at:
ahampl@med.muni.cz**