

# Lecture 12

## Cardiovascular system

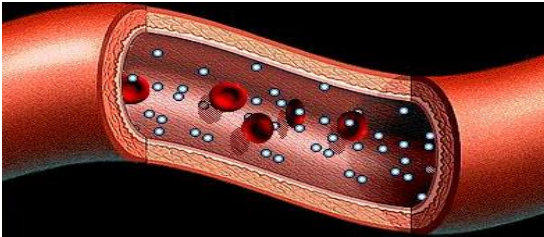
- Overall concept of blood circulation
- Vessels
- Arteries
- Microcirculation
- Veins
- Lymphatics
- Heart

Brno, May 2021

# Cardiovascular system = part of circulatory system

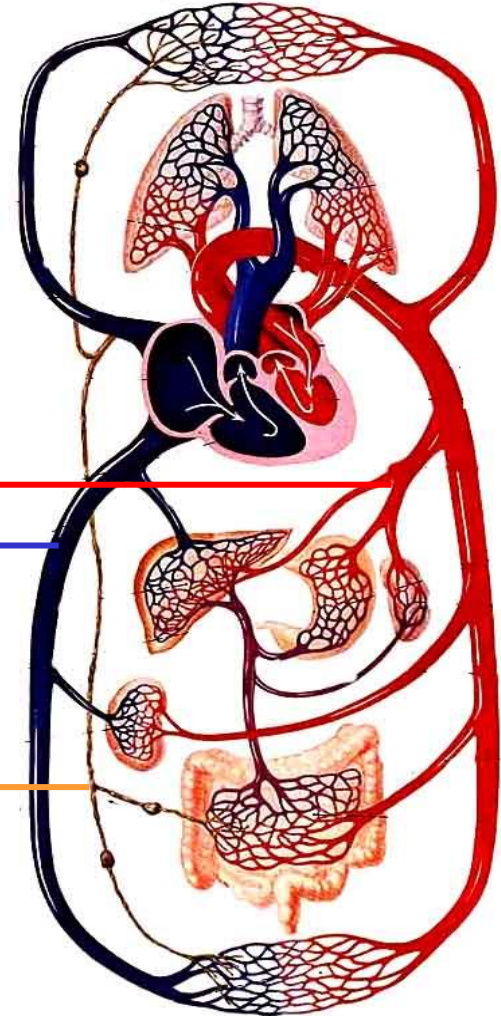
**Circulatory s. = Closed tubular system**

(carries fluids (blood, lymph) in tubes)



**Blood cardiovascular**

**Lymphatic vascular system**

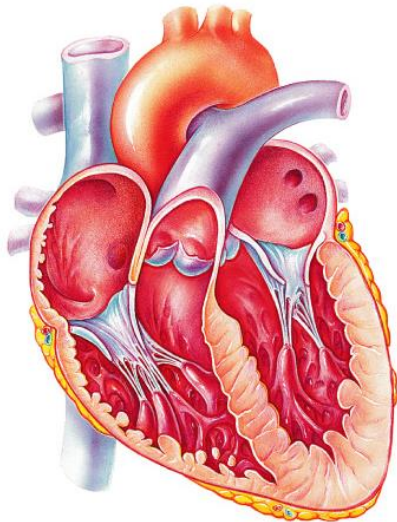


# Cardiovascular system – overall composition

## 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

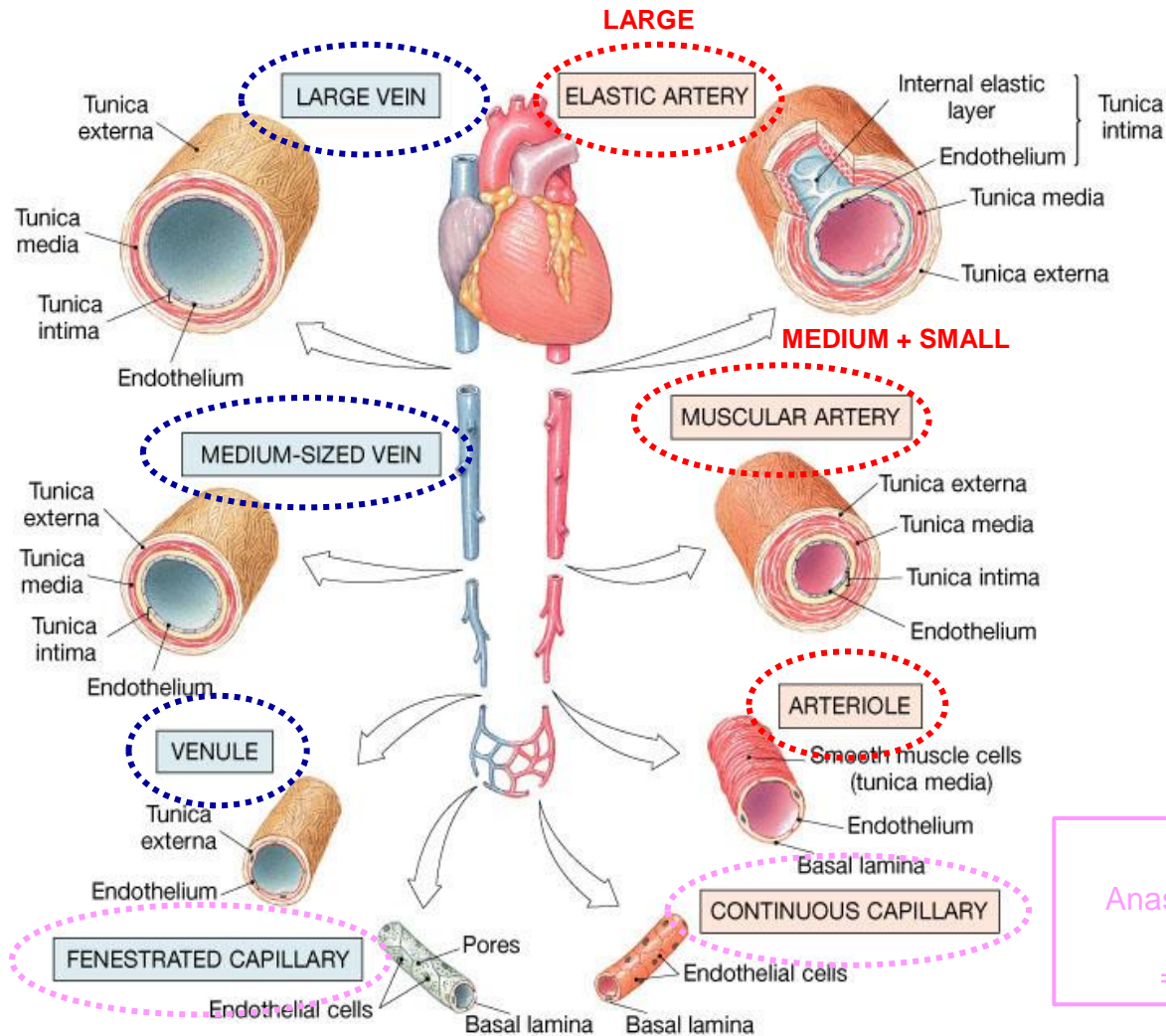
**ALWAYS** return the blood to the heart  
(contain about 2/3 body's blood at any given time)

## Arteries

**ALWAYS** carry blood from the heart to the periphery

Macrovasculature – diameter >0.1 mm

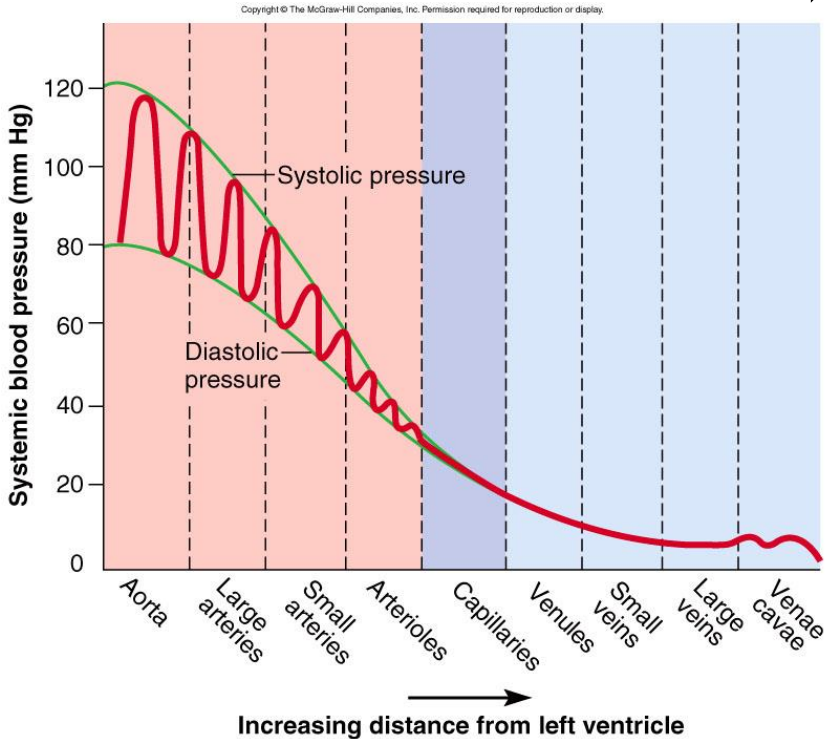
Microvasculature – <0.1 mm



**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

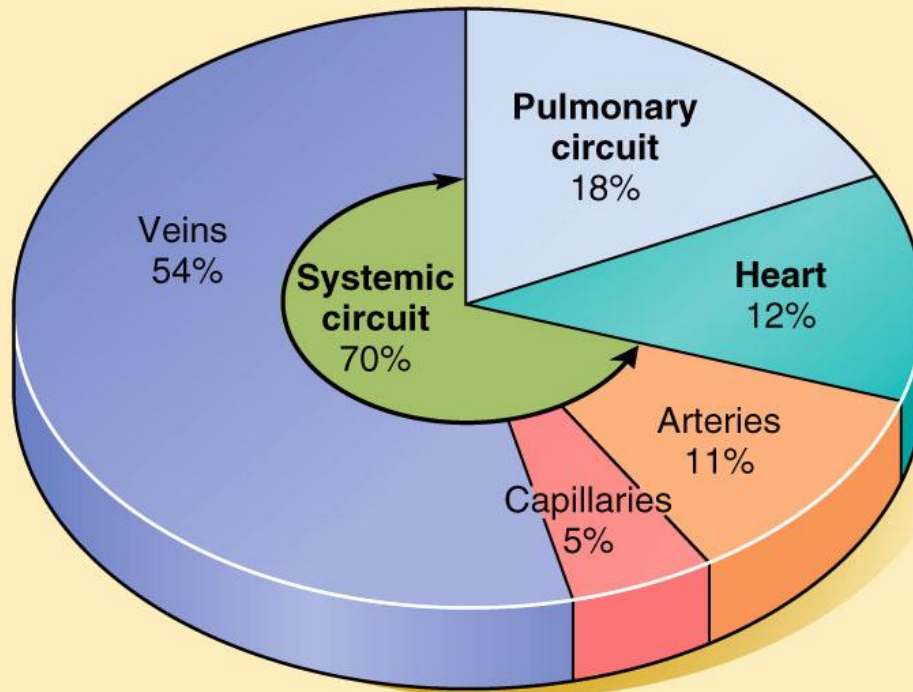
### At ventricular diastole:

- 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



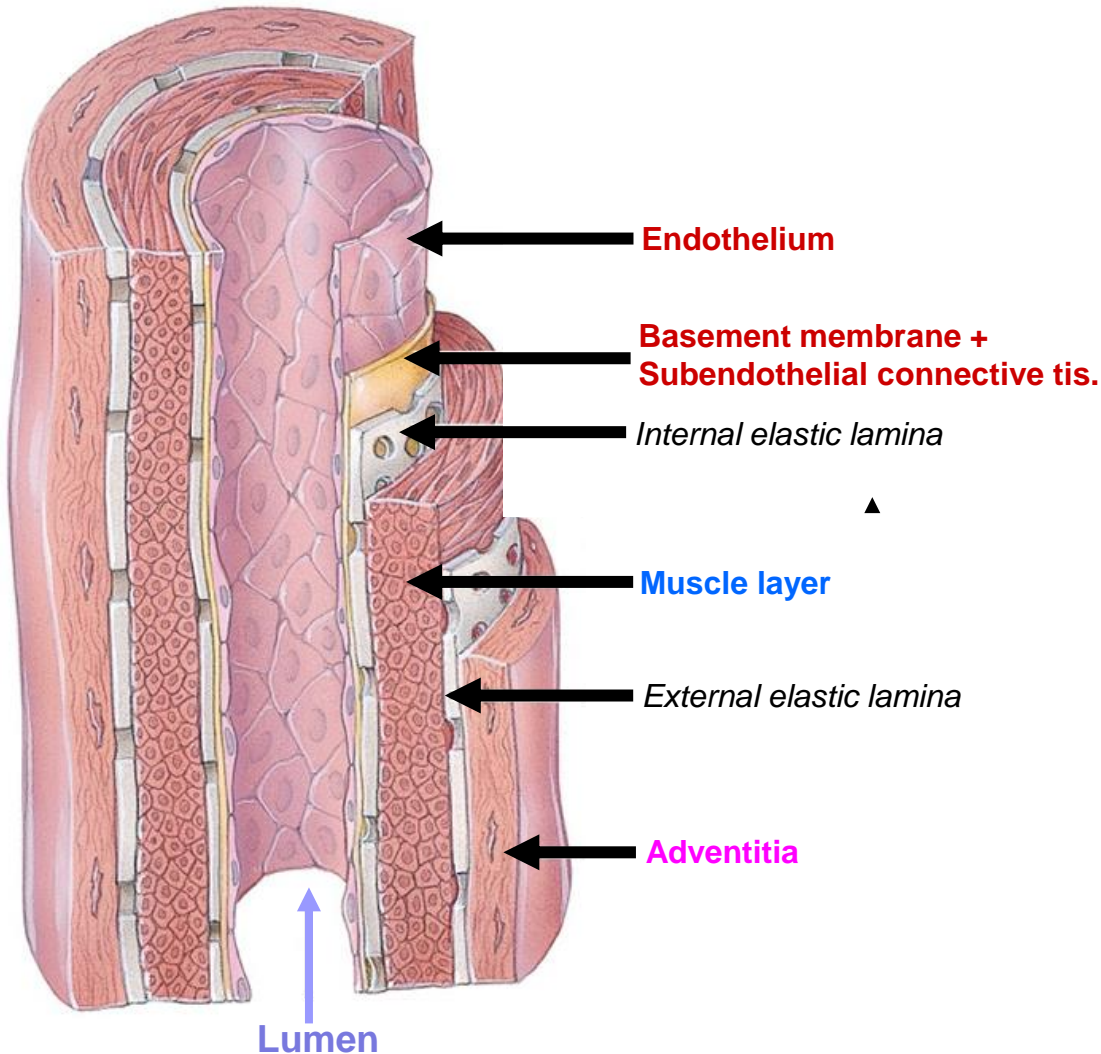
### 65 – 70% in veins

- Reservoir
- Lumens are larger than in corresponding arteries

### Capillaries

~ 100 thousand km (estimate)  
&  
only 5% of blood volume  
&  
largest surface area (~ 600 m<sup>2</sup>)  
&  
most of the cells are no farther than 50  $\mu$ 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  $\mu\text{m}$ )
- 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)*

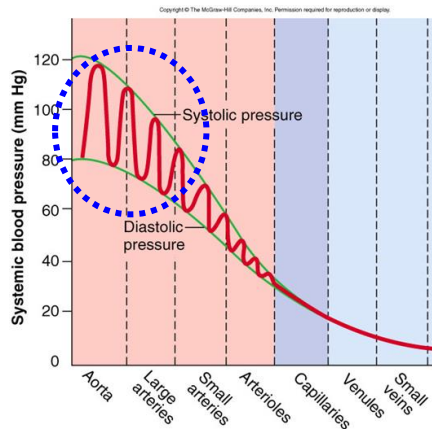
**Medium-sized = distributing = muscular artery** ( $D > 1 \text{ mm}$ )

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

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

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





## Large = elastic = conducting arteries

### Conducting

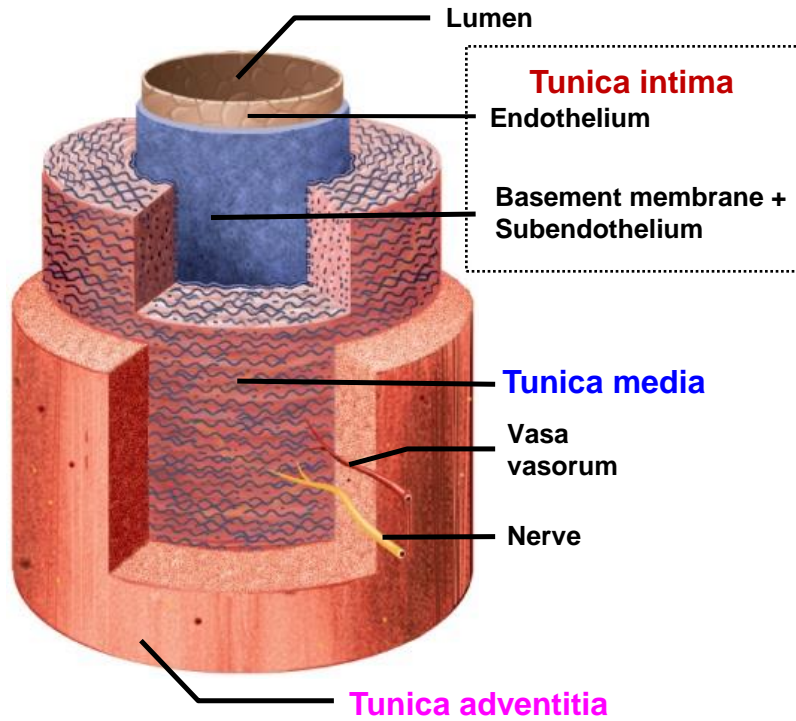
- their major function is to transport blood away from the heart

### 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**

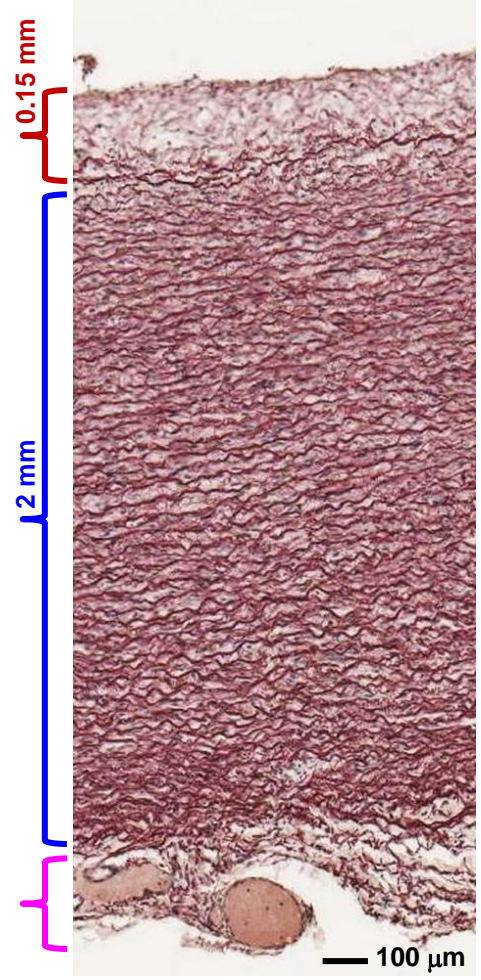
- loose connective tissue
- contains many fine longitudinal elastic fibres - these gradually merge into the elastic components of t. media
- some smooth muscle cells near the boundary with t. media - longitudinally arranged
- place of atherosclerotic changes

**Internal elastic lamina**

- not clearly demarcated

- elastic fibers arranged circularly as discontinuous fenestrated membranes about 2.5  $\mu\text{m}$  thick - about 50 lamellae
- smooth muscle cells - circularly oriented, interspersed between elastic membranes

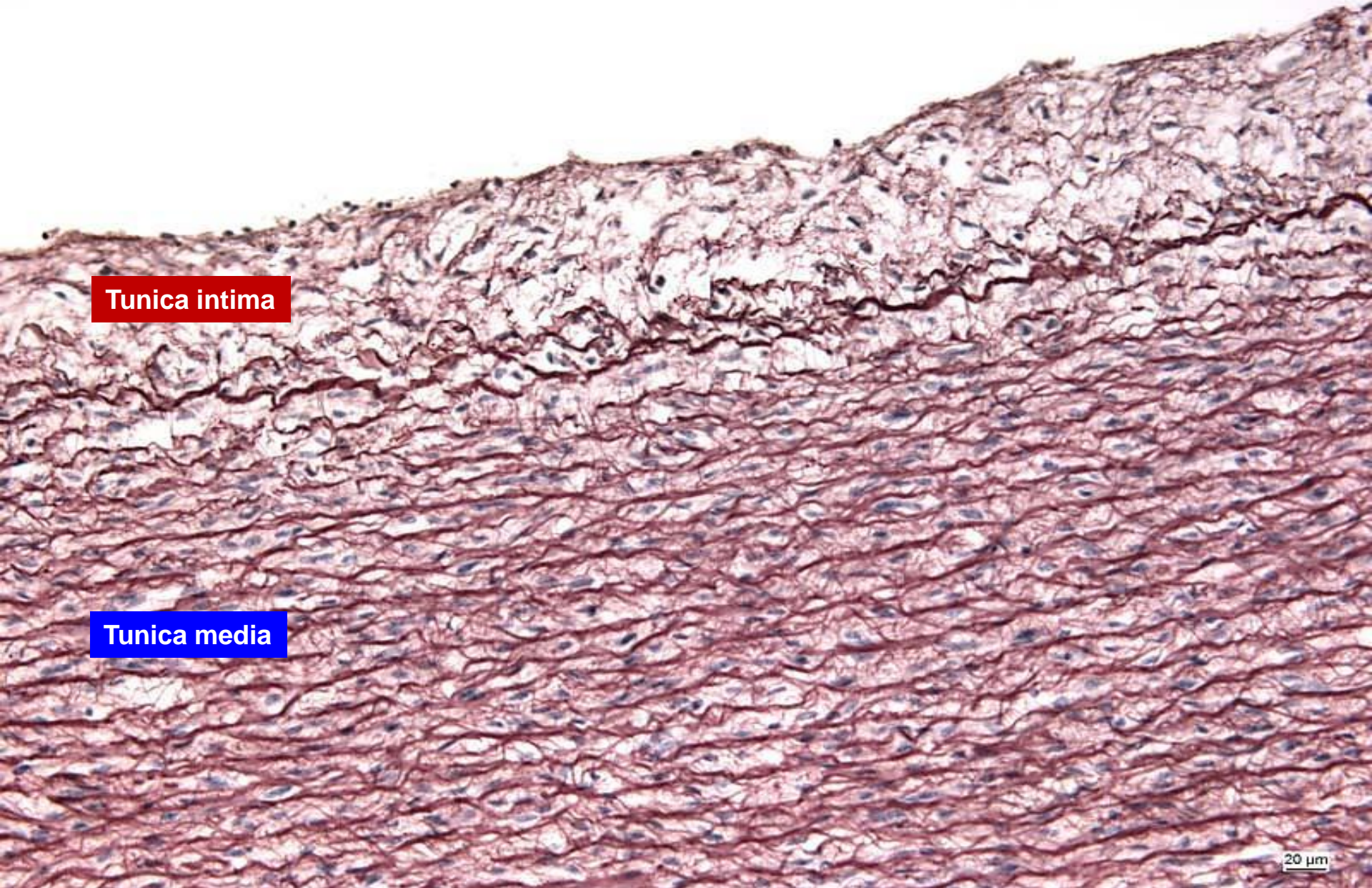
- relatively thin
- loose connective tissue
- some elastic fibers – longitudinally arranged, next to the t. media
- vasa vasorum and lymphatics (some into t. media)
- nerves



# Large = elastic = conducting arteries

Tunica intima

Tunica media

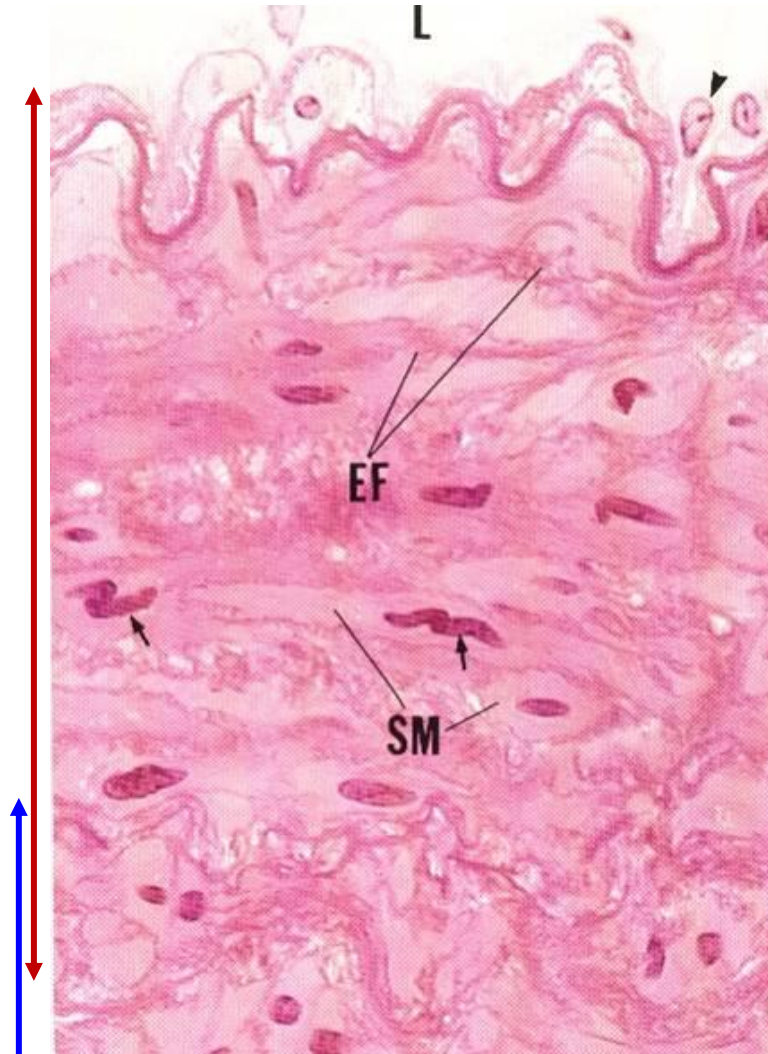


# Large = elastic = conducting arteries

Monkey  
H & E  
x540

Tunica intima

Tunica media

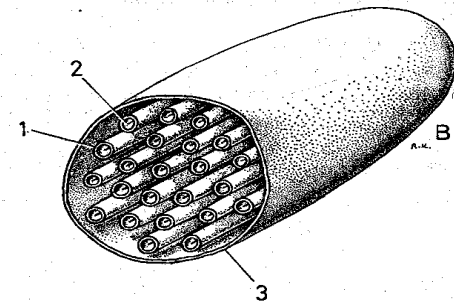
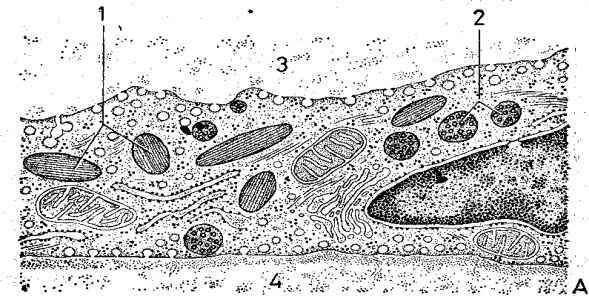


transition

# 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

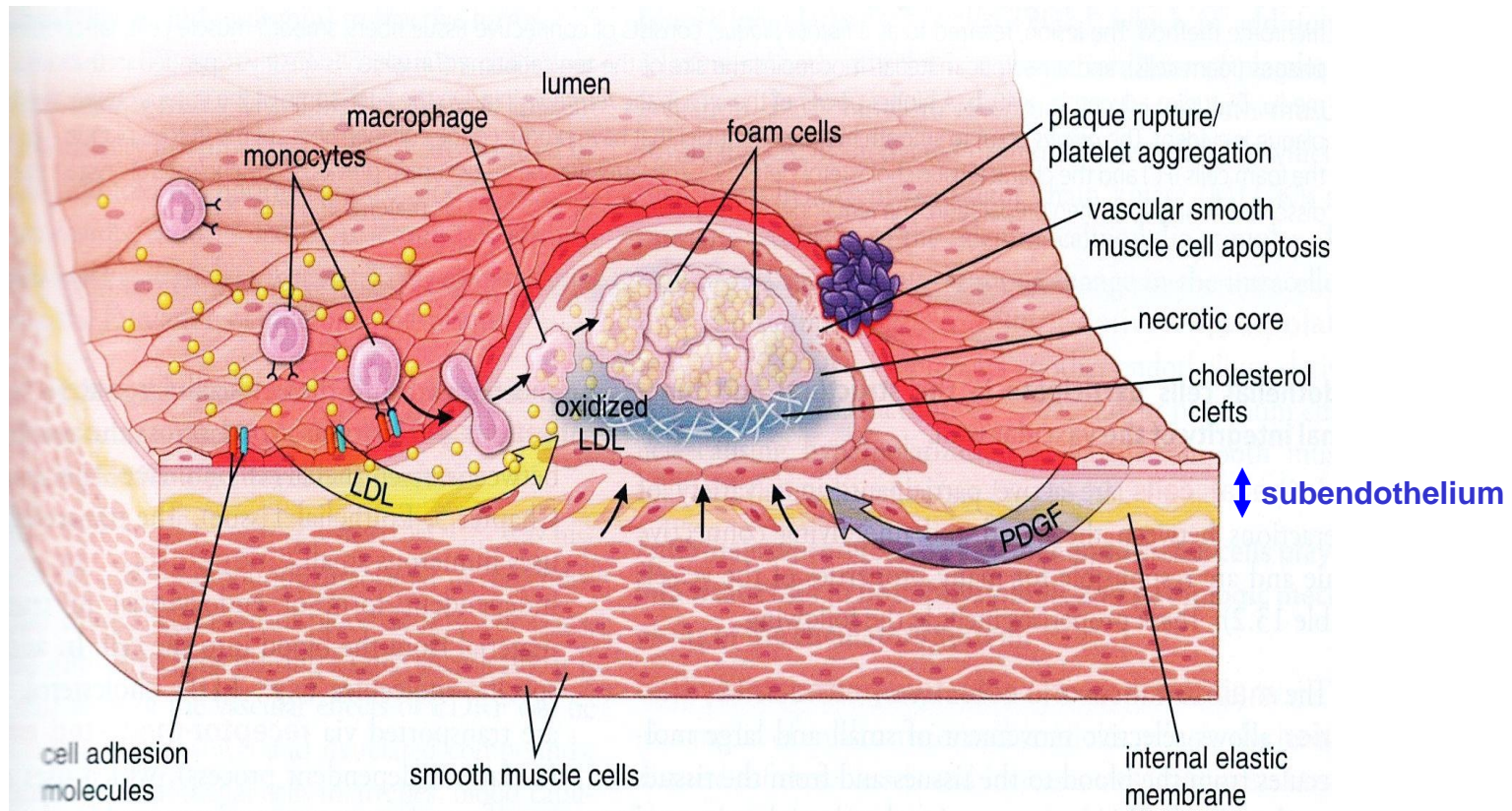
**Endothelial injury**  
(upon predisposing factors)

**Production of ROS**

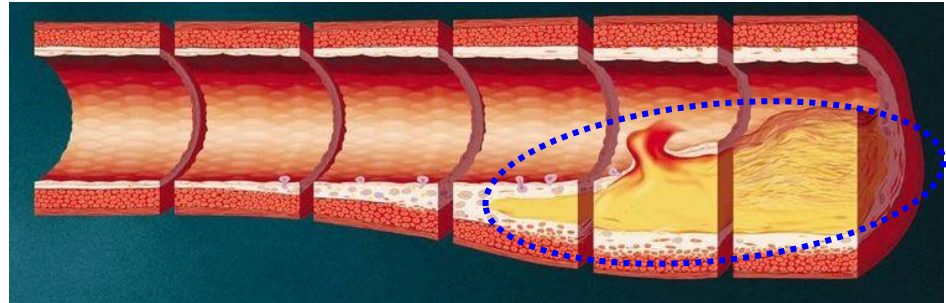
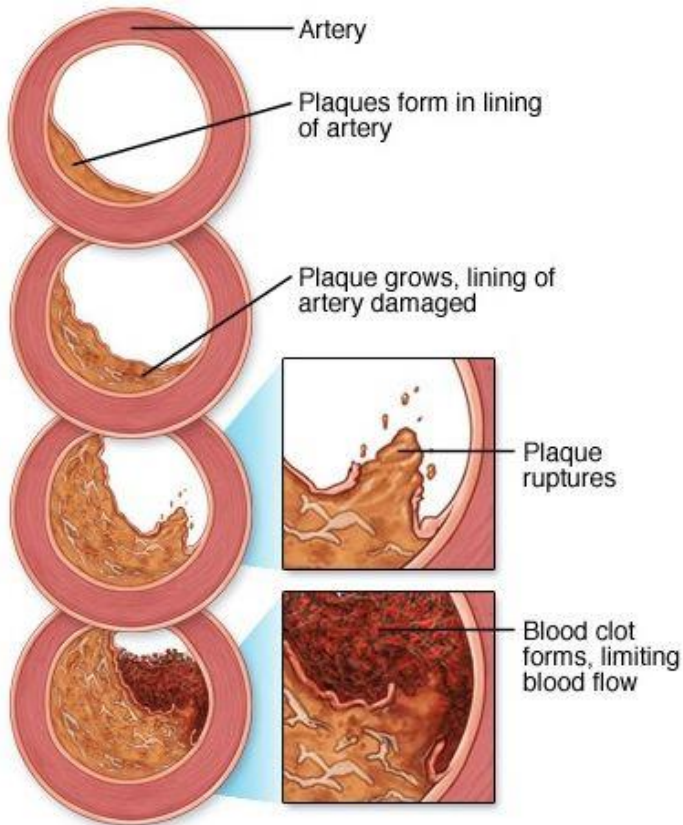
**Oxidizing of LDL**

**Entry of monocytes**  
(conversion to foam cells)

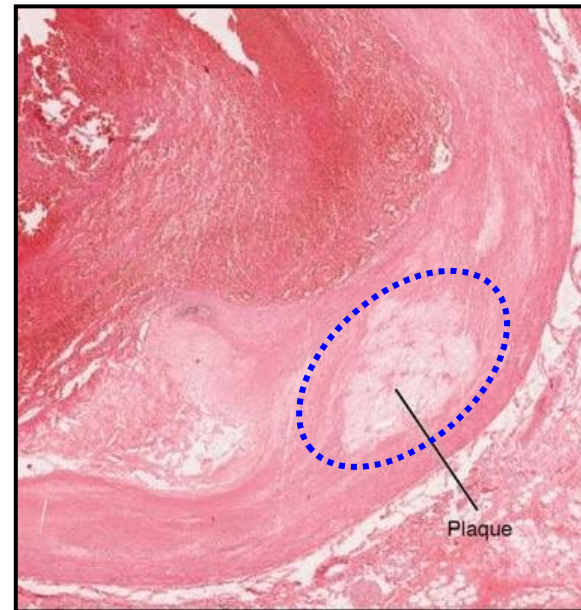
**Plaque formation**  
(necrosis + lipid accumulation)



# Arteries - Atherosclerotic changes



Atheromatous plaque



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Artery clogging

# Muscular arteries = distributing arteries

## Distributing

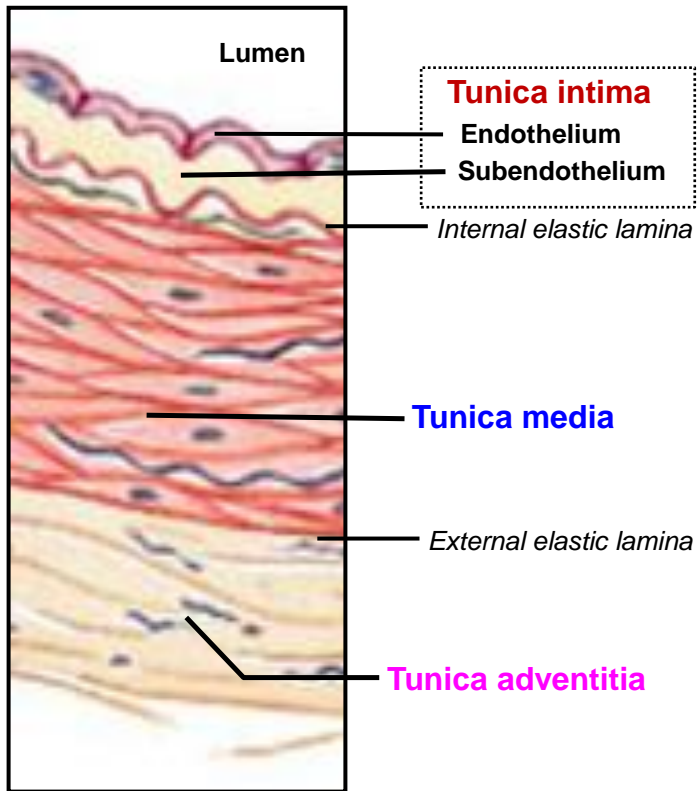
- distribute blood to specific destinations/organs
- size varies from centimeter down to just visibility by unaided eye

## 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

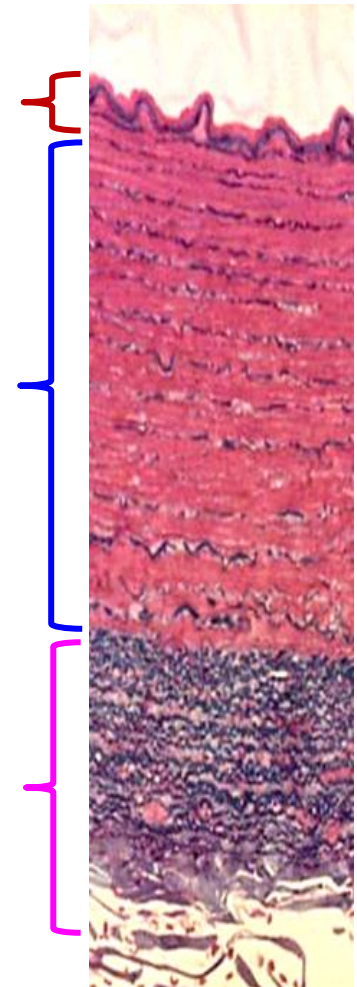
- well developed

- 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)

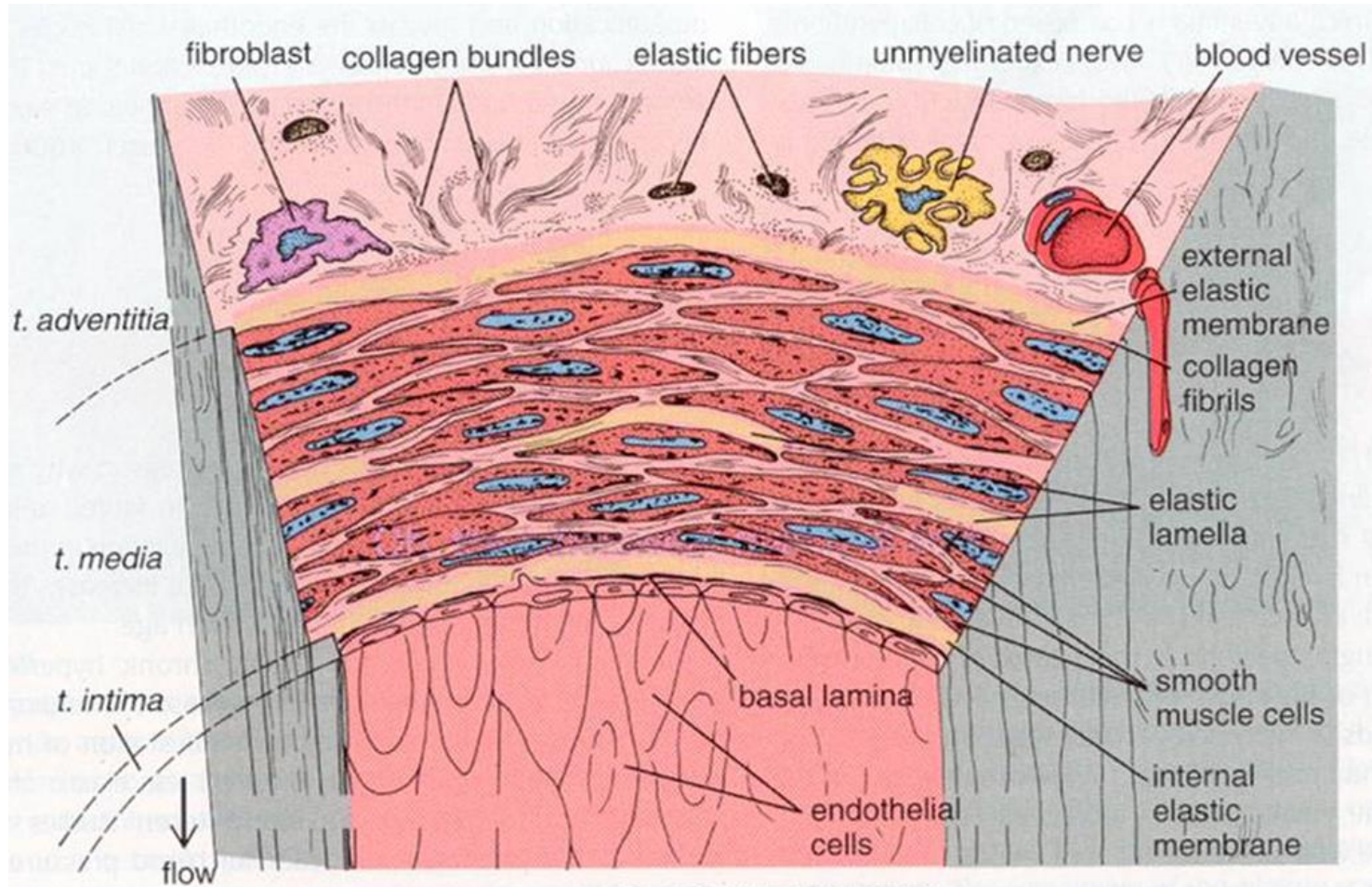
## External elastic lamina

- 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

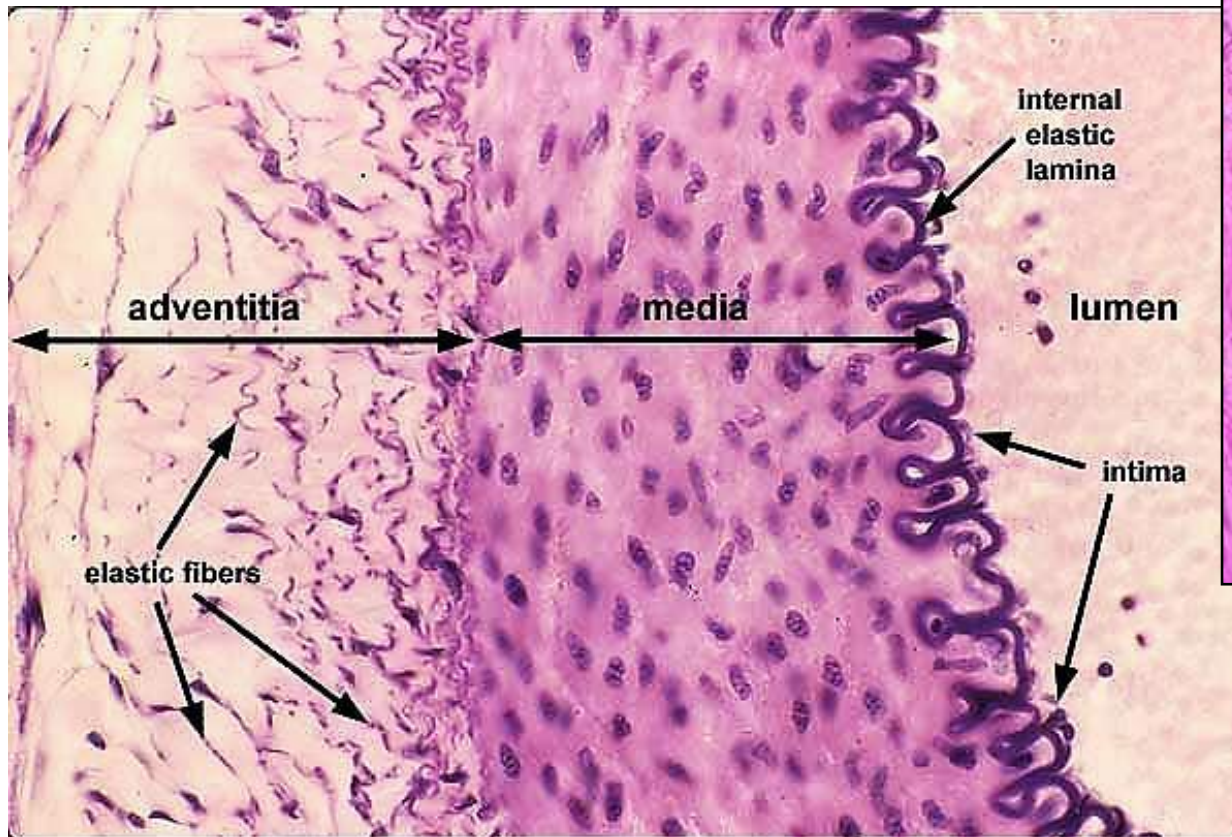


# Muscular arteries = distributing arteries

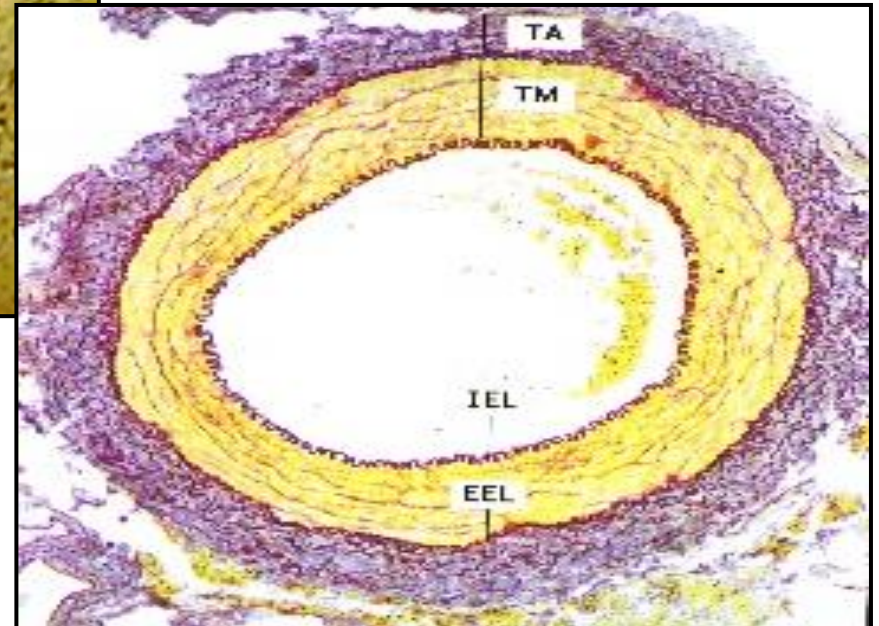
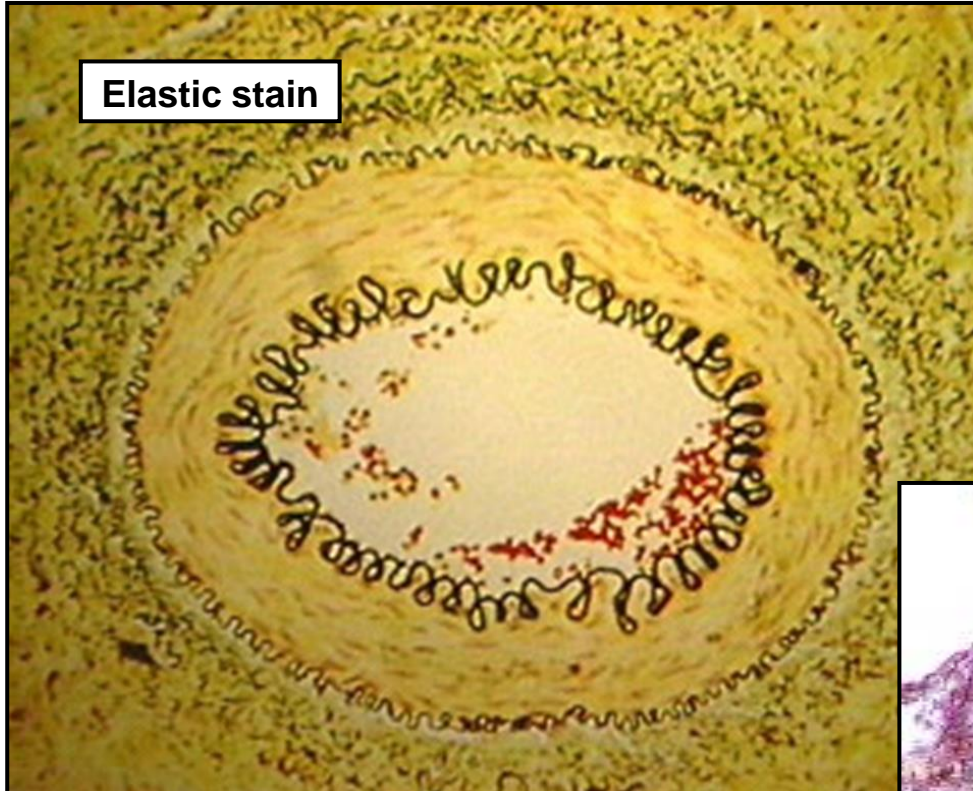


# Muscle arteries = distributing arteries

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

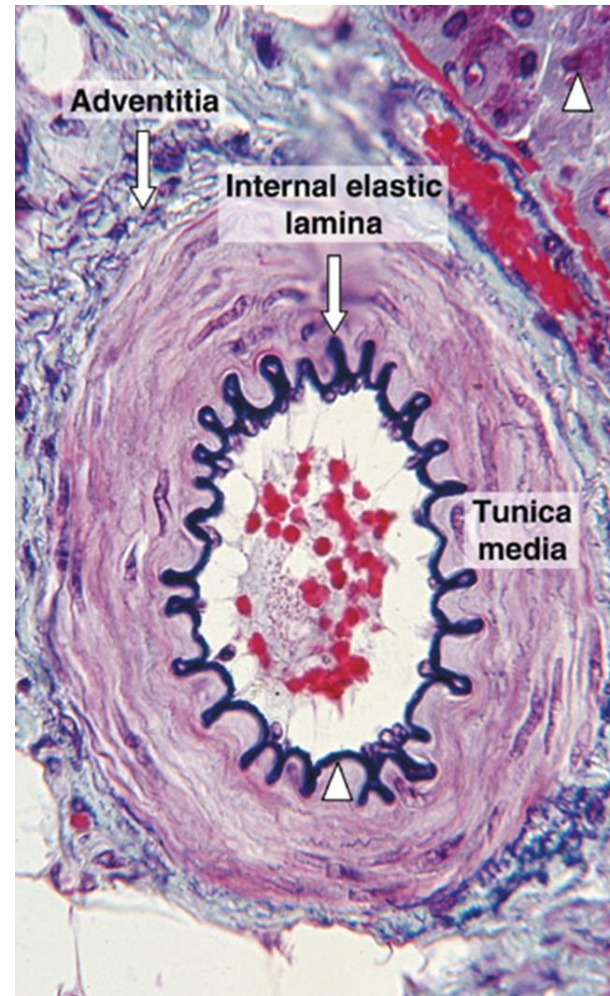
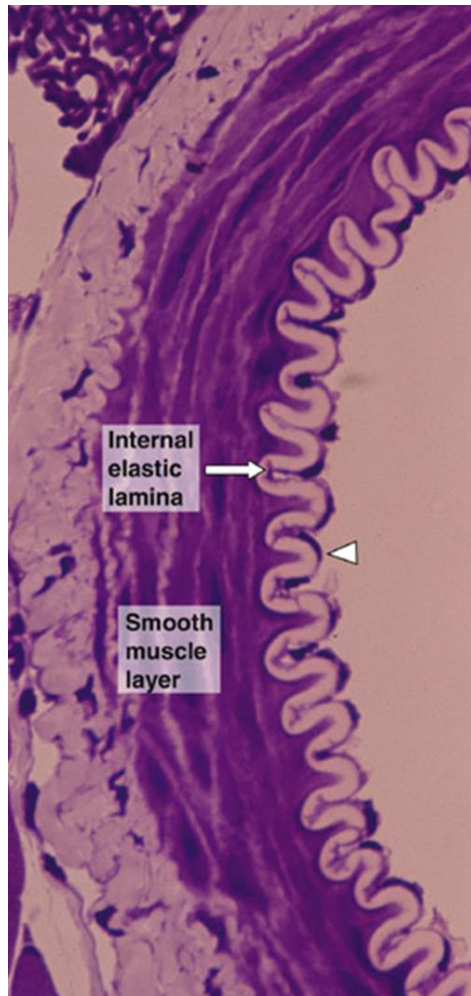


# Muscle arteries = distributing arteries

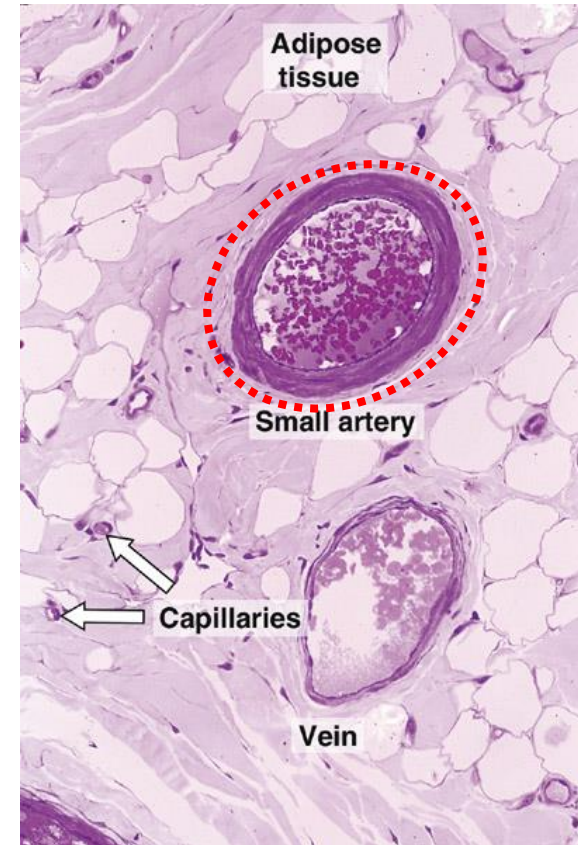
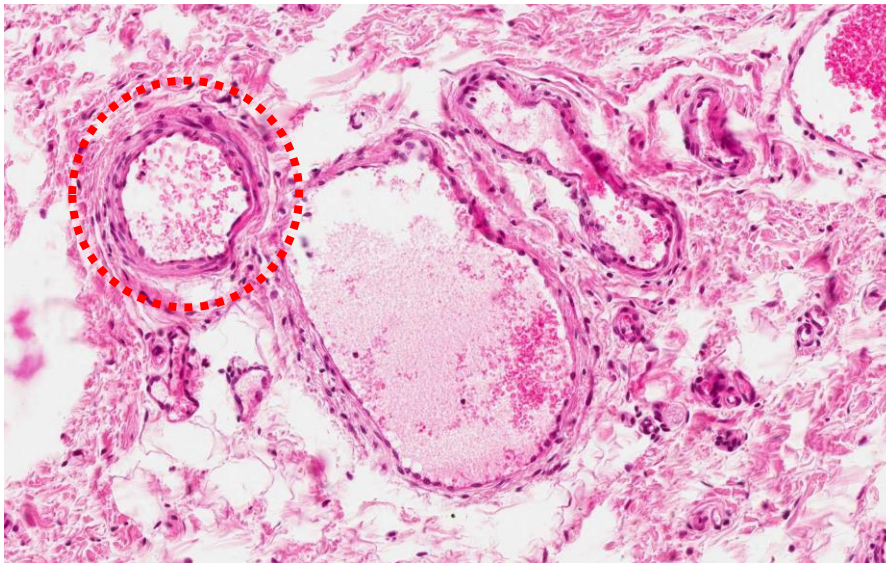
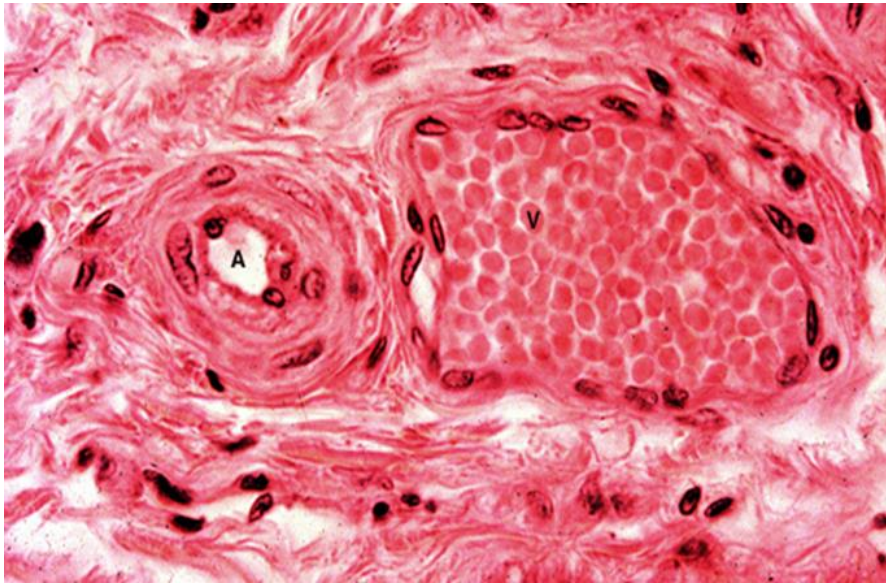


# Muscle arteries = distributing arteries – *small sized*

- **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



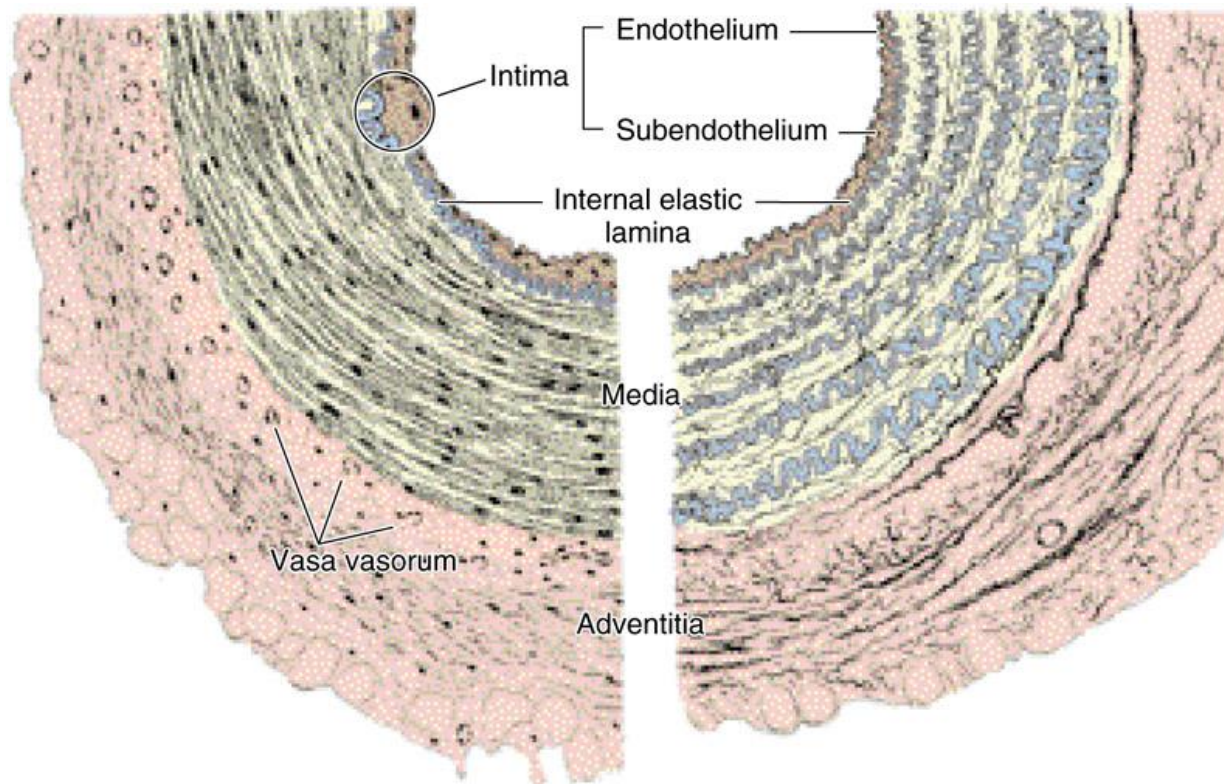
# Muscle arteries = distributing arteries – *small sized*



# Muscle arteries x Elastic arteries

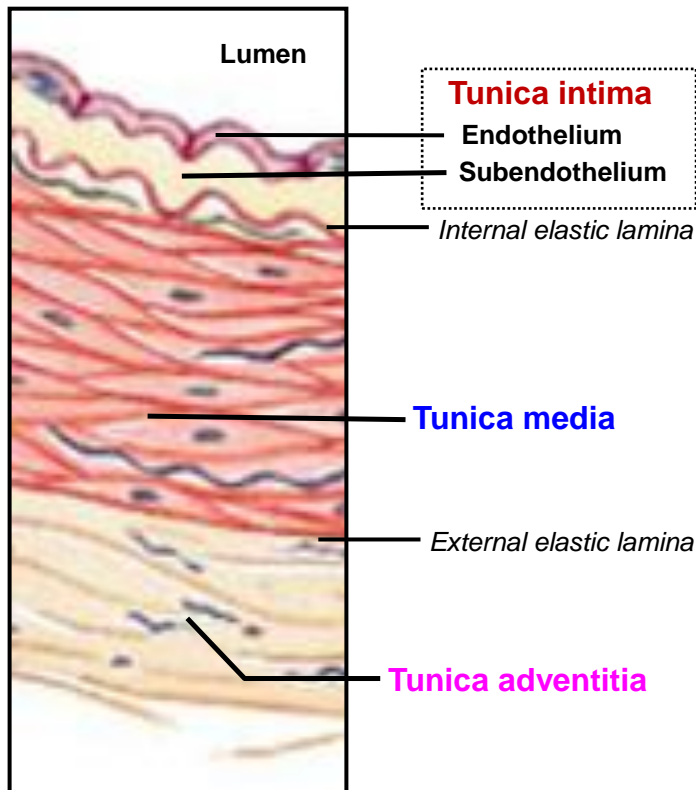
Smooth muscle cells predominate in their media

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

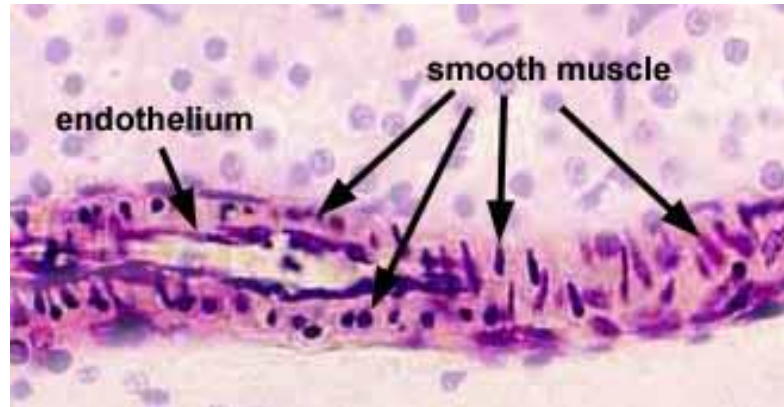
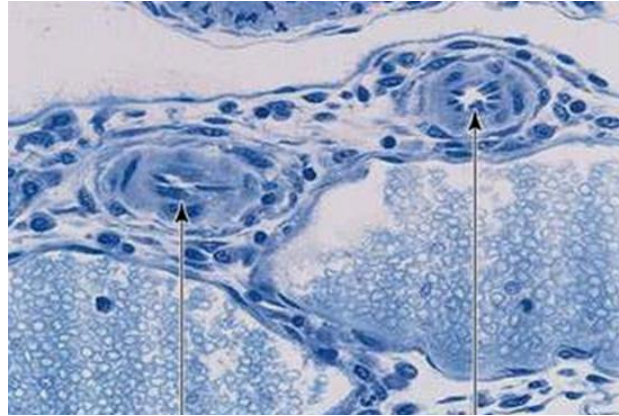
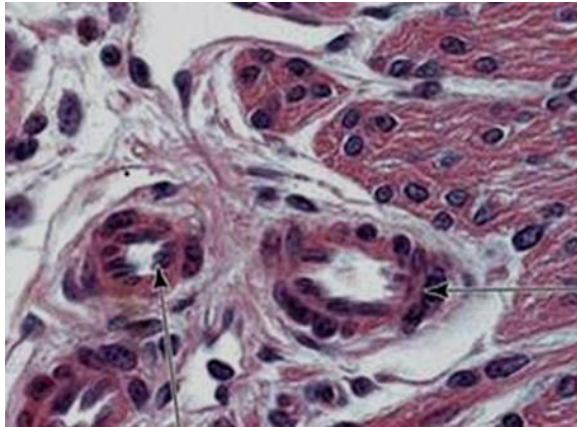
## External elastic lamina

- non-developed

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

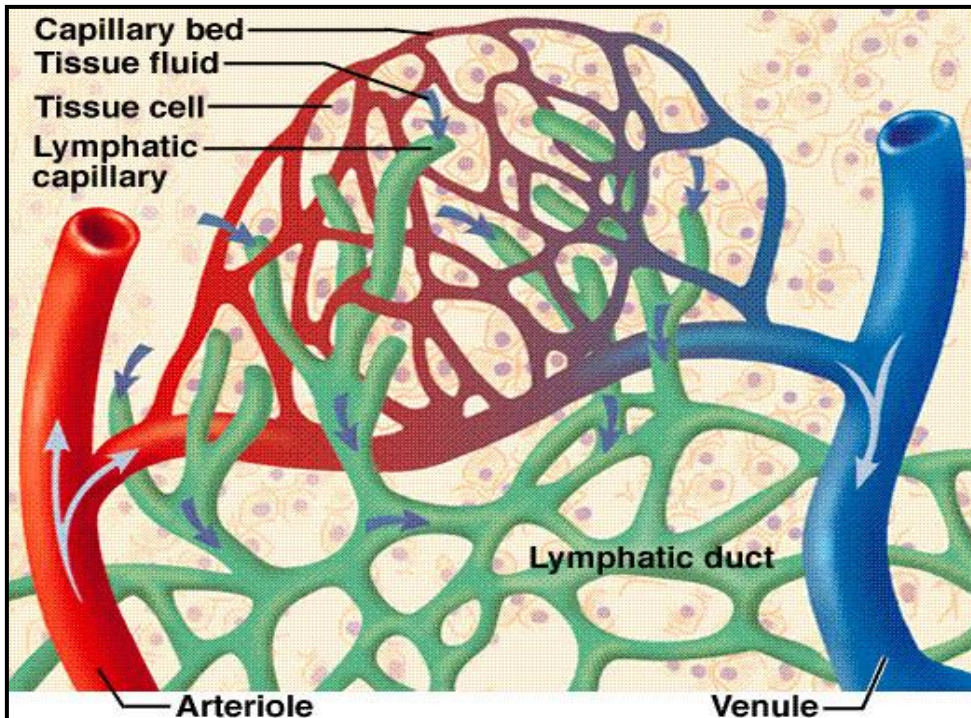


# Arterioles



# 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

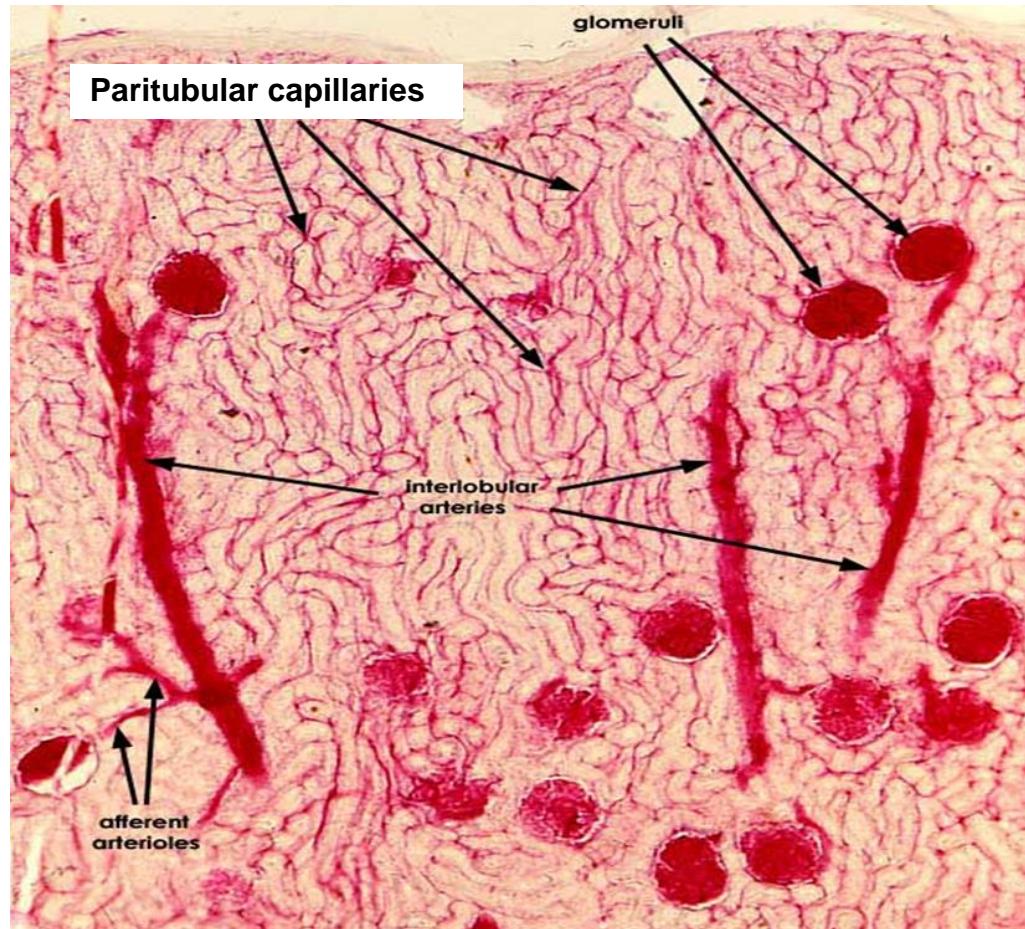
Maximal distance of tissue cell from the capillary =

**about 50  $\mu\text{m}$**

The length of the capillaries usually varies between

**about 0.25 and 1 mm**

# Capillaries

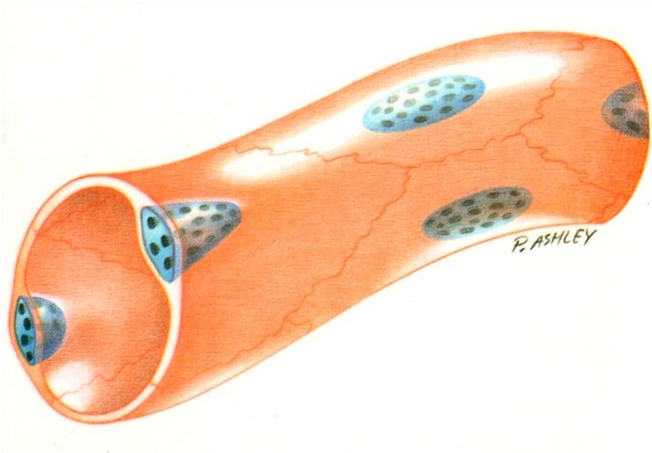


**Extensive vasculature of renal cortex (perfused by red dye)**

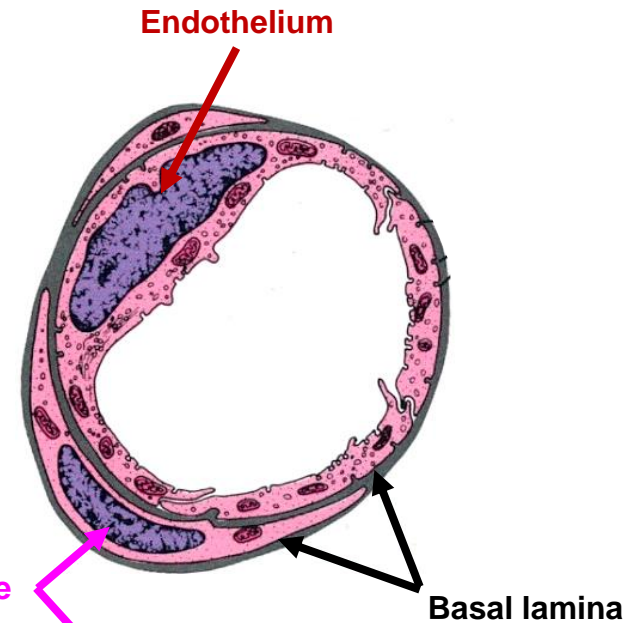
**Scarse in:** tendons, ligaments

**Absent from:** cartilage, epidermis, cornea

# Capillaries



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



## Capillary wall

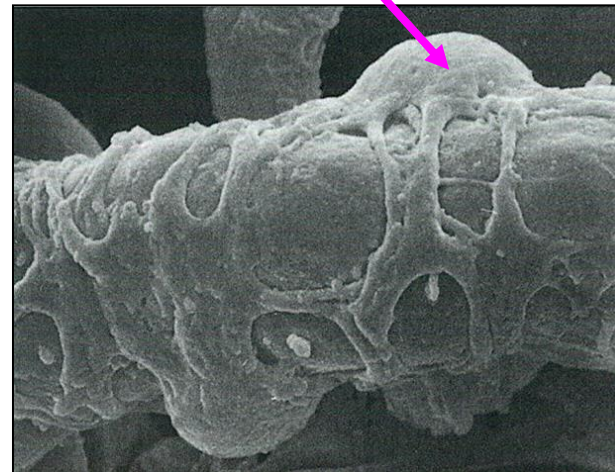
### Endothelium

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

### Basal lamina

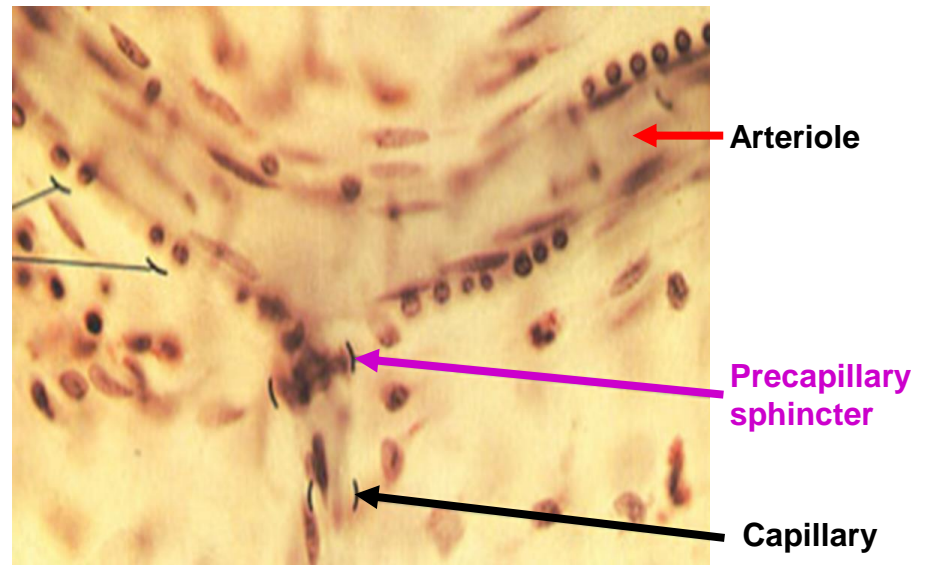
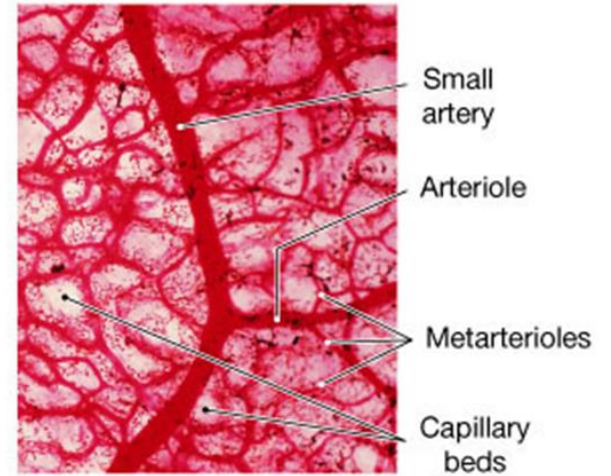
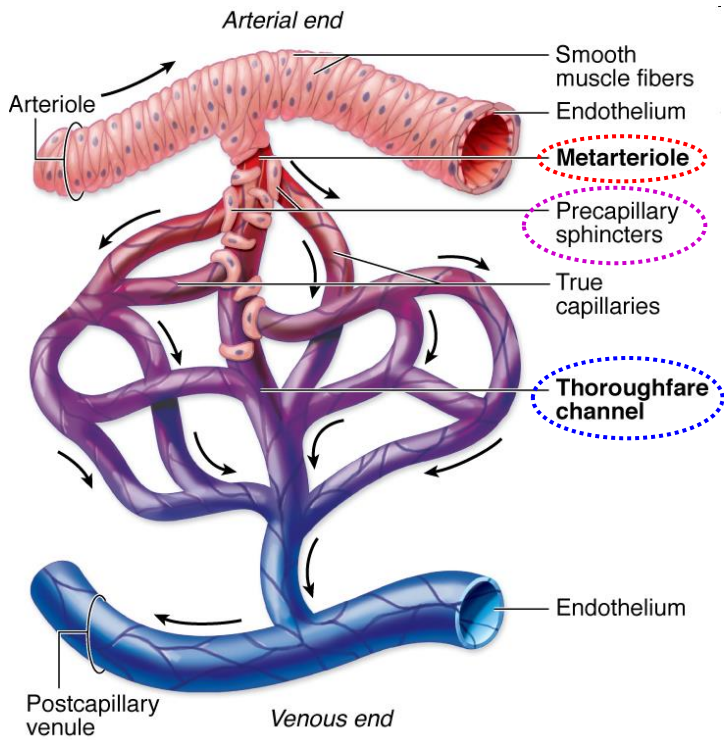
#### „Envelope“

- 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

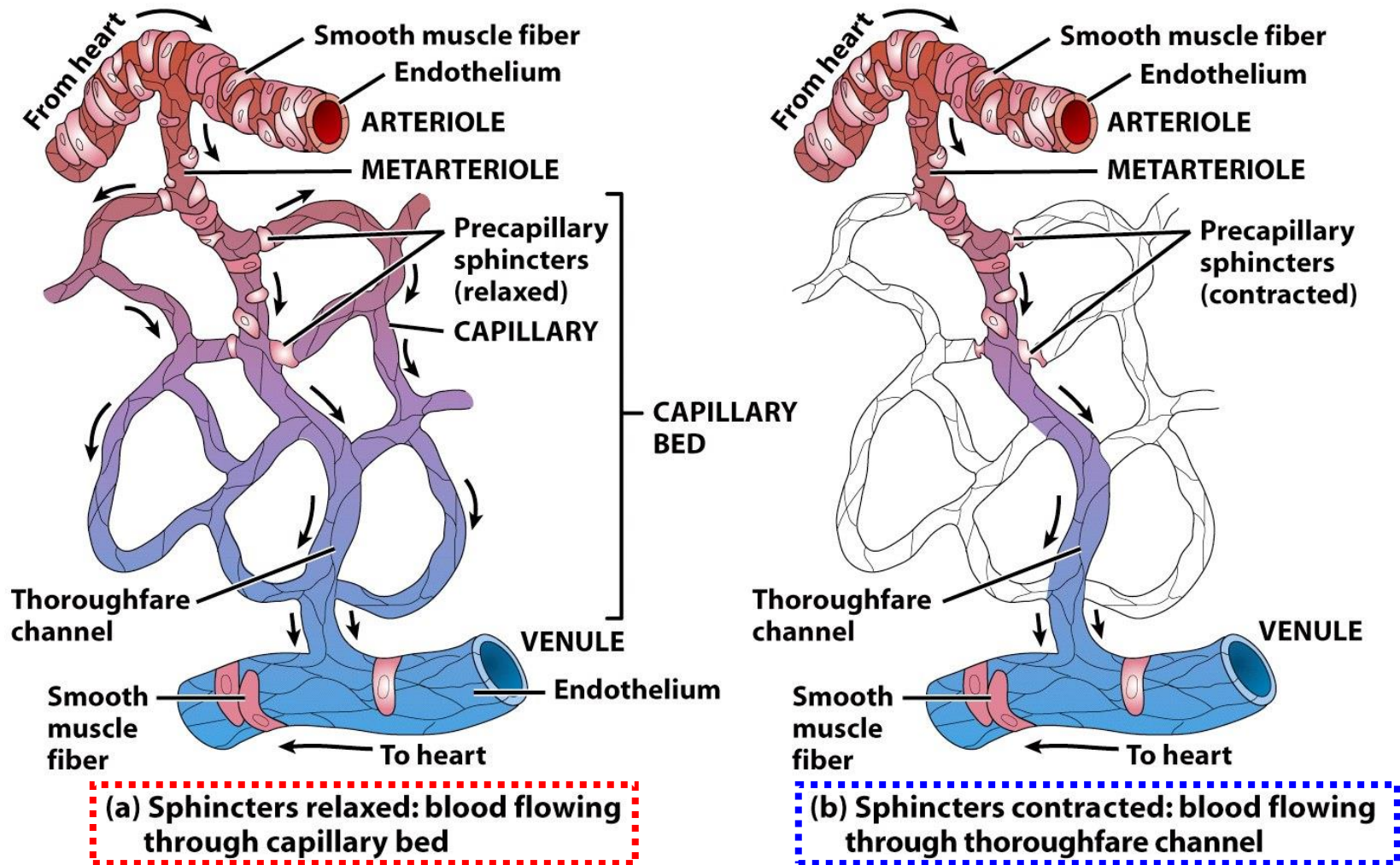
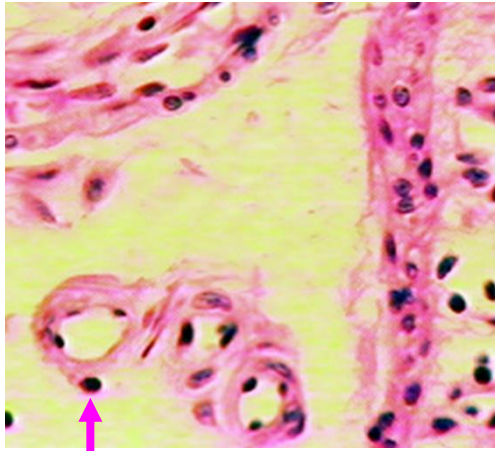
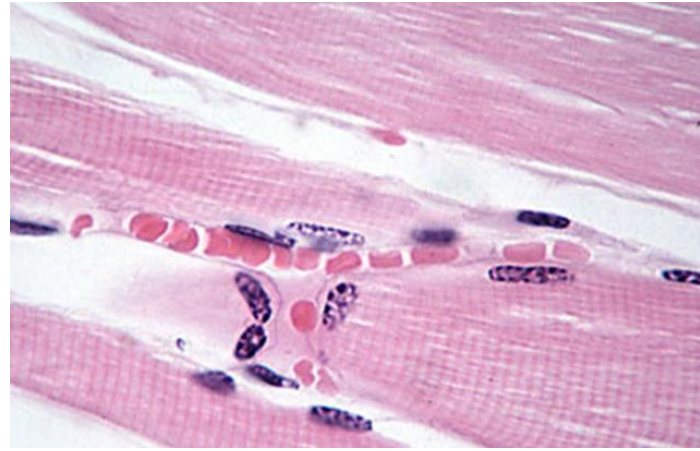


Figure 21-3 Principles of Anatomy and Physiology, 11/e  
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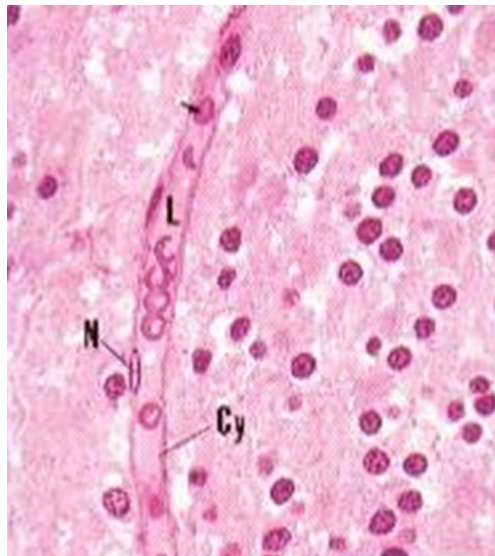
# Capillaries



Pericyte



Striated muscle

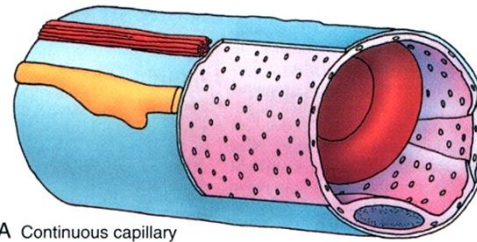


Cerebellum (monkey)

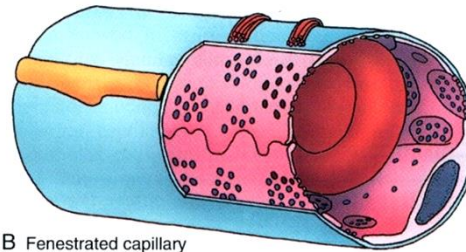
# Capillaries

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

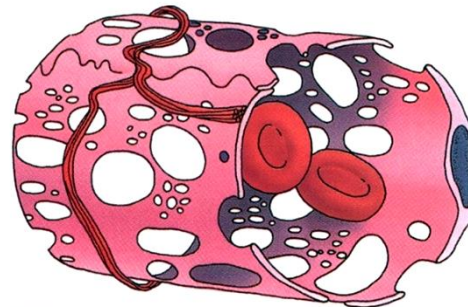
- **Continuous capillary**
- **Fenestrated capillary**
- **Sinusoidal**



A Continuous capillary



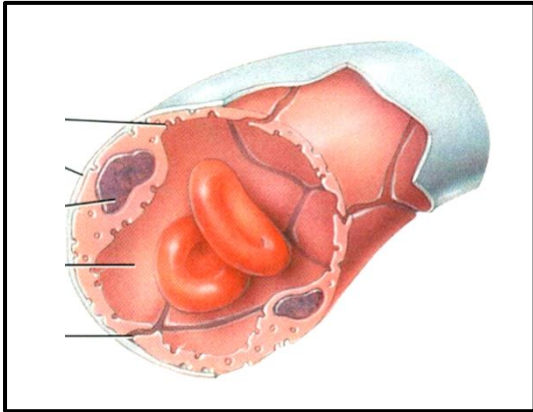
B Fenestrated capillary



C Sinusoidal (discontinuous) capillary



# Capillaries - Continuous

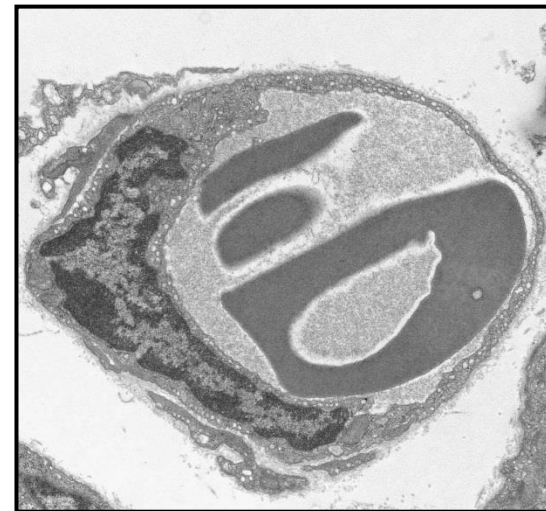
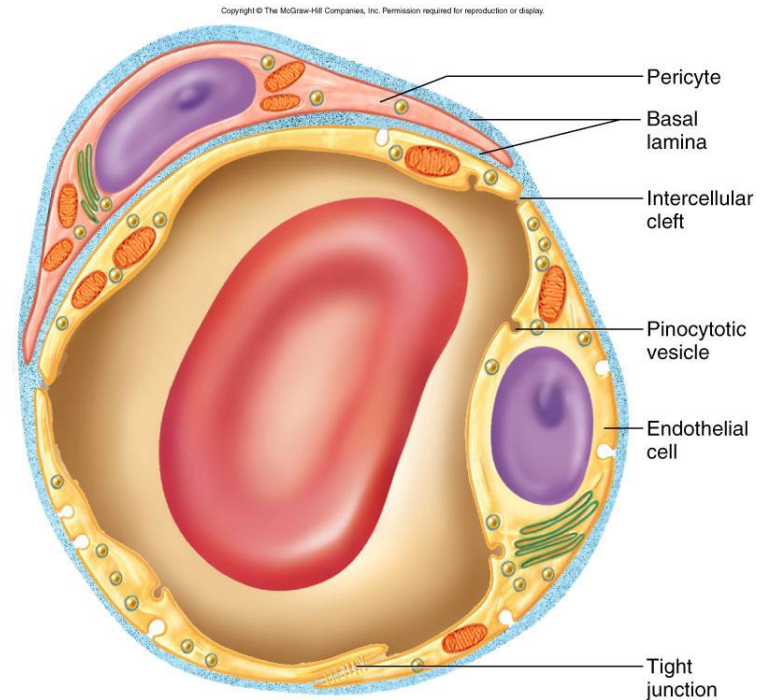


## How ?

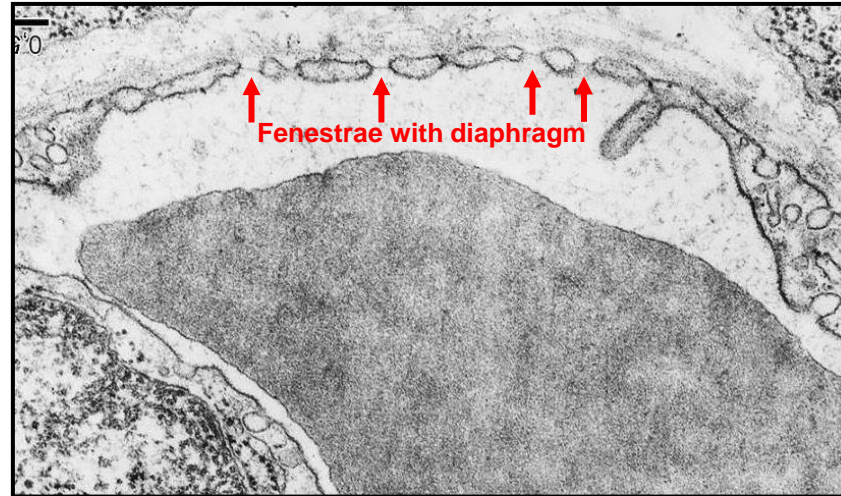
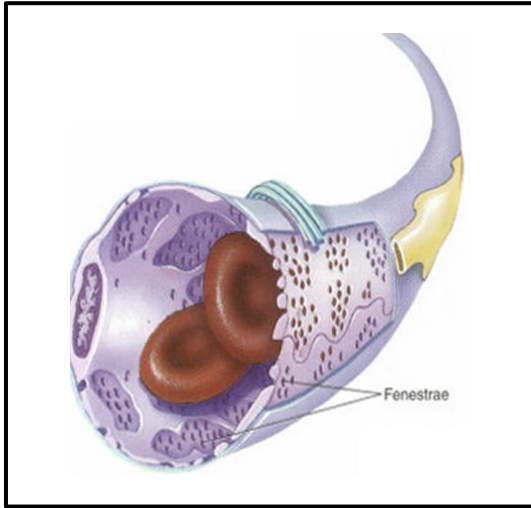
- non-interrupted lining
- no defects in the wall (endothelium + basal lamina)

## Where ?

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



# Capillaries - Fenestrated

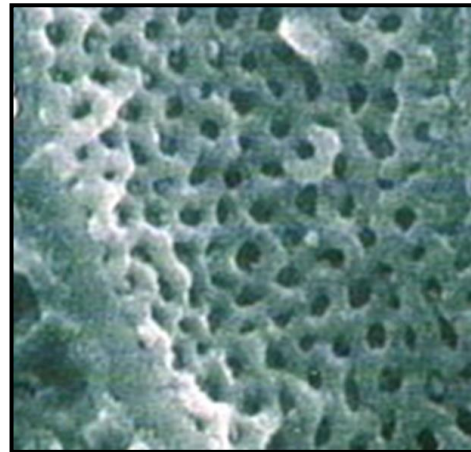


## How ?

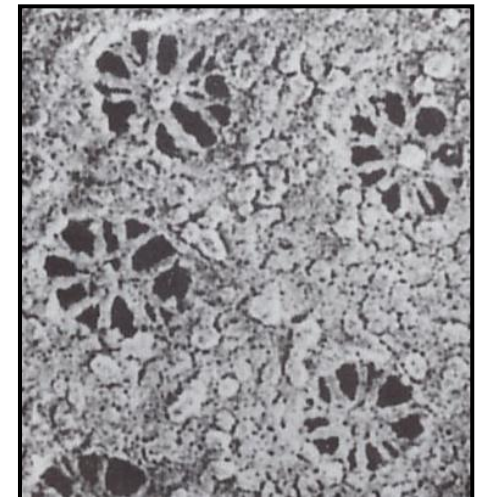
- endothelial cells perforated (diameter ~60-80 nm; diaphragm 4-6 nm)
- continuous basal lamina

## 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

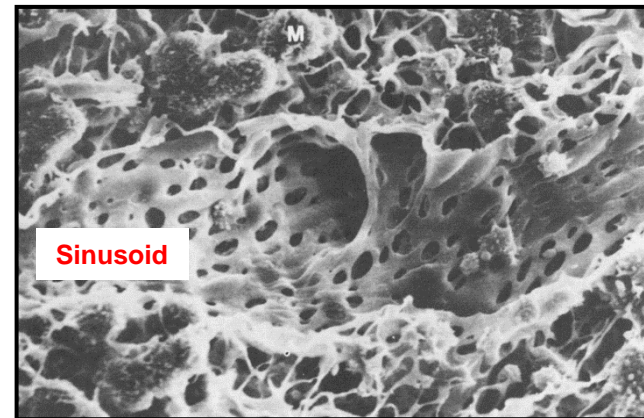
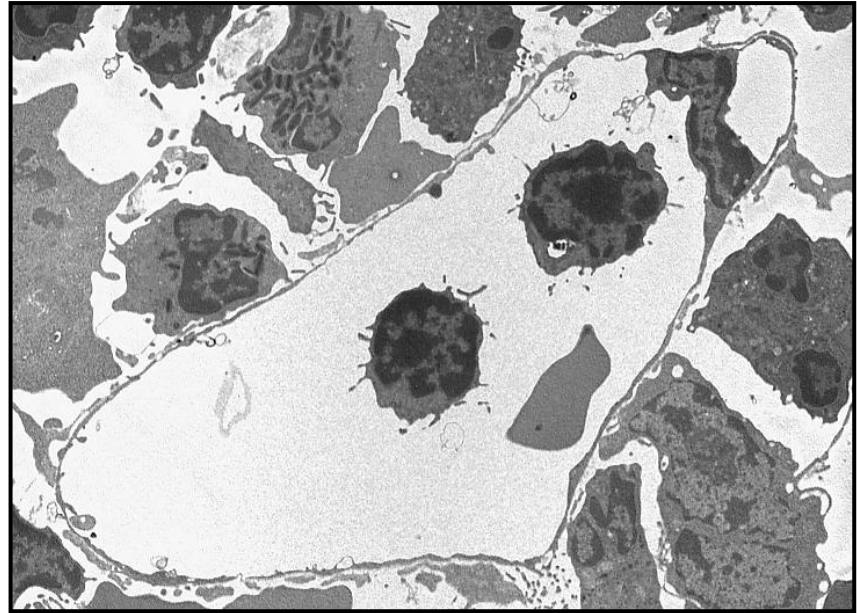


## How ?

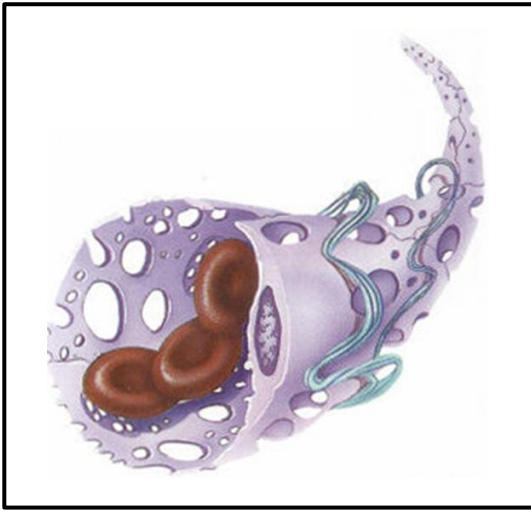
- enlarged diameter (up to 40  $\mu\text{m}$ )
- endothelial cells with large pores without diaphragm
- large clefts between endothelial cells
- discontinuous basal membrane (or even absent)
- pericytes are absent (macrophages instead)

## Where ?

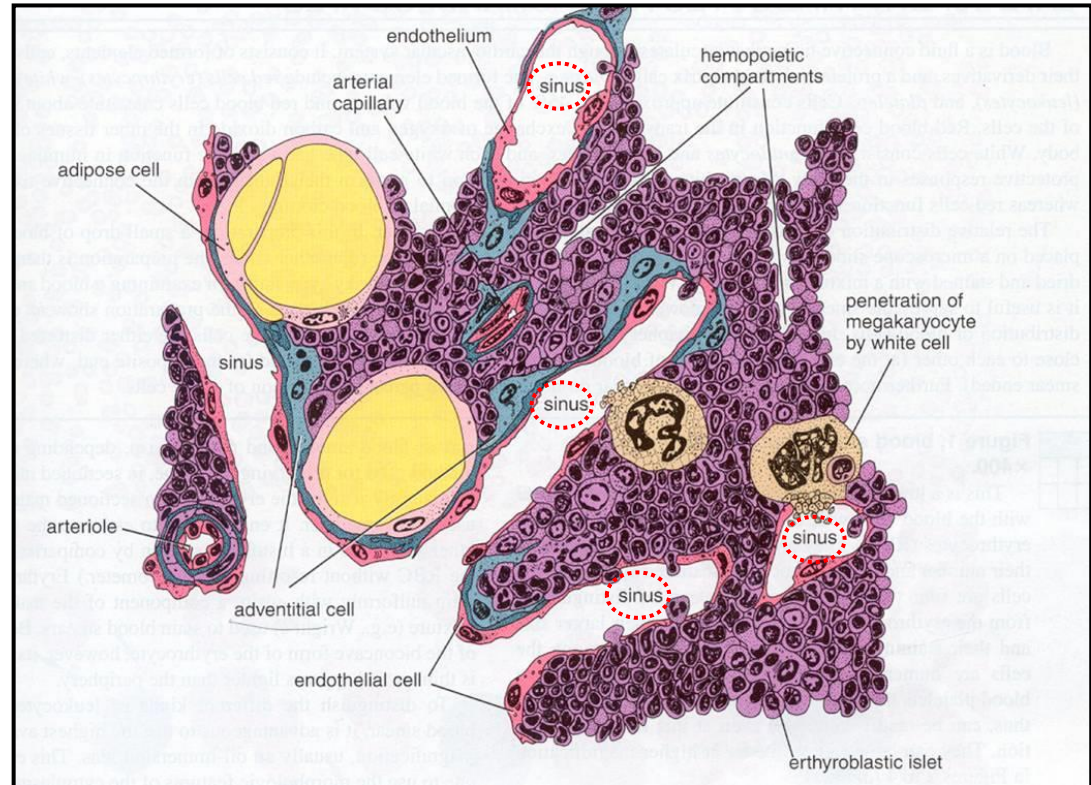
- liver (pores 100 nm)
- hematopoietic regions (bone marrow)
- endocrine glands (adenohypophysis, islets of Langerhans)



# Capillaries – Sinusoidal - Discontinuuos



## Bone marrow



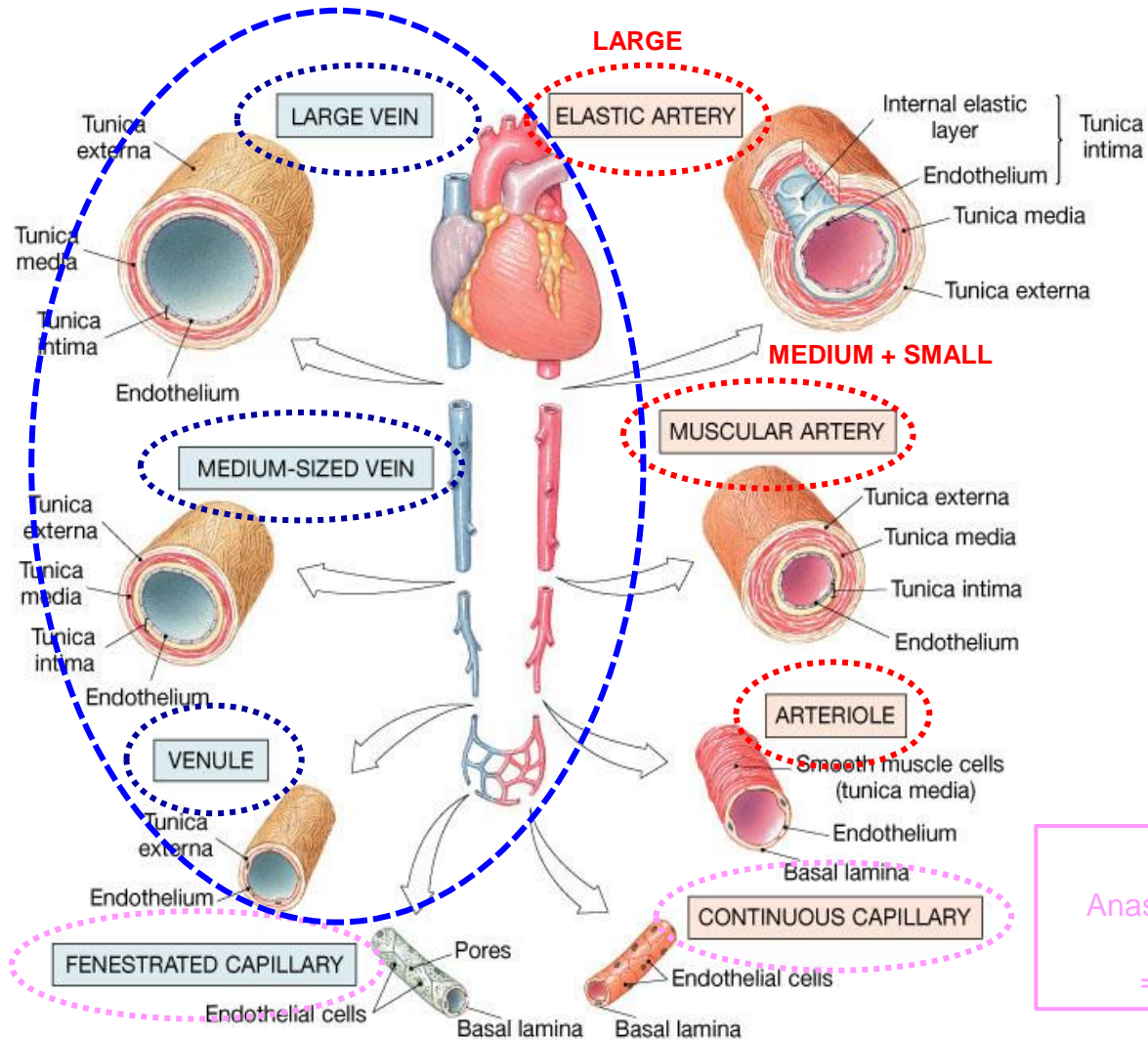
# Blood vessels – several different flavours

**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

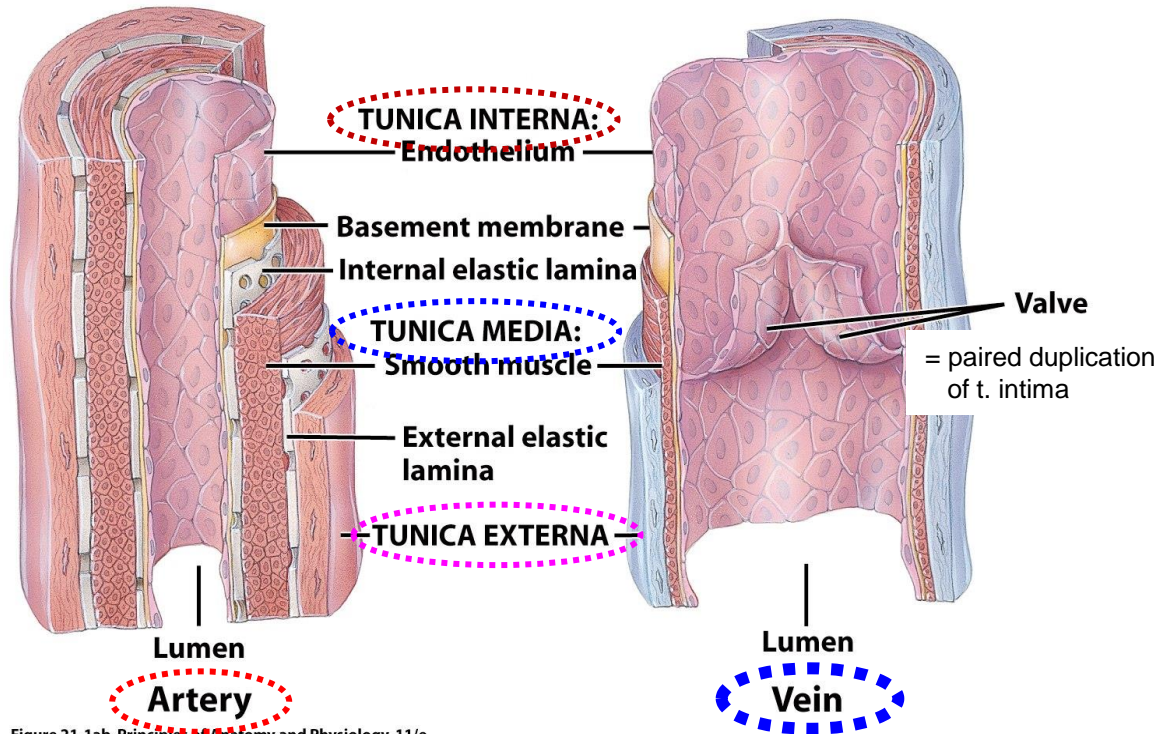
Microvasculature – <0.1 mm



**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  $\mu\text{m}$ )

## Collecting & Muscular venules

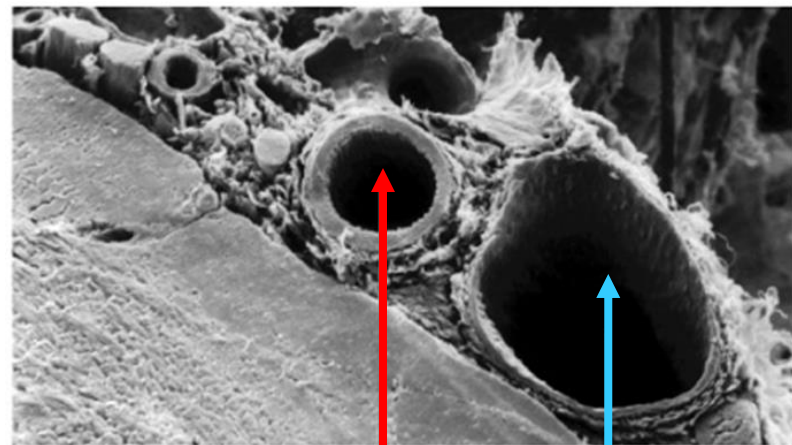
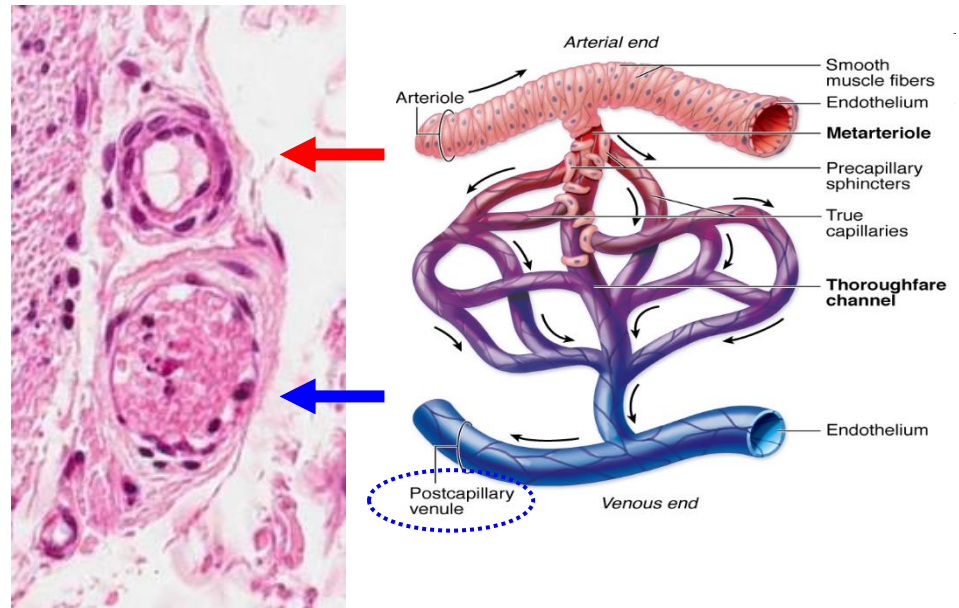
- increasing number of contractile cells
- tunica media is defined in muscular venules

## Small- & Medium-sized veins

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

## Large veins

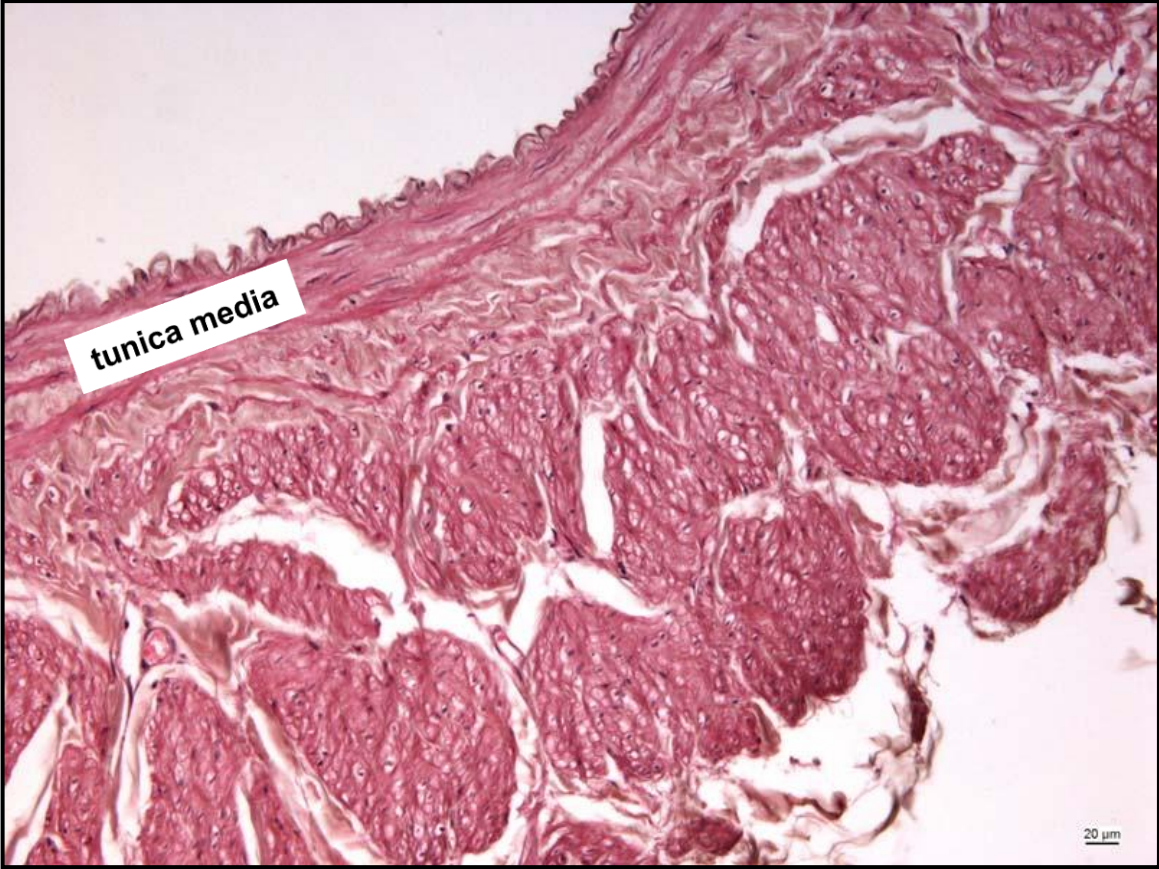
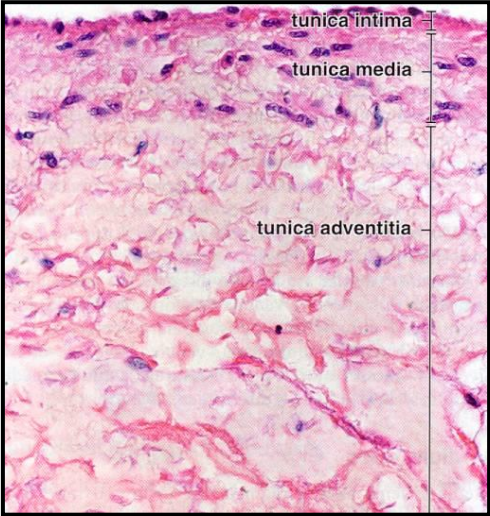
- close to the heart
- (*v. cavae, pulmonary veins, internal jugular veins*)
- paired with elastic arteries
- diameter > 10 mm
- with valves
- t. media is thin (muscle cells+connective tissue)
- thick t. externa (with longitudinal bundles of SMC; myocardial sleeves)



Artery

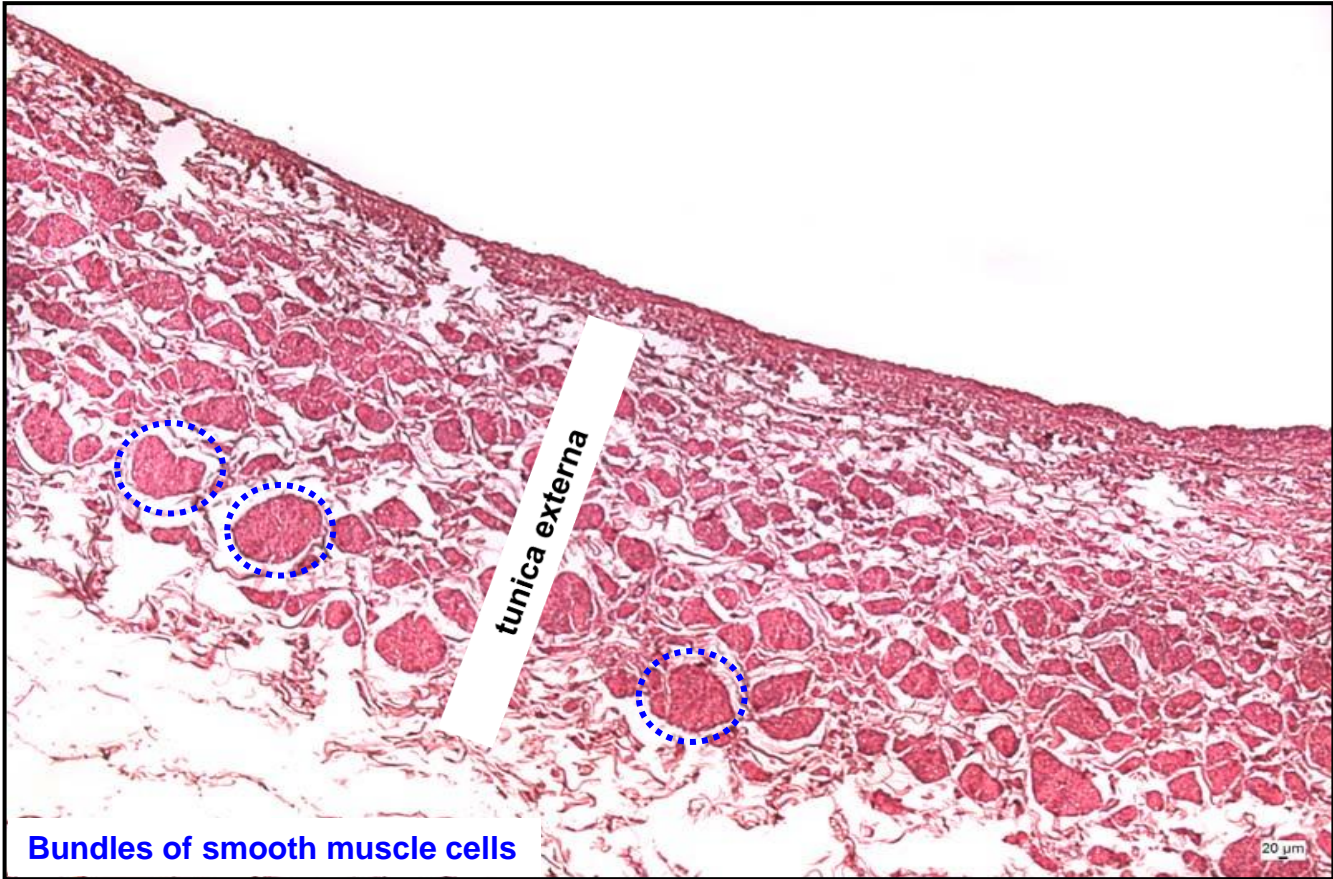
Vein

# Veins – Middle-sized

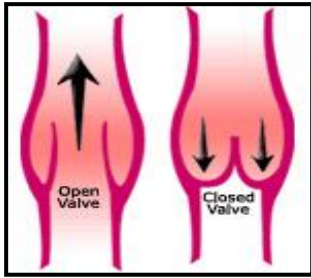




# Veins - Large



*Vena cava*

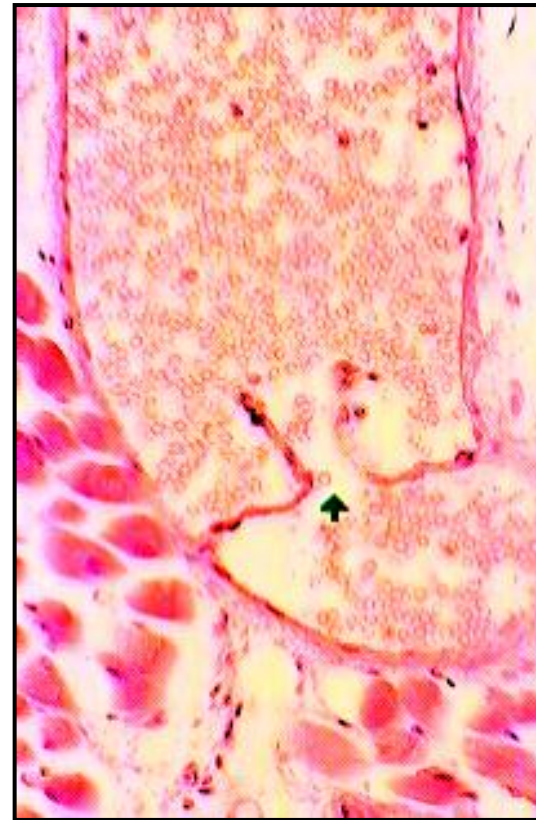


## Veins – Valves

- 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



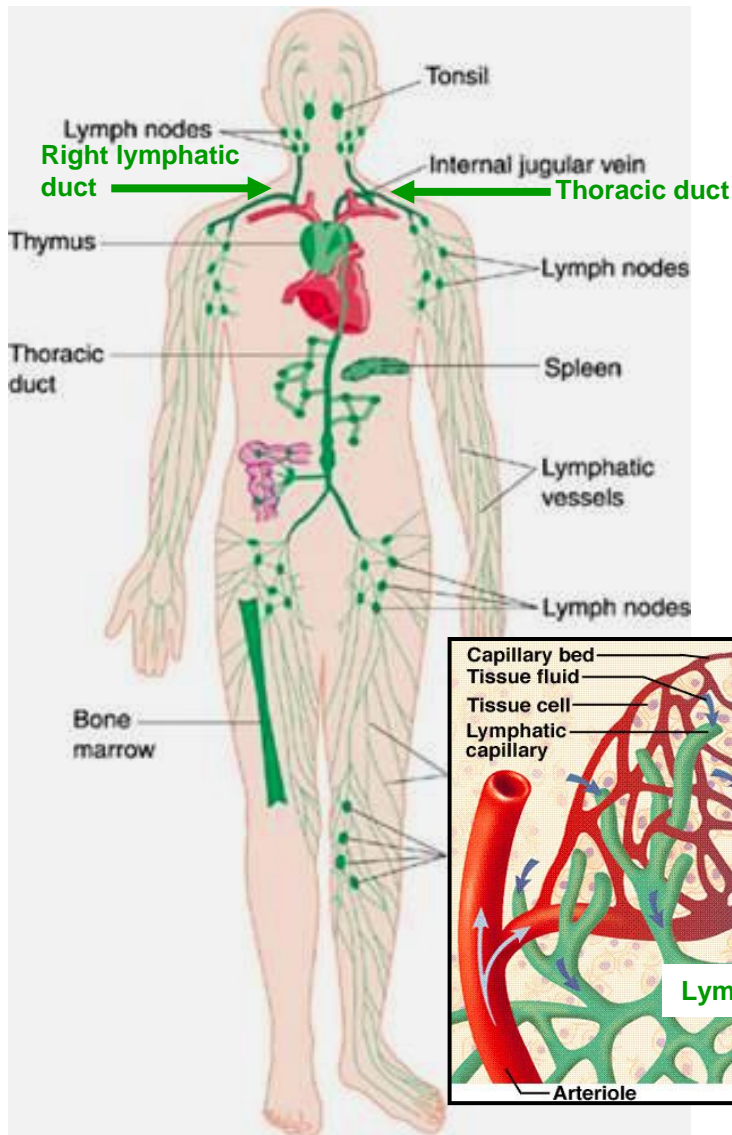
Appearance of internal surface



Histological view

# Lymphatic vessels

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

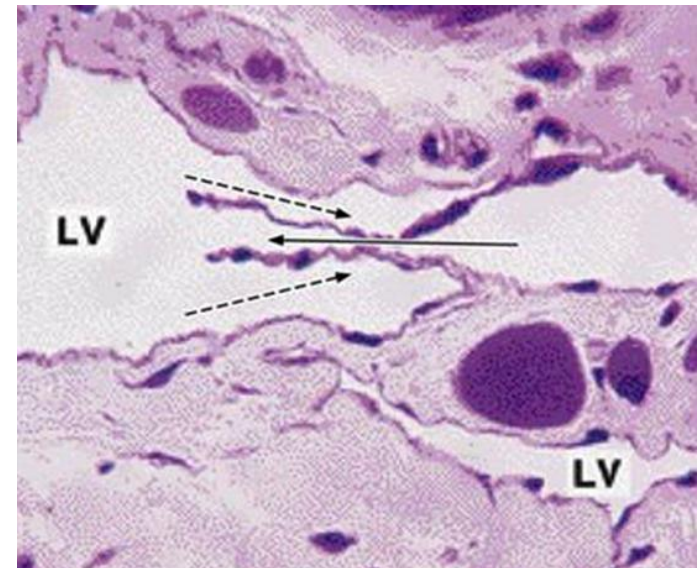
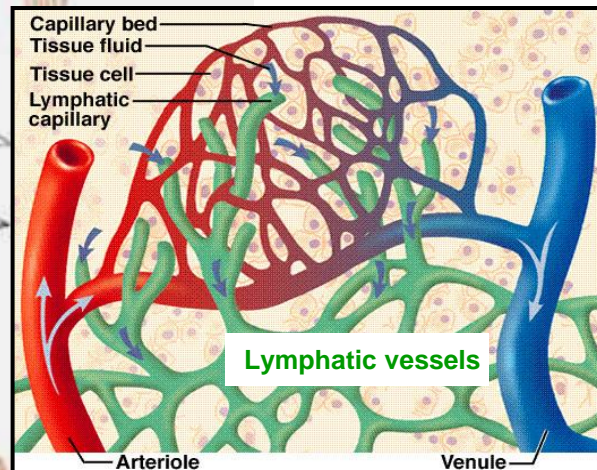


## Lymphatic capillaries

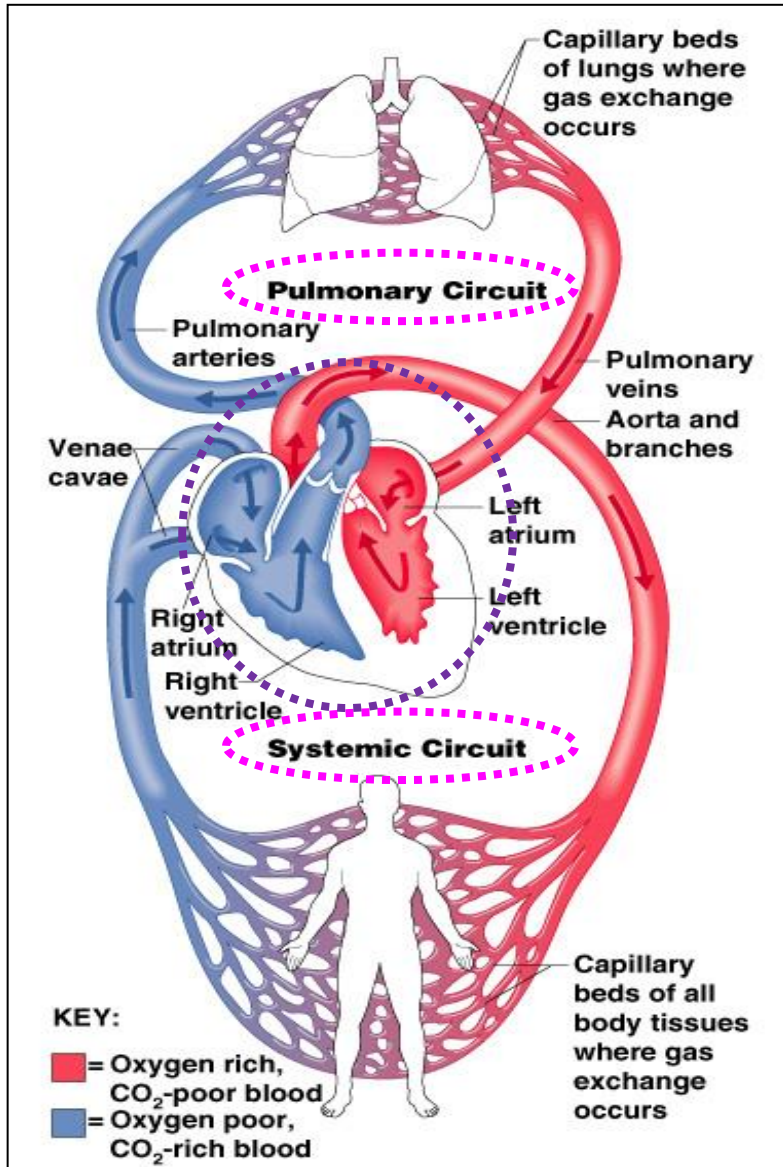
- blunt ended
- very simple structure
- endothelial cells + fine reticular fibres of circular orientation
- the basal lamina is not developed

## Lymphatic vessels and ducts

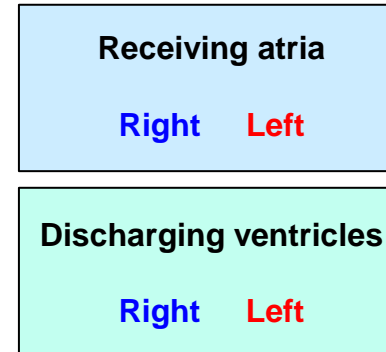
- thin walled tubes
- resemble veins in their structure (intima+media+adventitia)
- have valves



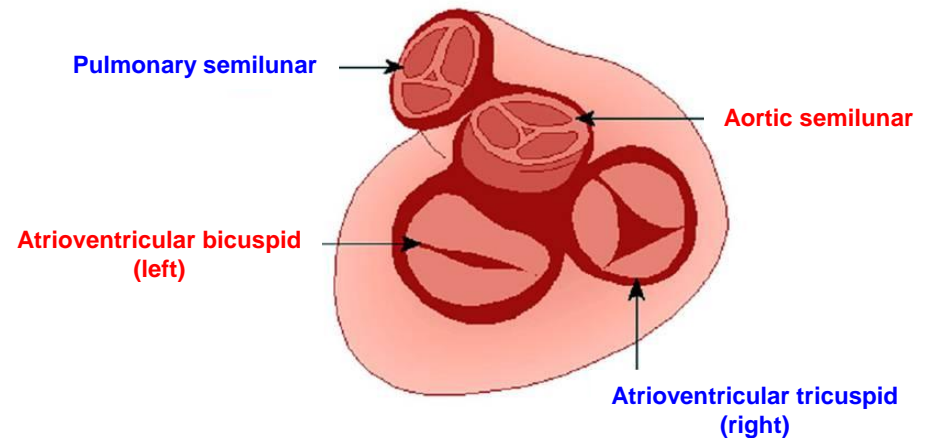
# Heart - Anatomy



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

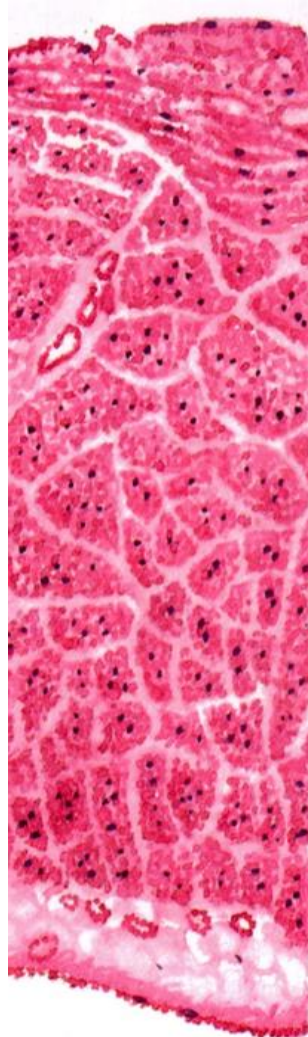


- it is equipped by four valves (blood can travel in only one direction)



# Heart - Wall

inner surface



## Endocardium

- endothelium
- subendothelial layer
- subendocardial layer

## Myocardium

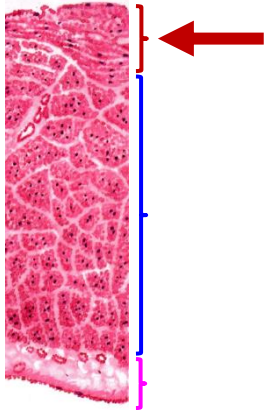
## Epicardium

- mesothelium
- submesothelial layer

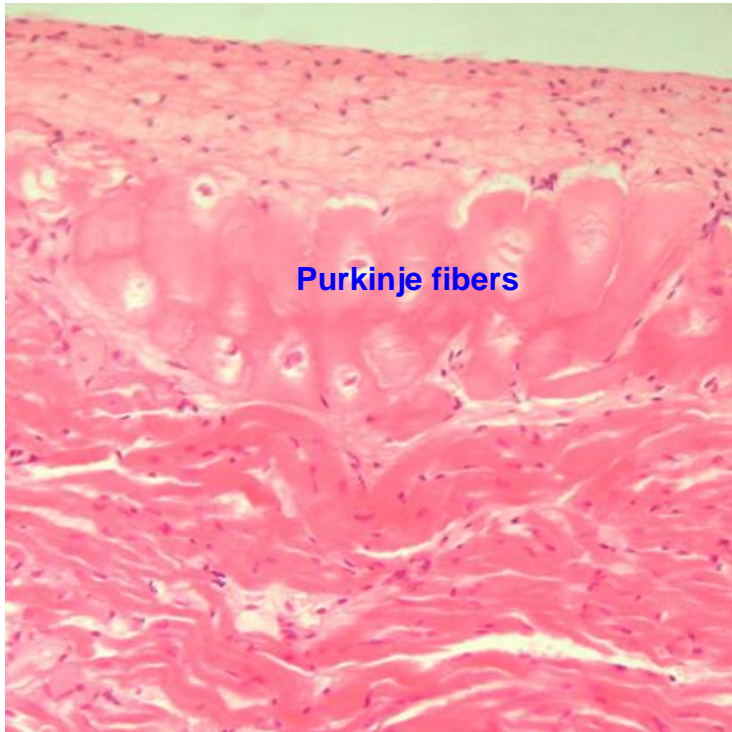
outer surface

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

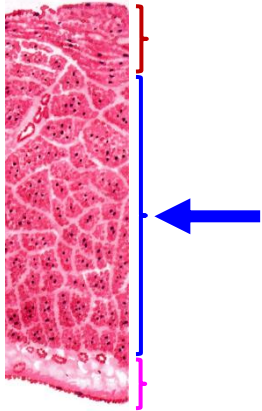
## Subendothelial layer

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

## Subendocardial layer

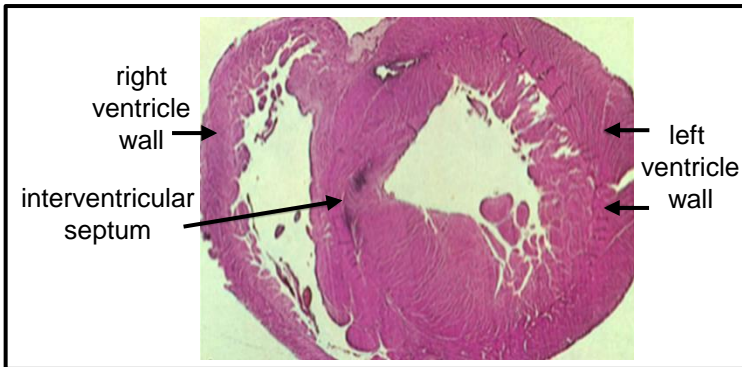
- loose connective tissue
- continuous with endomysium of the myocardium
- nerve fibers, vessels, **impuls-conducting system**

inner surface

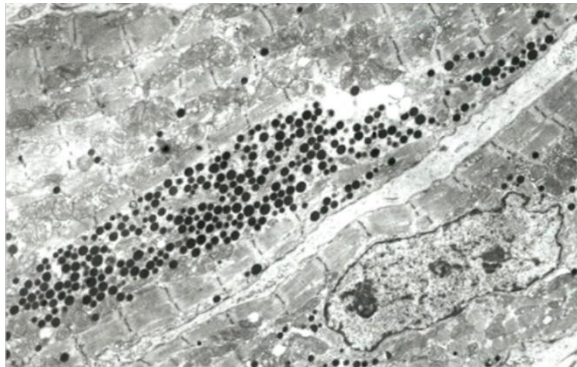


# Heart - Myocardium

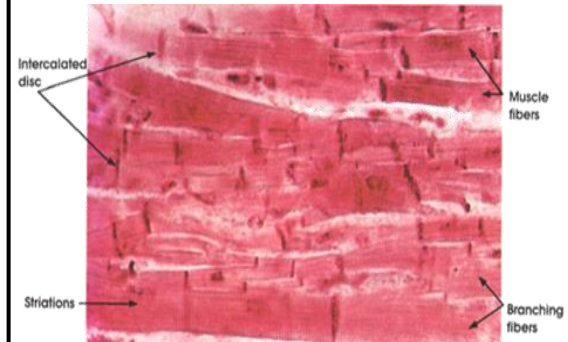
- its thickness varies in different parts (thickest – left ventricle; thin in atria)
- has rich blood supply (many capillaries)
- has no regenerative capacity
- muscle fibers are arranged circularly around chambers
- masses of connective tissue in between the muscles – **cardiac skeleton** (anuli fibrosi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



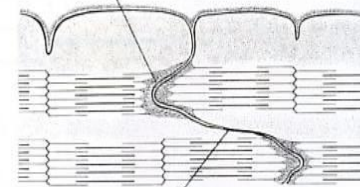
**Atrial natriuretic peptide**  
(endocrine function of contractile cells; acts on kidney)



## Intercalated discs

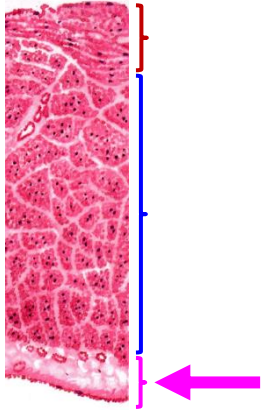


Transverse portion (myofibrillar junctions, desmosomes, and gap junctions)



Longitudinal portion (contains large gap junctions)

inner surface



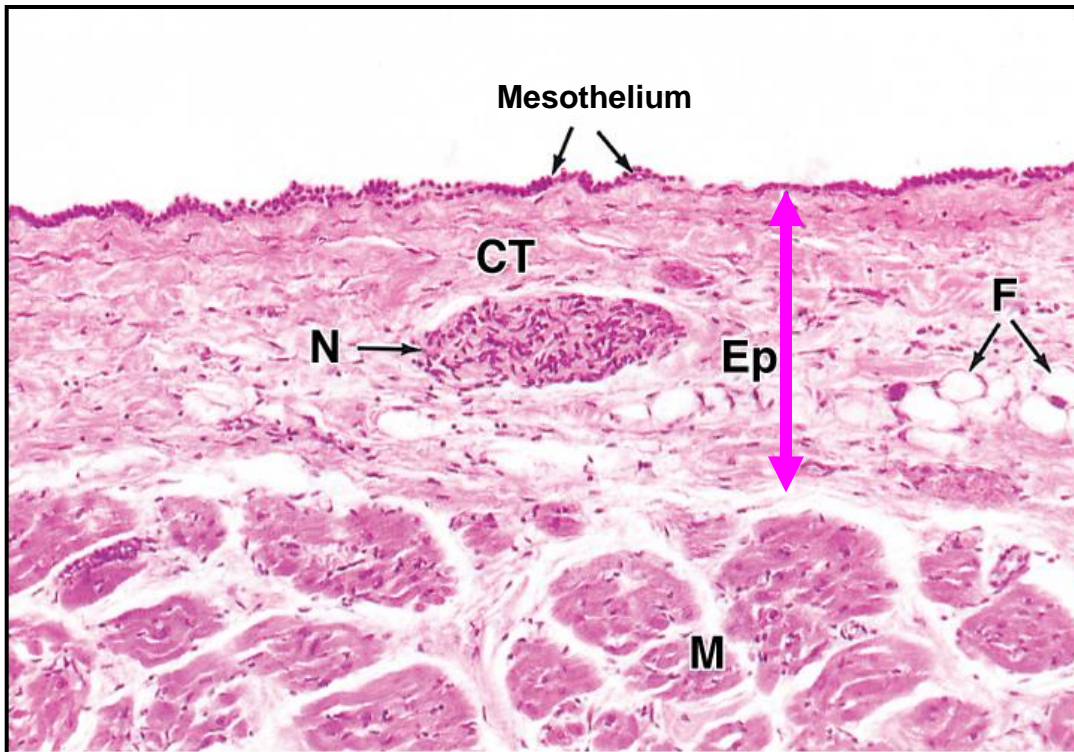
# Heart - Epicardium

- 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

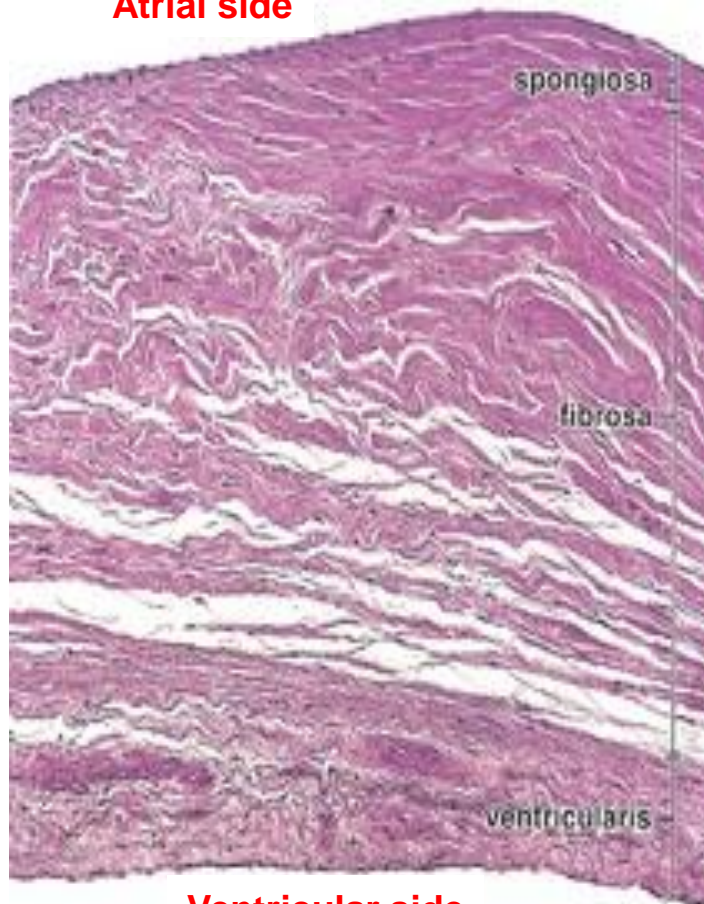
- loose connective tissue
- elastic fibers
- nerves
- blood and lymphatic vessels
- home of coronary vessels
- adipocytes (high in obese individuals)



# Heart - Valves

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

**Atrial side**



**Ventricular side**

## Spongiosa

- loose collagen

## Fibrosa

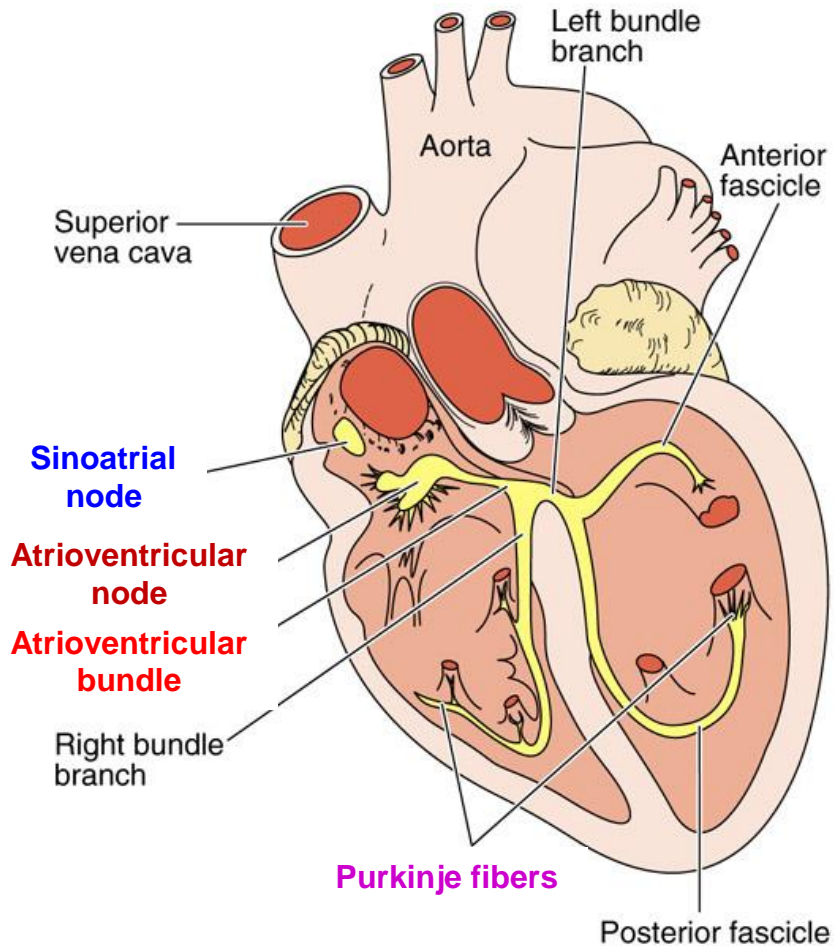
- dense core of connective tissue

## 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**

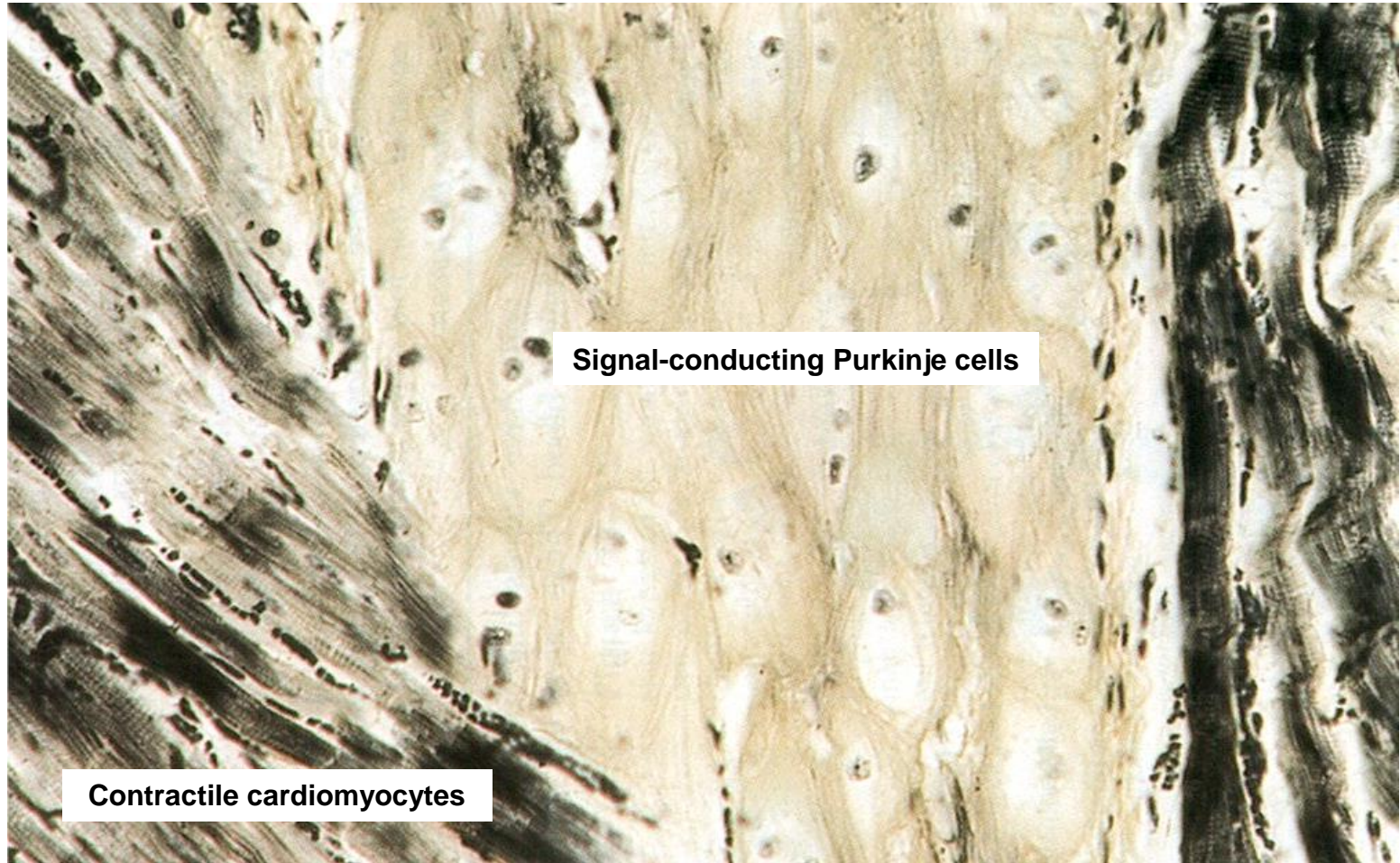
## Atrioventricular bundle (bundle of His)

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

## Purkinje fibres

- terminal ramifications of the AV bundle

# Heart – Conducting system

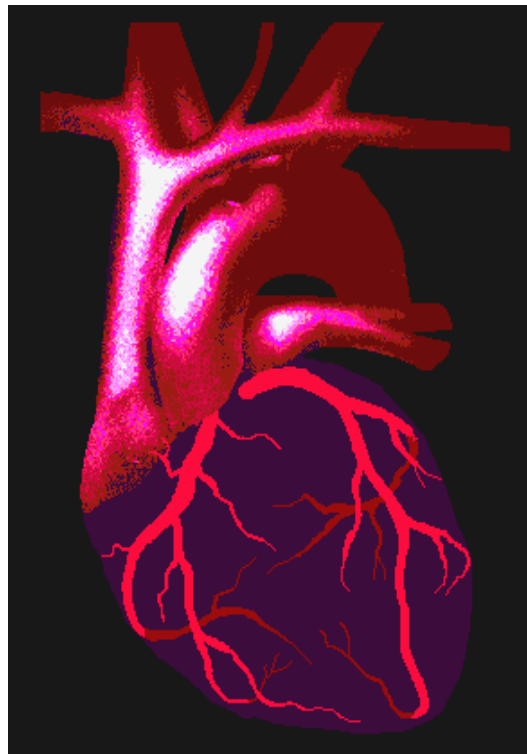


Signal-conducting Purkinje cells

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:  
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