Anatomy of the circulation and its relevance to function

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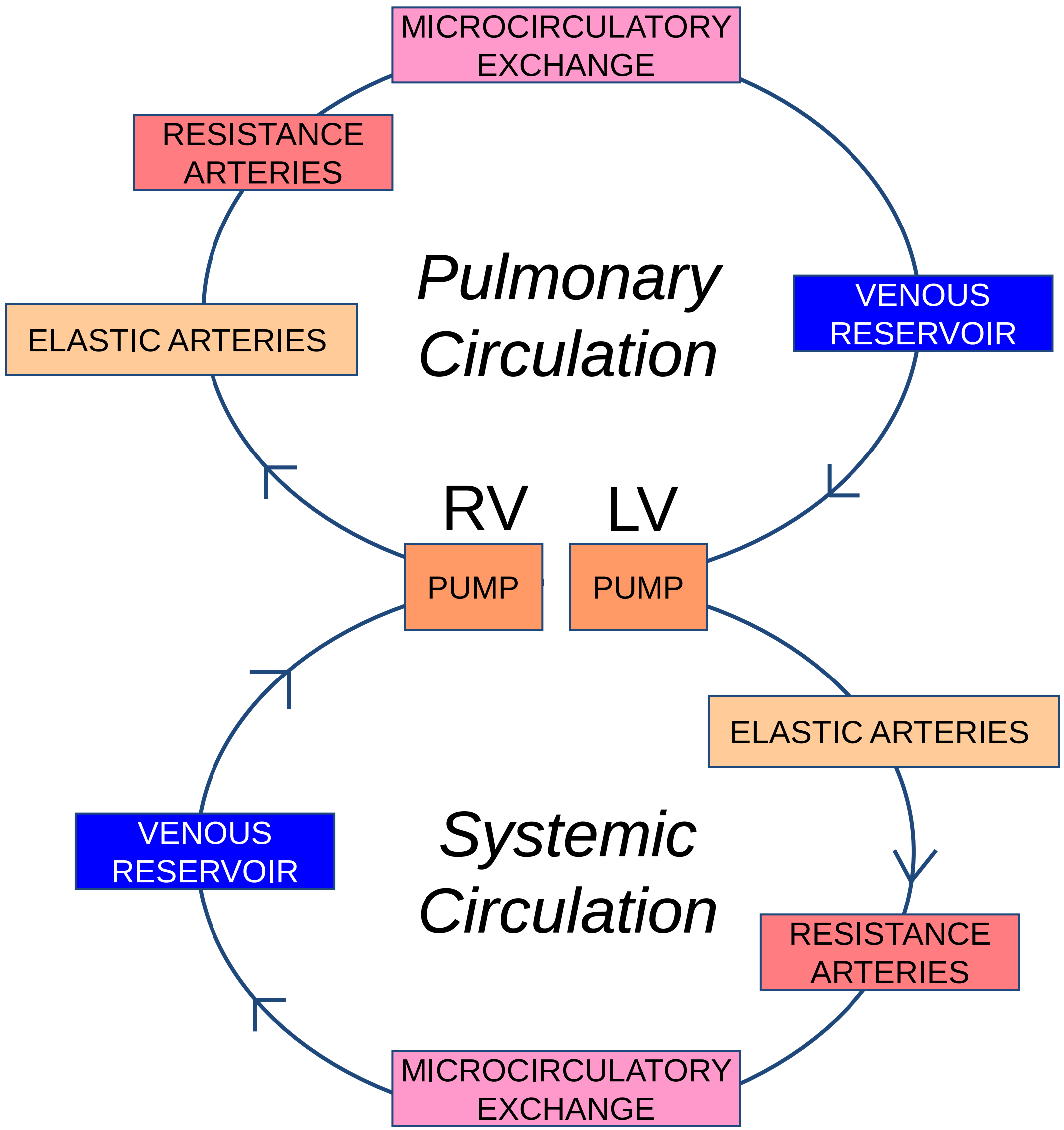
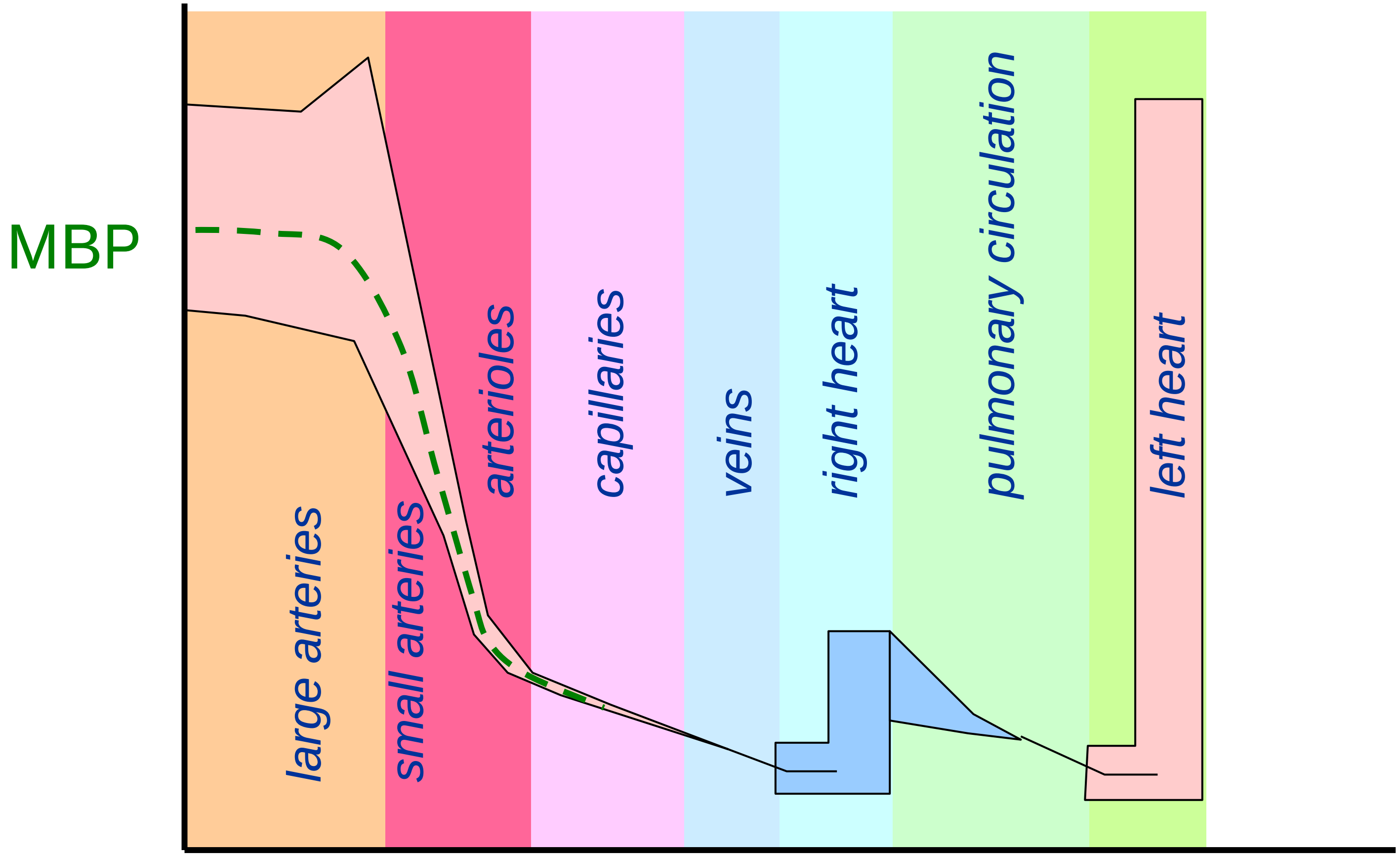
Role and design of the circulation

- To transport blood (a fluid containing cells) around the body to allow exchange of gas , nutrients, metabolites, ions, hormones, heat
- Flow is achieved by the action of a muscular pump (heart) propelling blood through a network of tubes (blood vessels).
- The circulation consists of two pumps (left and right heart) which are physically coupled and pump through the systemic and pulmonary circulations respectively.
- Diffusion is crucial for movement of materials through tissues
- Diffusion is only effective over short distances so a capillary needs to be ~10μm from every cell. This necessitates a highly branched structure.

Schematic design of the cardiovascular system



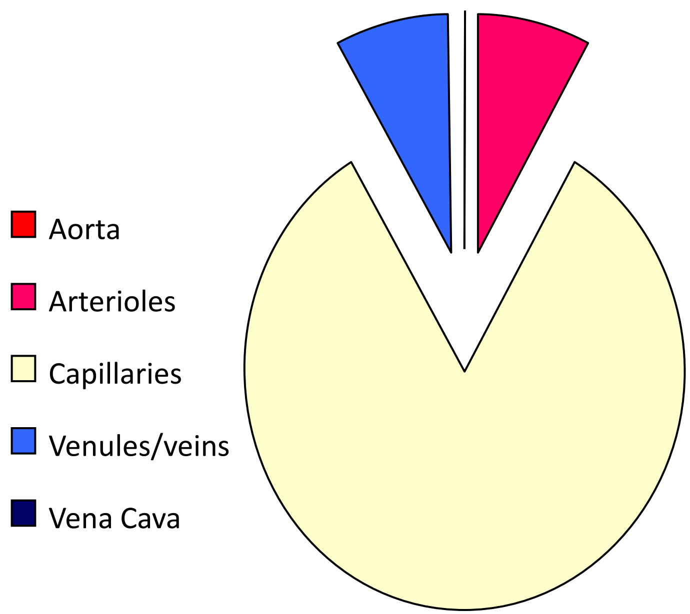
Pressure throughout the circulation



Pressure falls across the circulation due to viscous (frictional) pressure losses. Small arteries and arterioles present most resistance to flow.

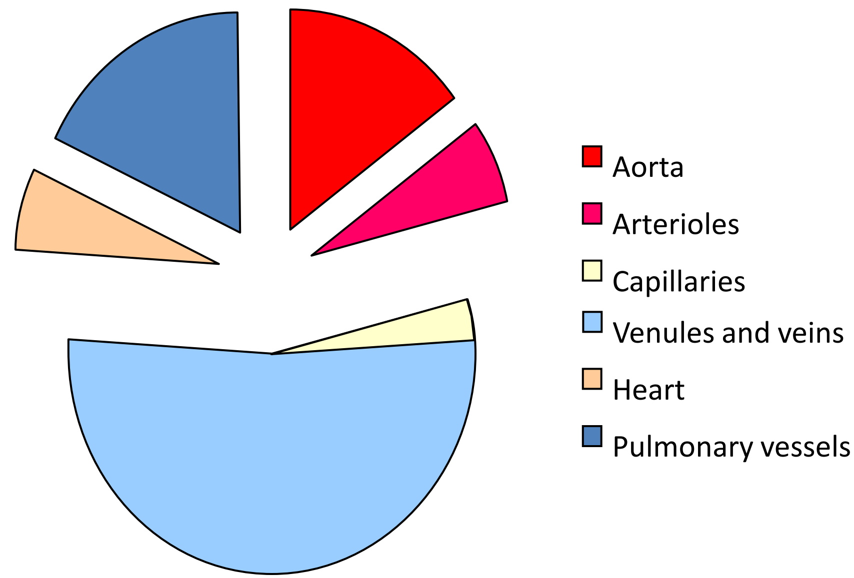
Relative areas and volumes in the circulation

Relative cross-sectional area



'Exchange' function

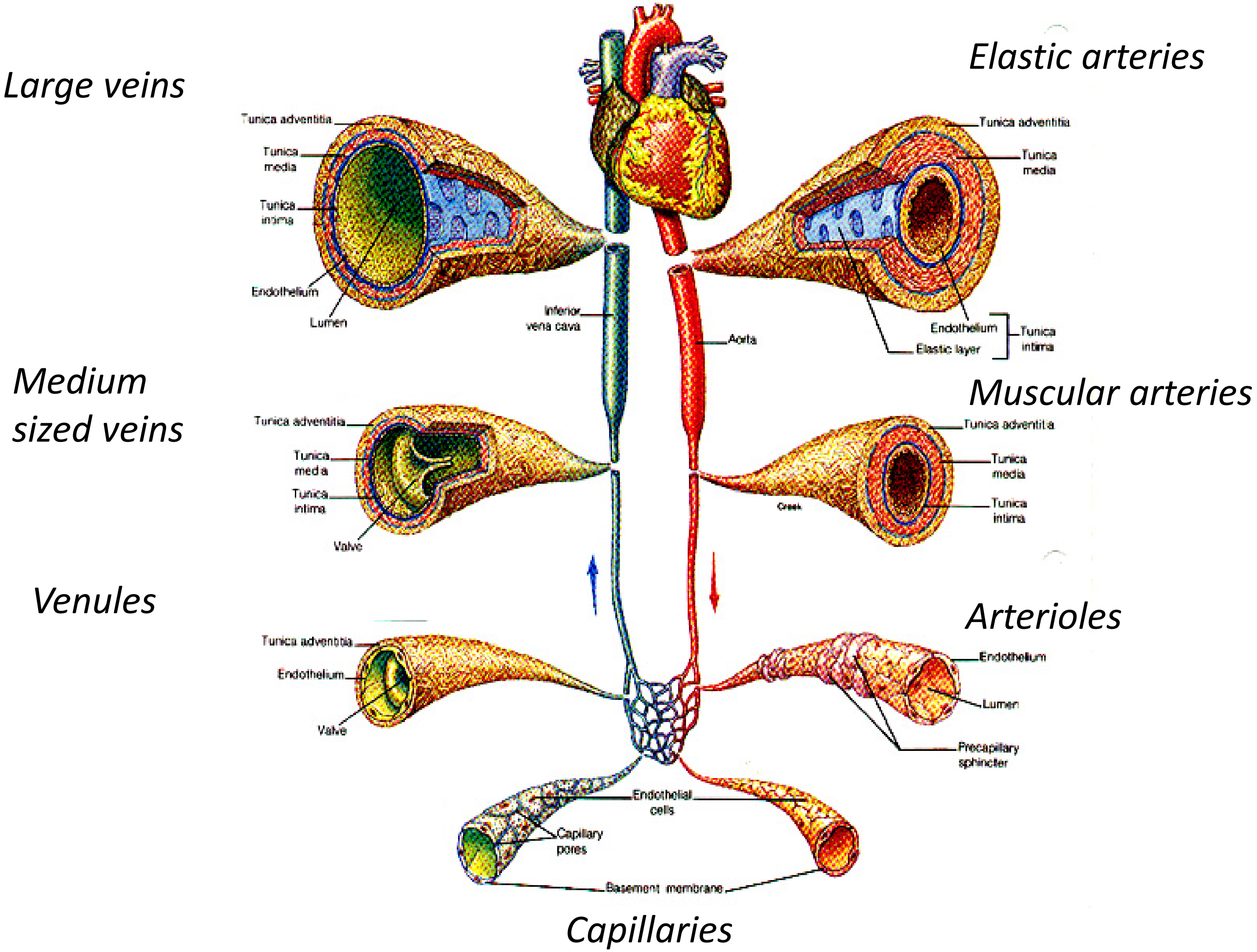
Blood Volume (Total = 5L)



'Reservoir' function

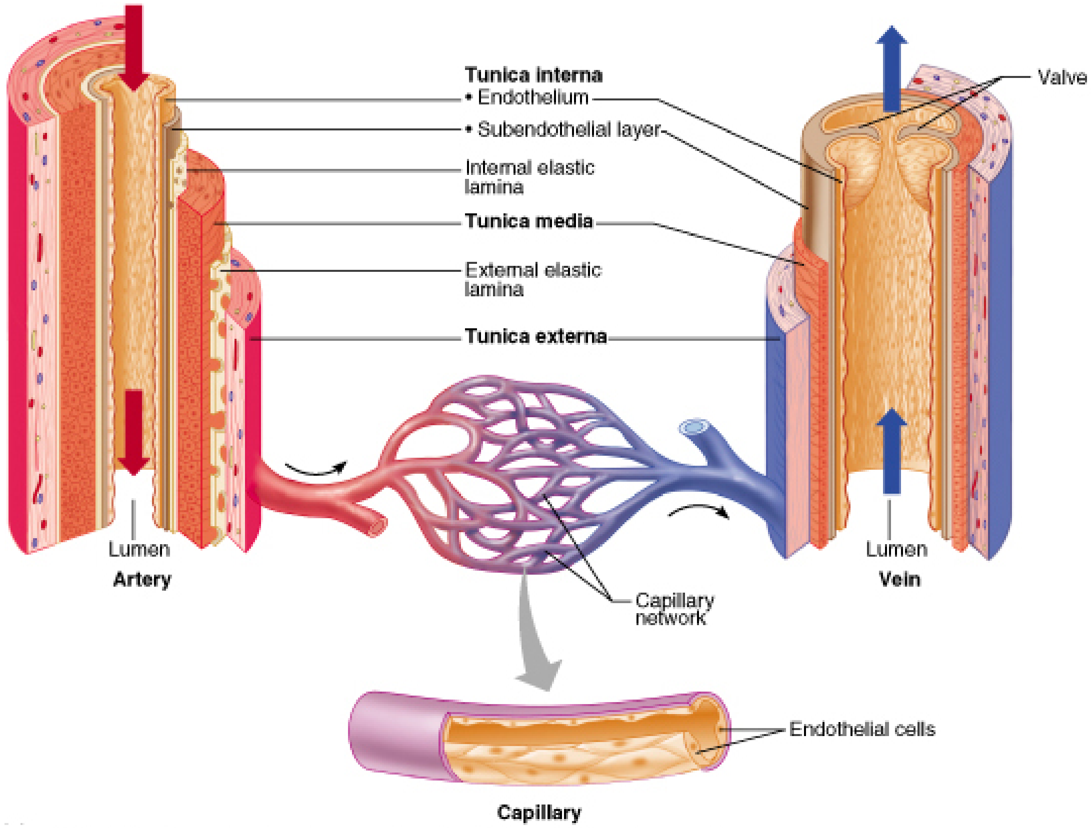
The anatomical design of the circulation

Chapter 19 : The Cardiovascular System: Blood Vessels. G.R. Pitts, J.R. Schiller, and J. F. Thompson

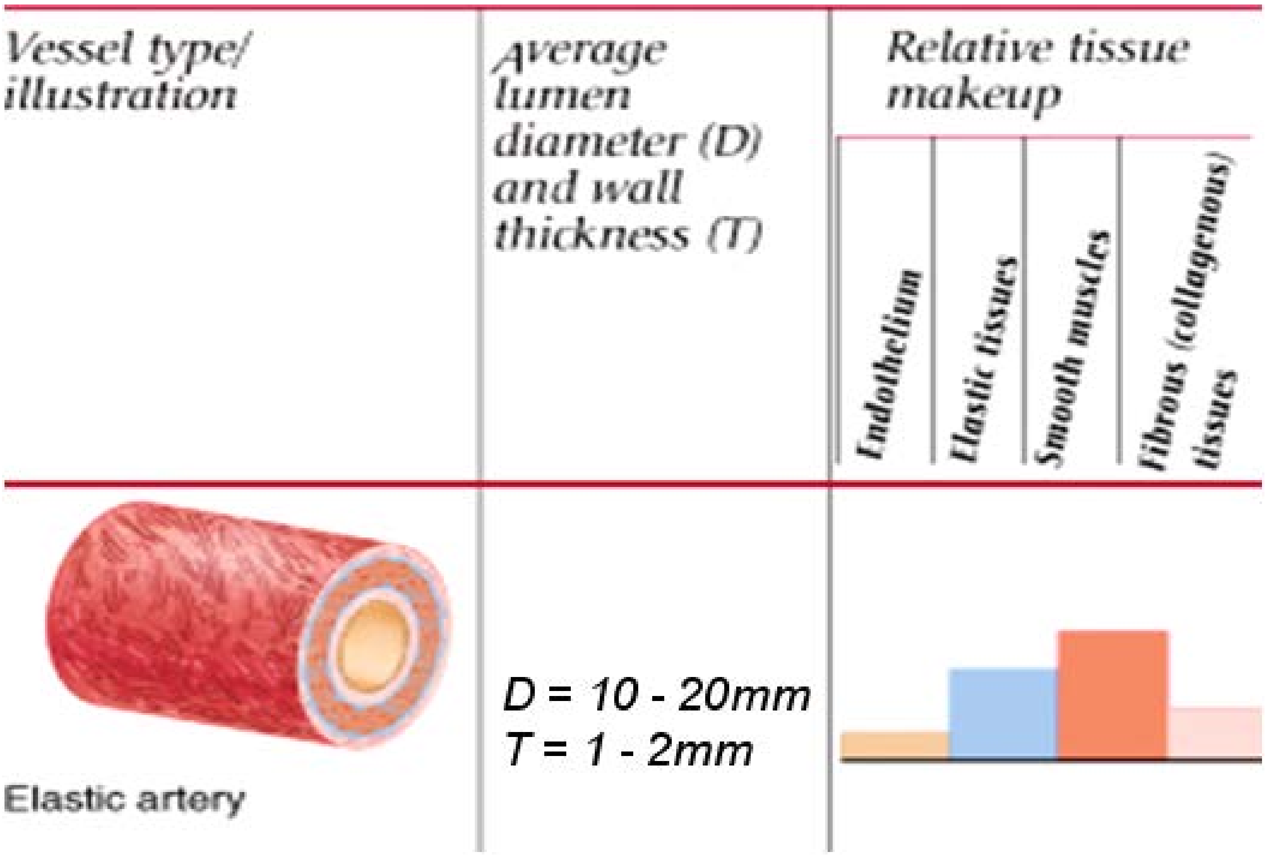


Arterial and Venular Structure

- Arteries and veins have a similar structure
  - Tunica adventitia (externa)
    - Collagen
    - Nerves
    - Vasa vasora
  - Tunica media
    - Smooth muscle and extracellular matrix
  - Tunica interna (intima)
    - Endothelium
    - Basement membrane
    - Internal elastic lamina

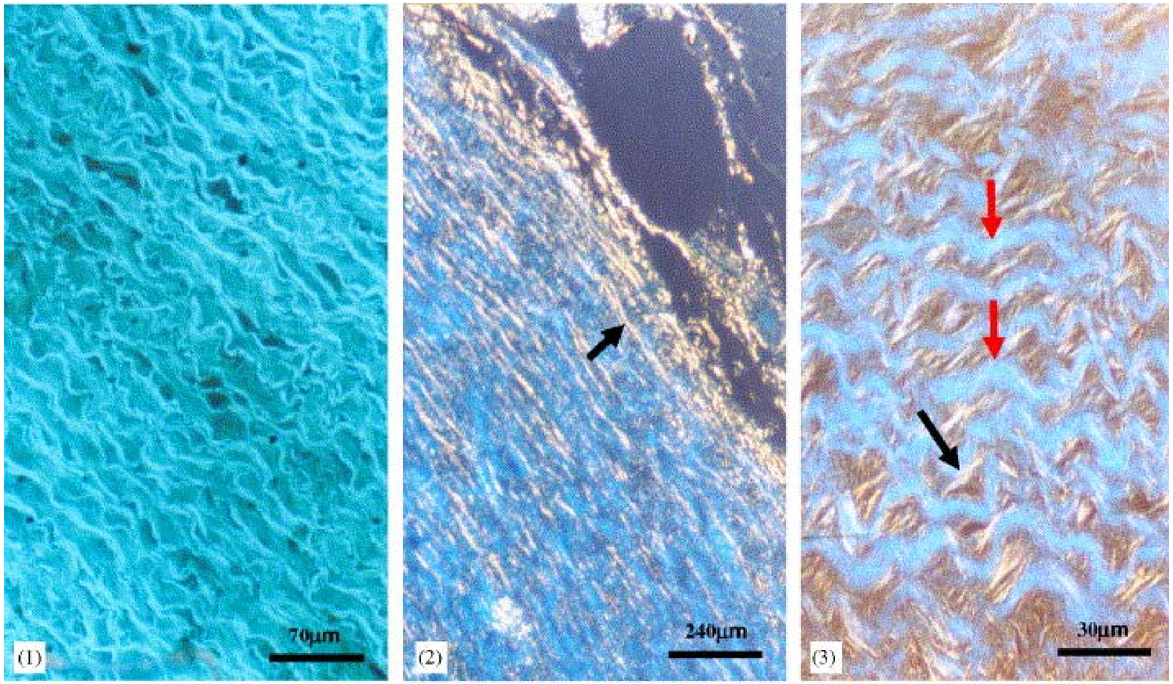


Aorta and elastic arteries



- Large diameter, thick walled arteries rich in elastin
- High compliance (distensibility) damps pressure fluctuation during the cardiac cycle

Elastin and lamellae in the aorta



Pig aorta stained with dansyl chloride

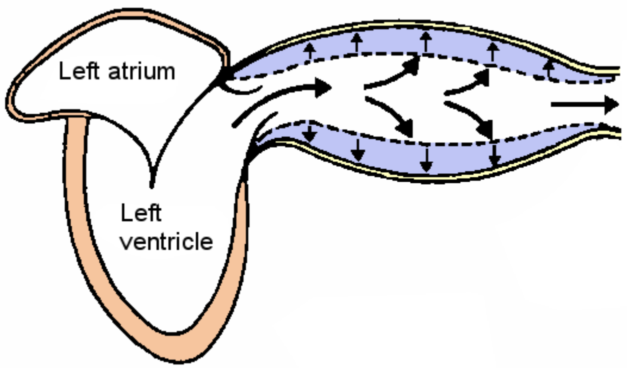
Braga-Vilela

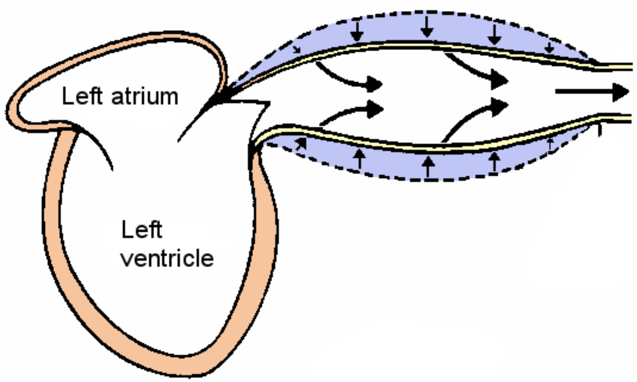
1) Fluorescence microscopy - elastic lamellae fluoresce blue
2) Polarized light microscopy. Black arrows indicate birefringent collagen fibrils.
3) Fluorescence and polarized light microscopy. Black arrows show collagen fibrils. Red arrows show elastic fibrils and lamellae.

The aorta and large elastic arteries show a lamellar structure.
Lamellae have a thickness of around 15µm in all species

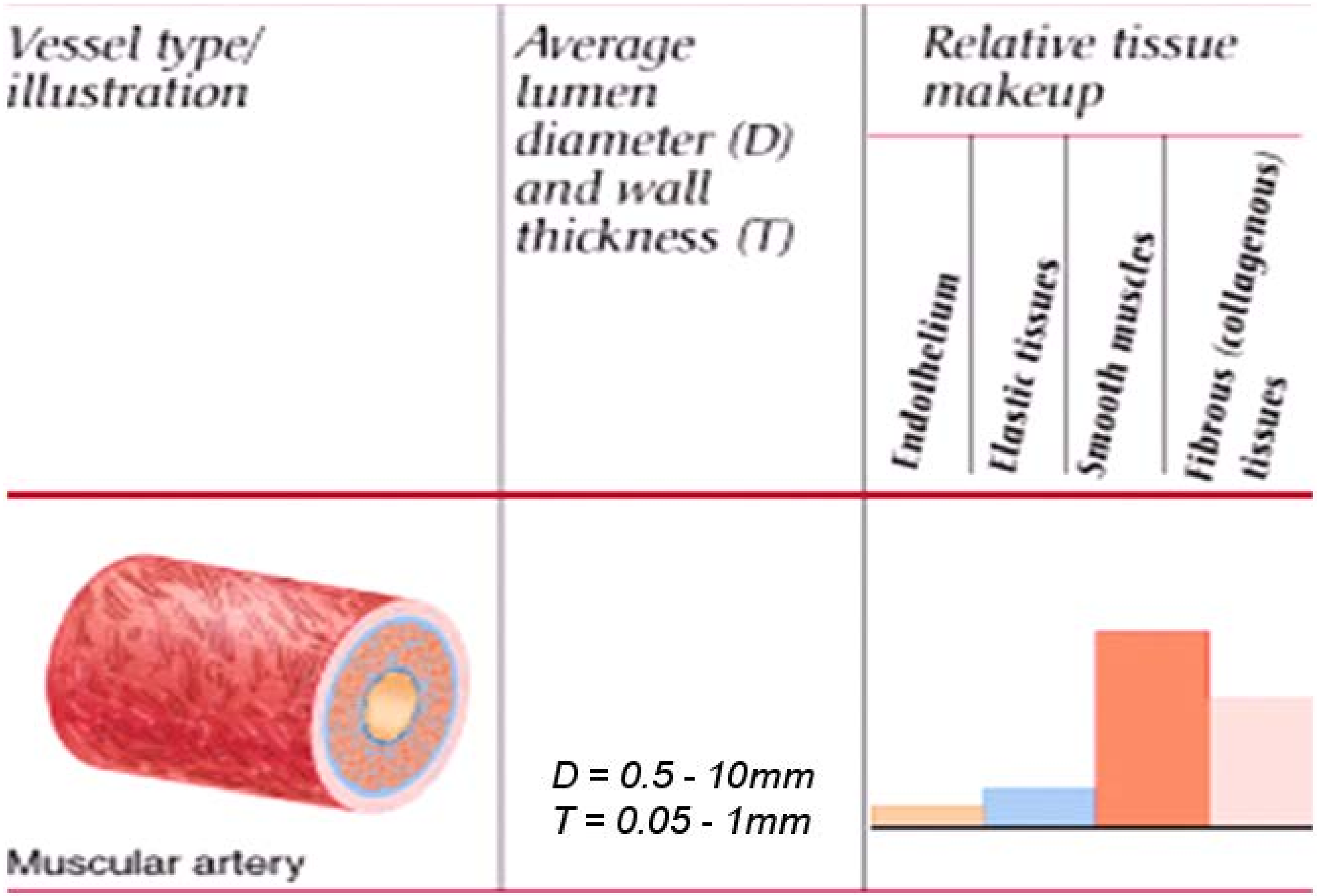
Arterial compliance and pulse pressure

- ~40% of the stroke volume is stored by the aorta and other elastic arteries during systole.
- The stored volume accounts for diastolic flow (there is no ejection by the heart in diastole).
- This is sometimes termed the ‘Windkessel’ and represents the effect of arterial compliance



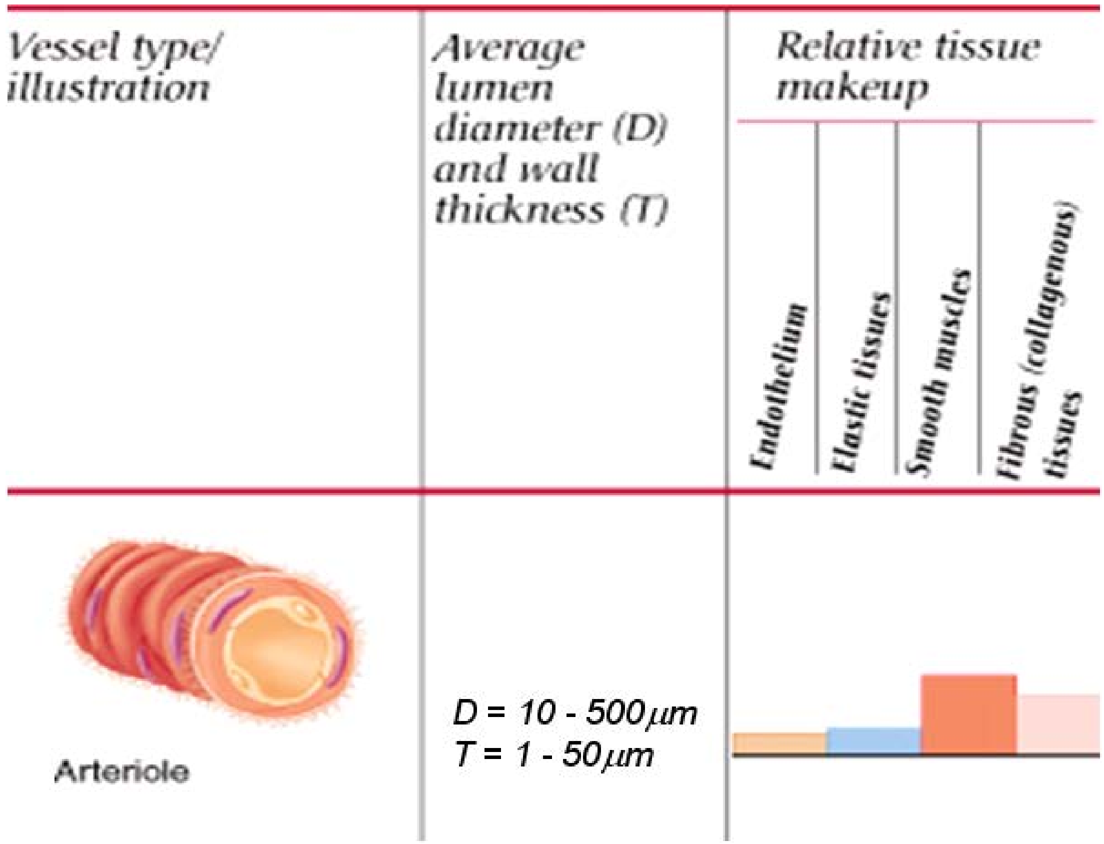


Muscular (conduit/distributing) arteries



- more smooth muscle cells, fewer elastic fibers than elastic arteries

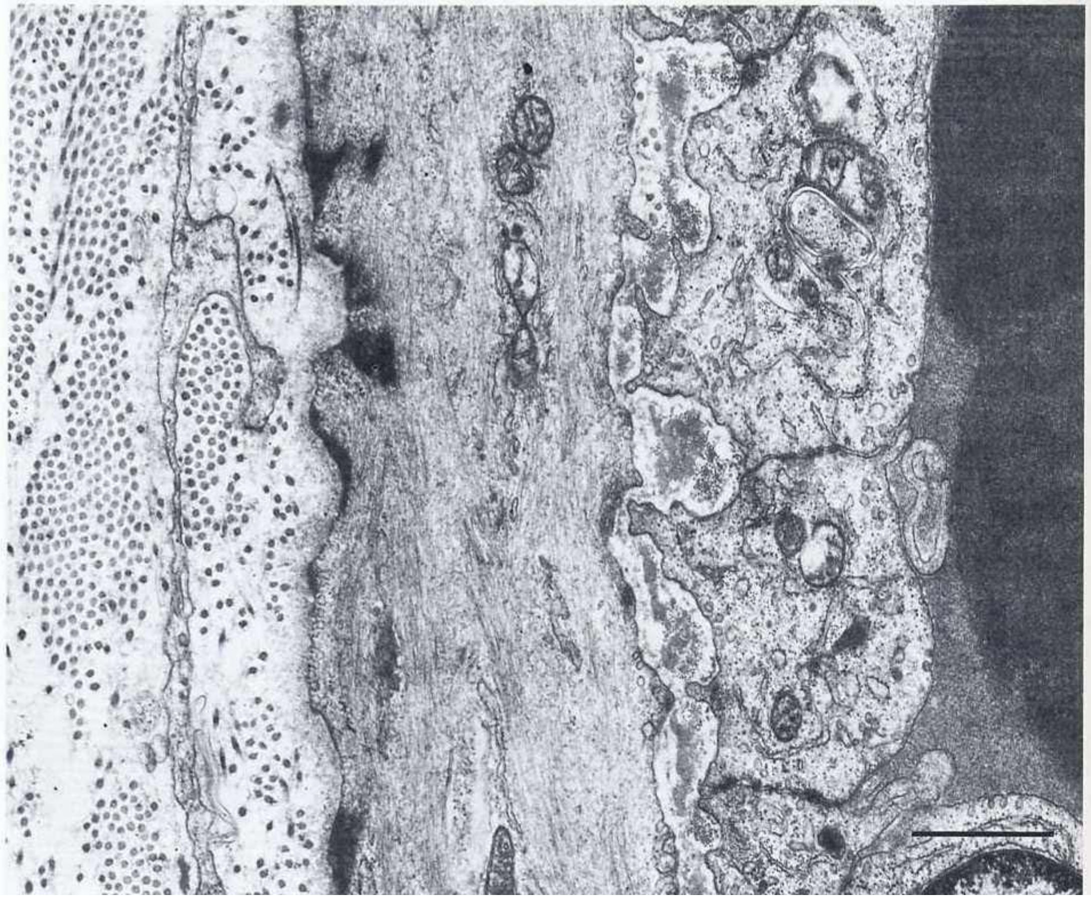
Small arteries and arterioles



- Regulate distribution of blood to and within organs
- regulate resistance and blood pressure by changing diameter

Cells in the arteriolar wall

adventitia *media* *intima* *lumen*



Small arteries and arterioles - contraction

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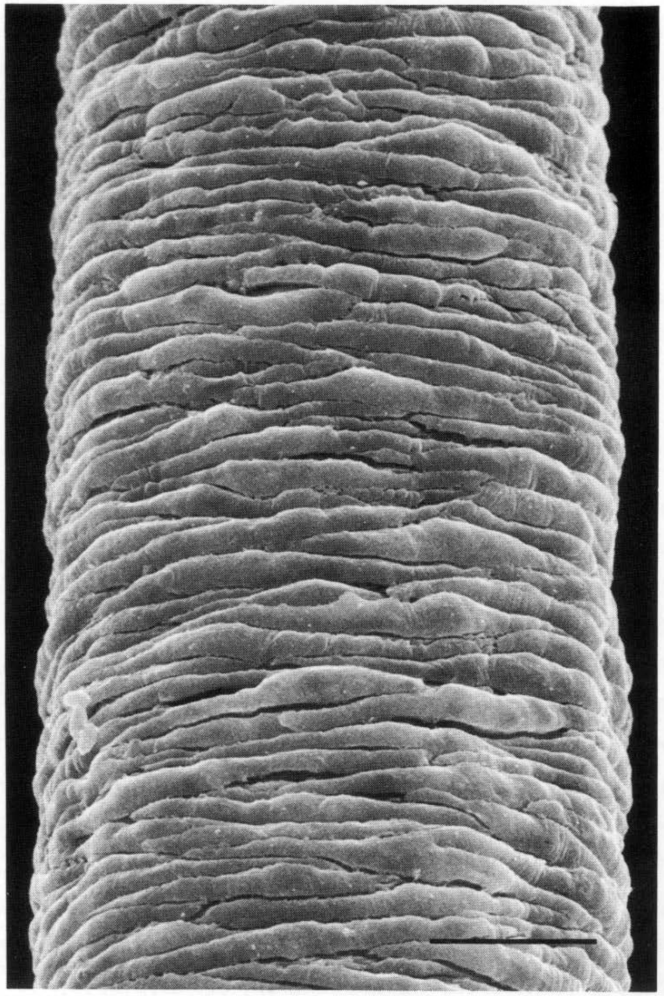

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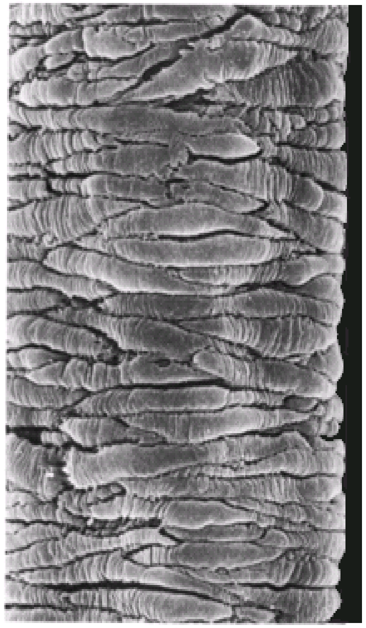
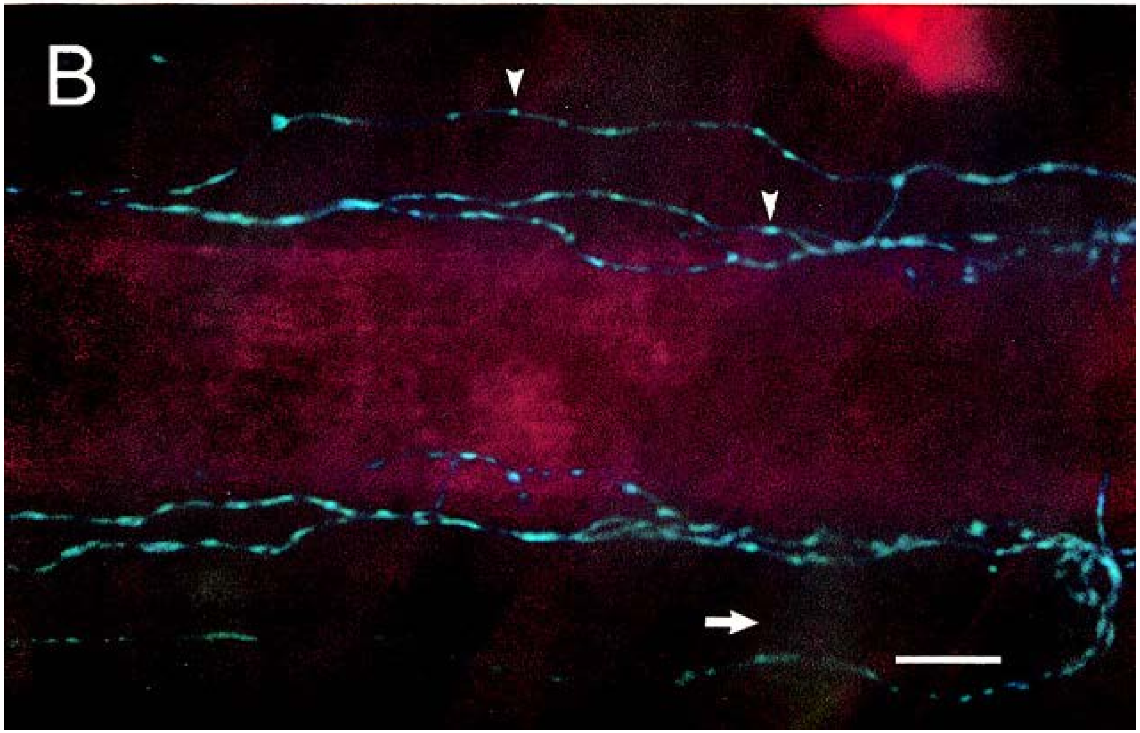


Sympathetic innervation of arterioles

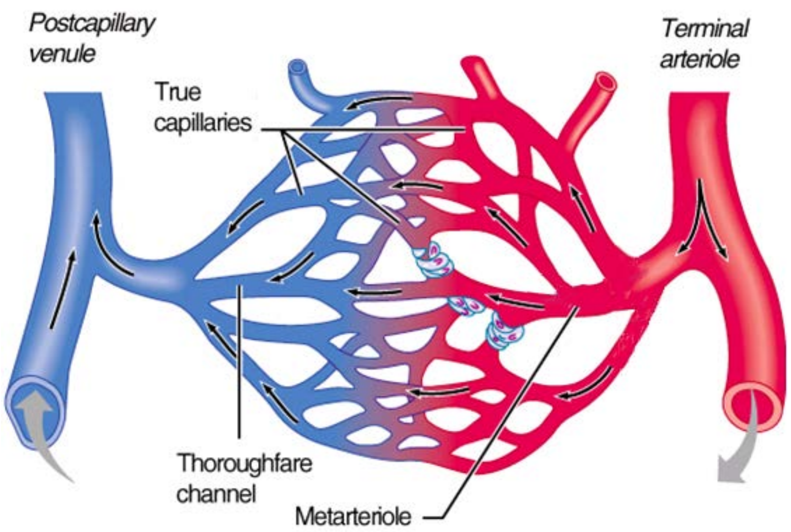


A high magnification view of a rat cremasteric arteriole catacholamine-containing varicosities (arrowheads) are visible (scale bar = 10 μm)

- Arteries and veins receive autonomic innervation (mainly sympathetic NS)
- Capillaries are rarely innervated

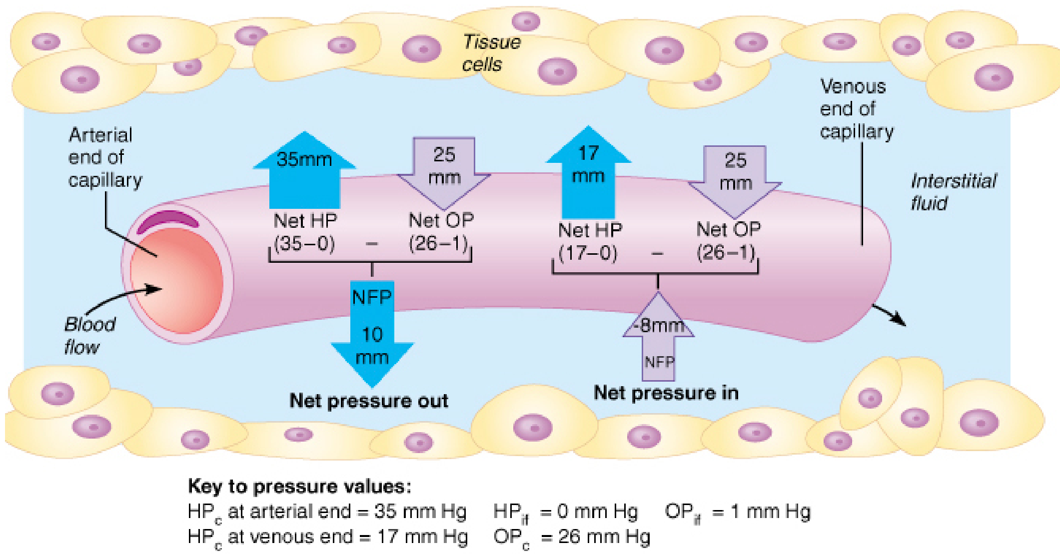
Hungerford et al., FASEB Journal. 2000;14:197-207

Microcirculation



- The microcirculation is located between arteries and veins
- the higher the metabolic activity, the denser the capillaries in a tissue
- Flow is intermittent and governed by vasomotion of terminal arterioles (pre-capillary sphincters probably artifact).
- Pericytes are associated with capillaries and important in angiogenesis and vascular maturation

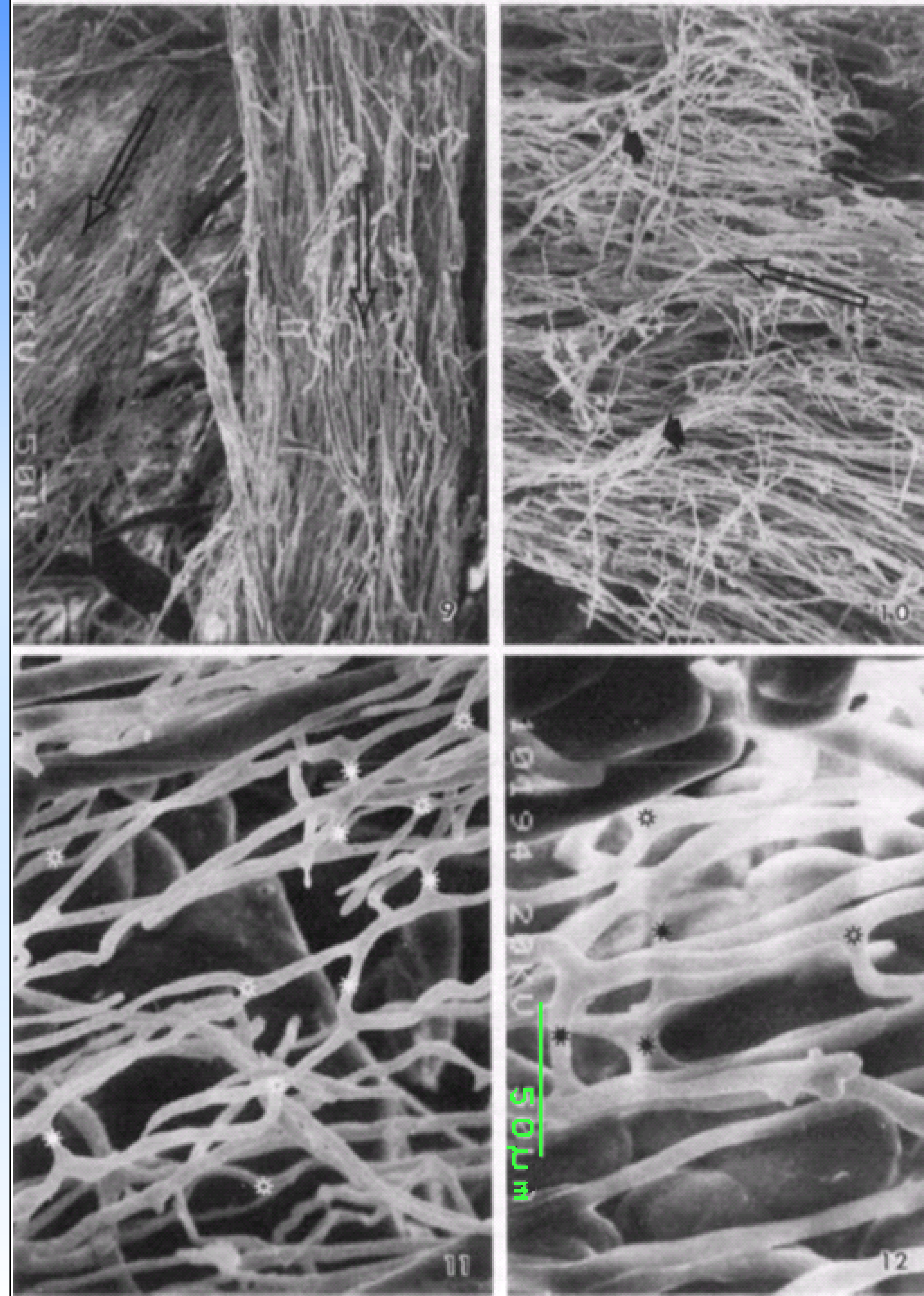
Fluid movement in capillaries – Starling's law



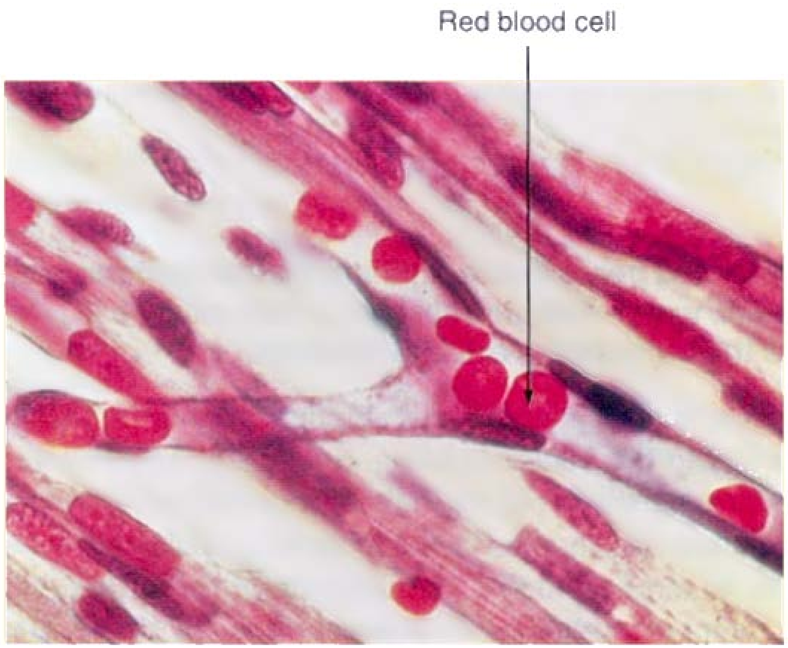
- Forces driving the movement of fluid
  - Hydrostatic pressure capillary (HP_c)
  - Hydrostatic pressure interstitial fluid (HP_{if})
  - Osmotic pressure capillary (OP_c)
  - Osmotic pressure interstitial fluid (OP_{if})
- **Net filtration pressure (NFP) is the net effect of all four forces at any point along the capillary**

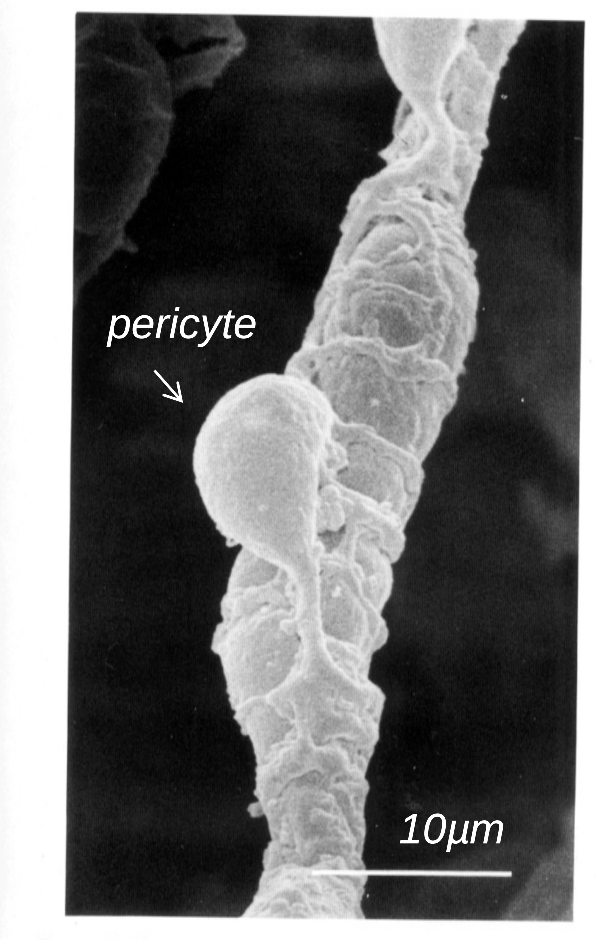
The branching structure of capillaries in the dog ventricle

(Anderson Am J Anat 1980; 158:217-227)



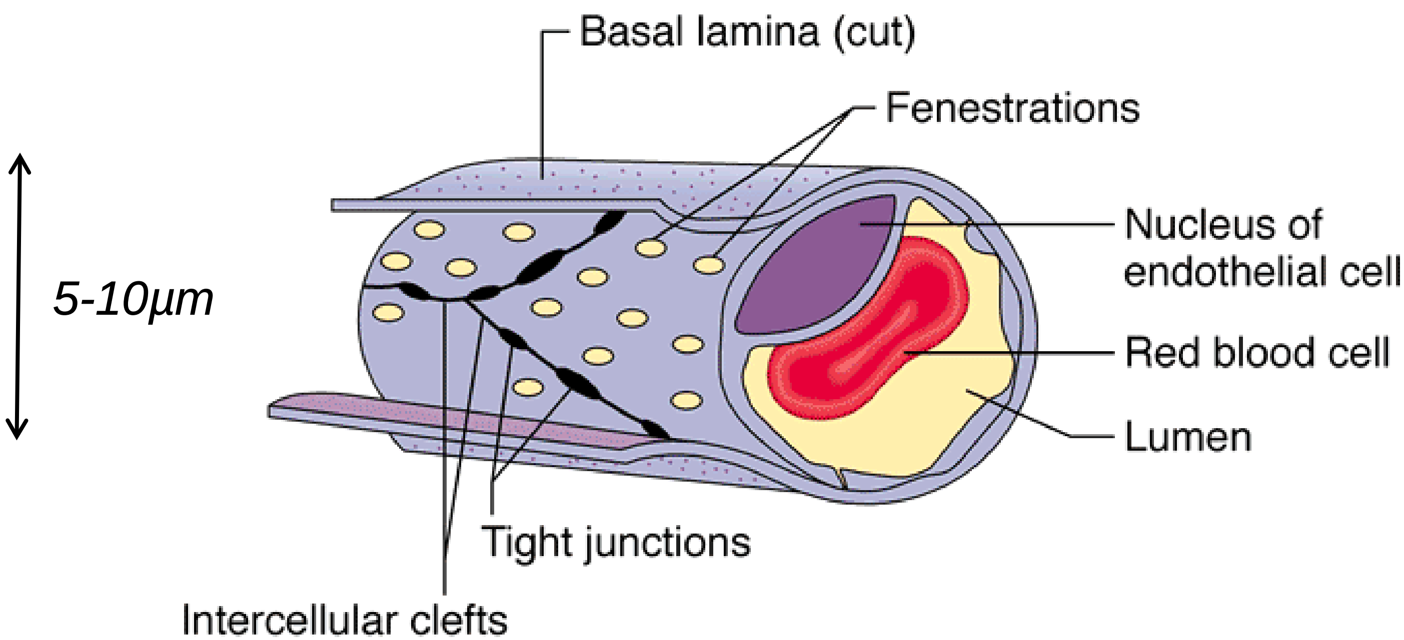
The microcirculation





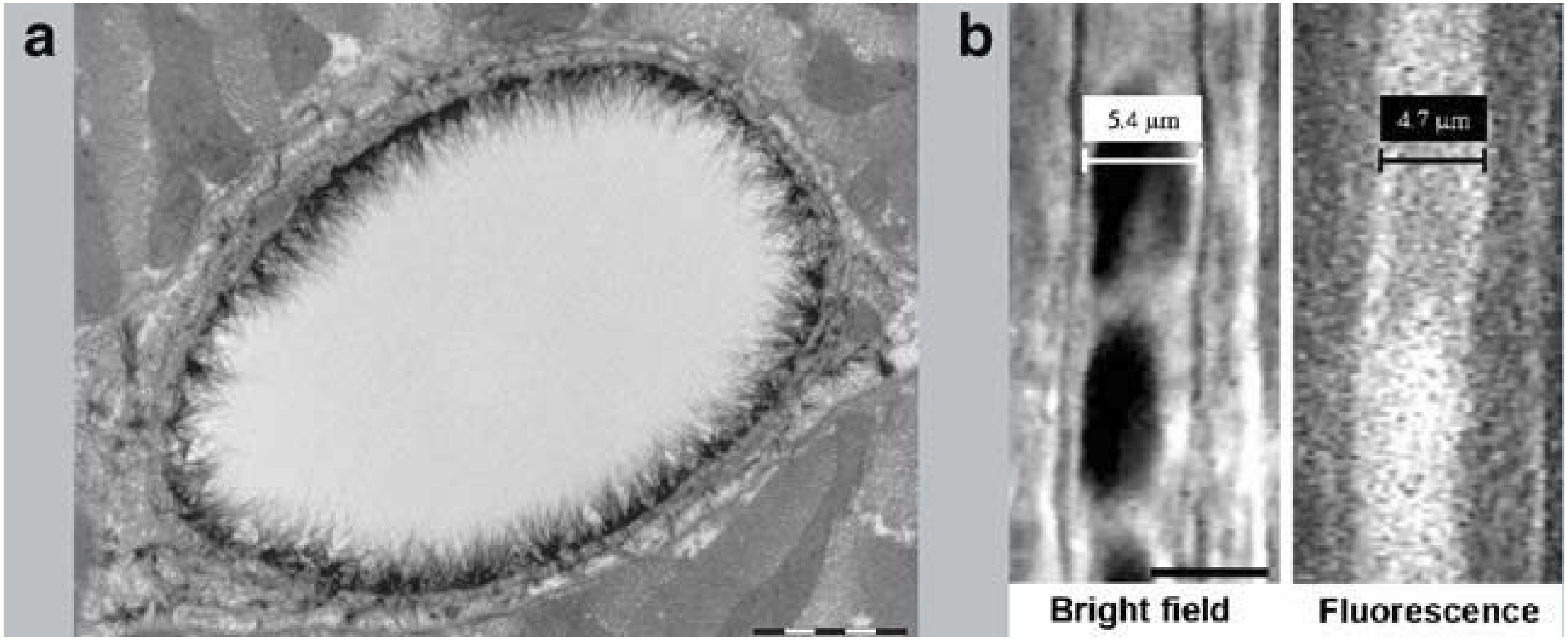
Capillary

Basic capillary structure



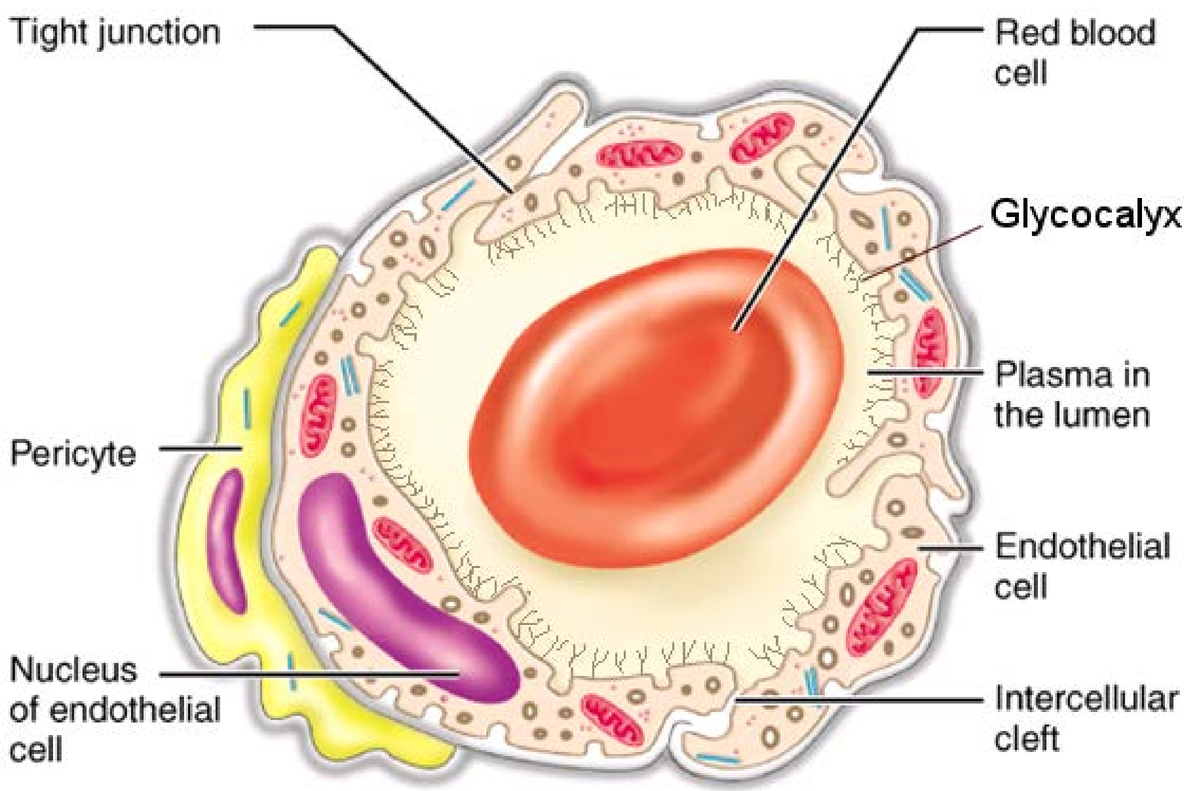
- Basal lamina (connective tissue), endothelial cells
- Details of structure determine specific functions
  - Types: continuous, fenestrated, sinusoid

Glycocalyx



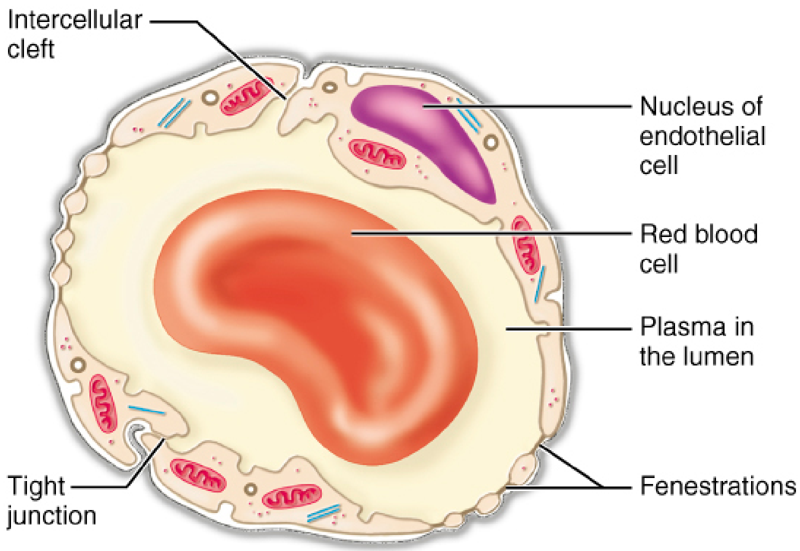
Visualization of the endothelial glycocalyx with different microscopic techniques. a Endothelial glycocalyx of a rat left ventricular myocardial capillary stained with Alcian blue 8GX and visualized using electron microscopy. Bar represents 1 µm. b Intravital microscopic recording of the endothelial glycocalyx of a hamster cremaster muscle capillary. The anatomical diameter of 5.4 µm is larger than the red blood cell column width (left pane) or the plasma column width (right pane) labelled with fluorescent dextran (70 kD). This difference is caused by the presence of the endothelial glycocalyx. Reitsma et al., Pflugers Arch - Eur J Physiol (2007) 454:345–359

Types of capillaries 1: *continuous capillaries*



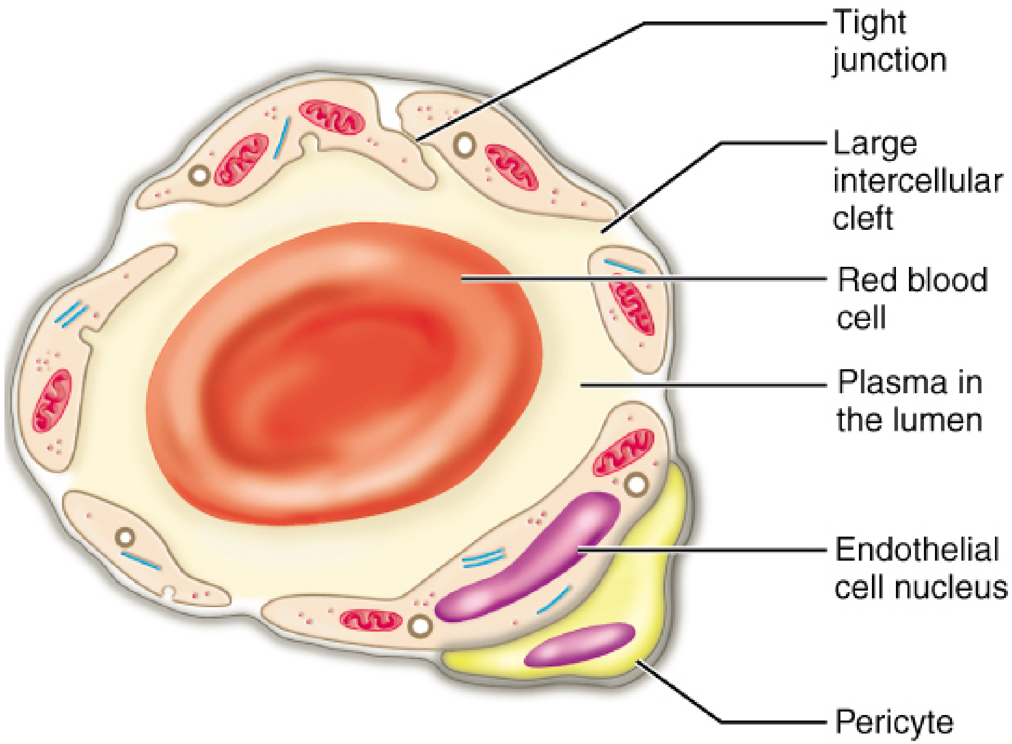
- continuous lining of endothelial cells except for the clefts between cells
- tight junctions between the endothelial cells
- most of the capillaries in the body

Types of capillaries 2: Fenestrated capillaries



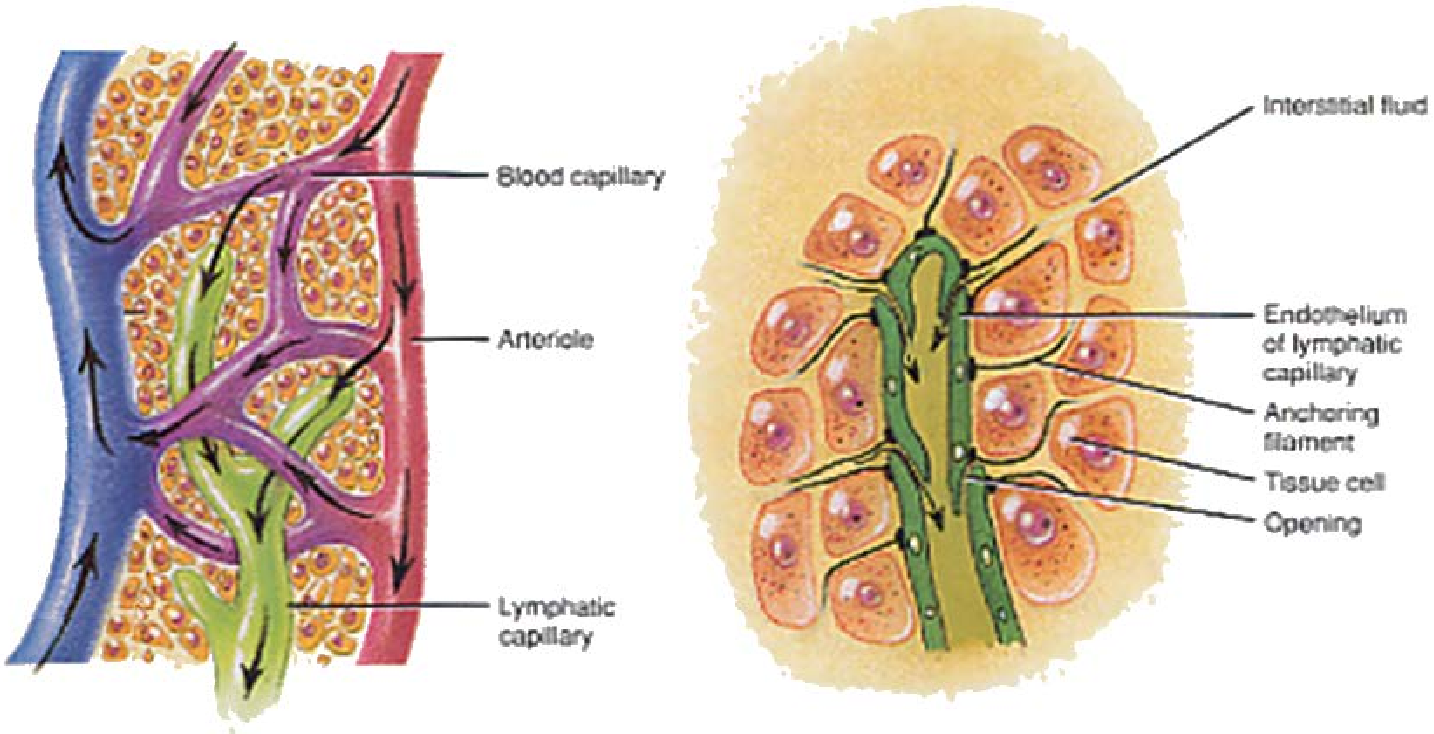
- fenestrations ("windows") are bridged by a thin membrane (ie not holes)
- More permeable to water and small lipid insoluble molecules
- Fluid exchange tissues
  - Kidney, exocrine glands, intestinal mucosa, joint synovium, chorid plexus, ciliary body of the eye.

Types of capillaries 3: Sinusoidal (discontinuous) capillaries



- wider intercellular gaps (>100μm)
- Highly permeable (even to plasma proteins and cells)
- found in tissues where red or white cells need to migrate in/out
  - e.g. liver, bone marrow, spleen, lymphoid tissue

Lymphatics

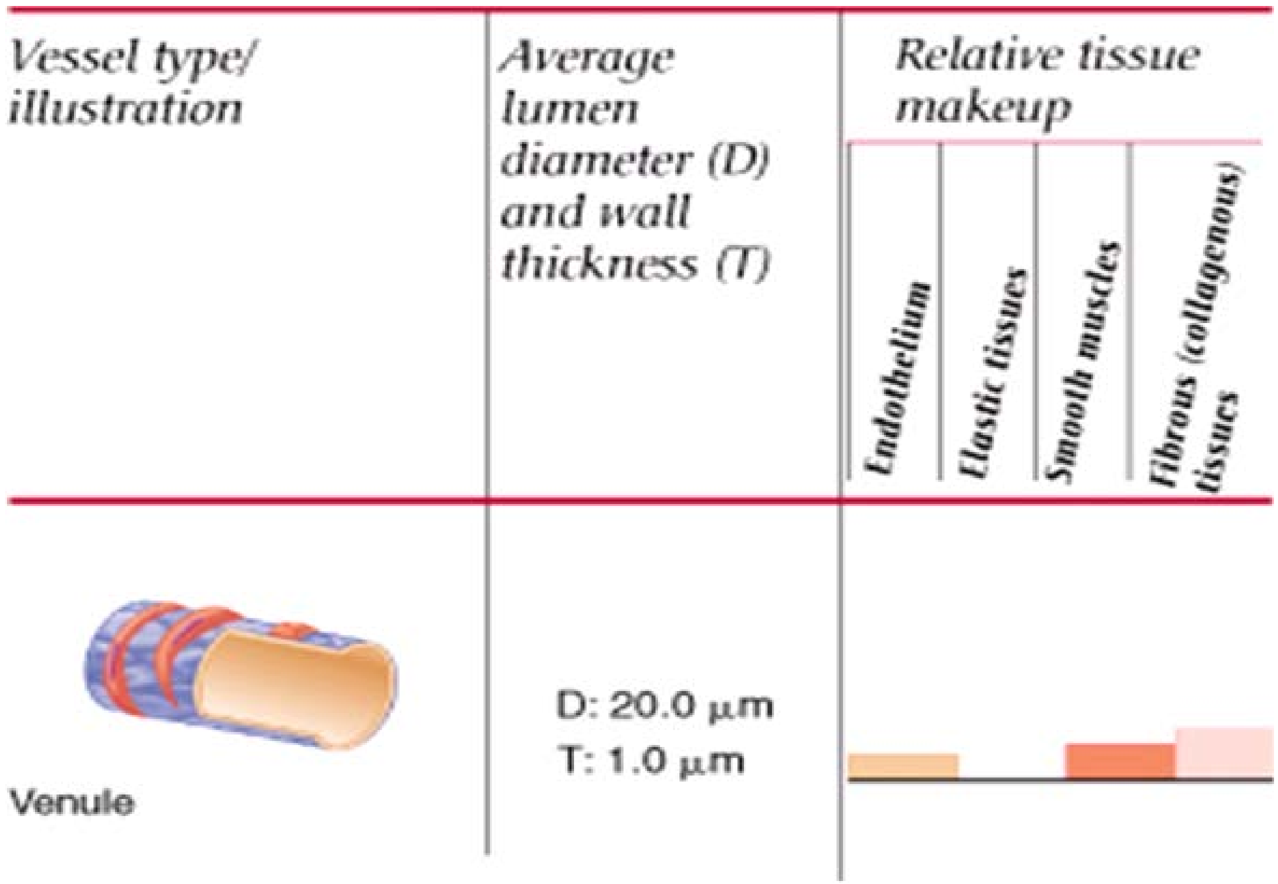


(a) Relationship of lymphatic capillaries to tissue cells and blood capillaries

(b) Details of a lymphatic capillary

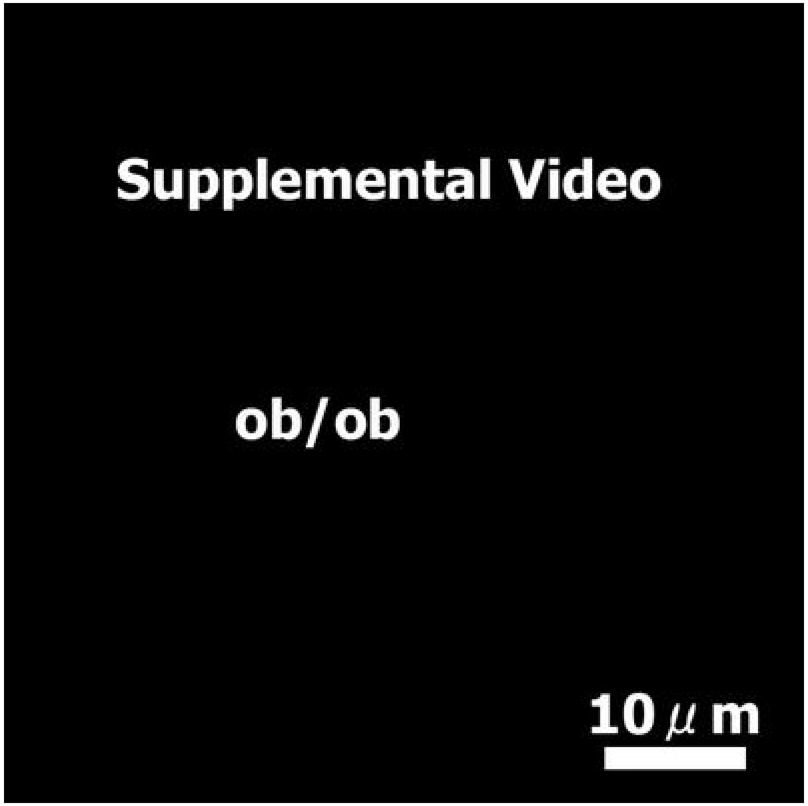
- Blind-ended terminal lymph vessels are ubiquitous in tissues
- Lymphatic endothelial cells overlap to form valve-like structures
- Interstitial fluid drains through lymphatic vessels

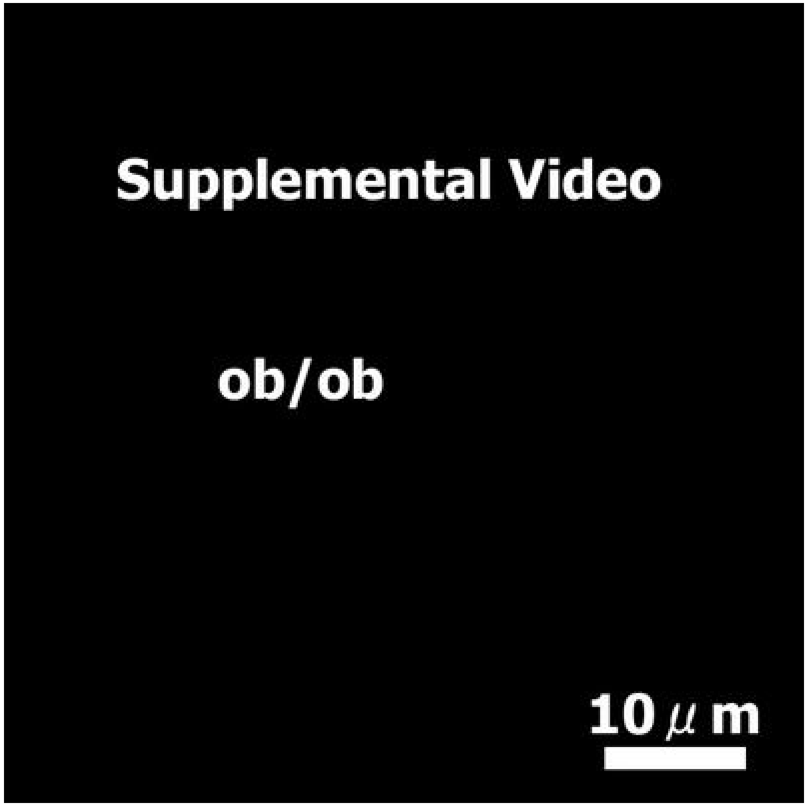
Venules



- Major site of emigration of leukocytes (e.g. in inflammation)
- More numerous than corresponding arteries and arterioles – low resistance to flow

Leukocytes in venules





In vivo imaging in mice reveals local cell dynamics and inflammation in obese adipose tissue J. Clin. Invest. Satoshi Nishimura, et al. 118:710 doi:10.1172/JCI33328

Veins

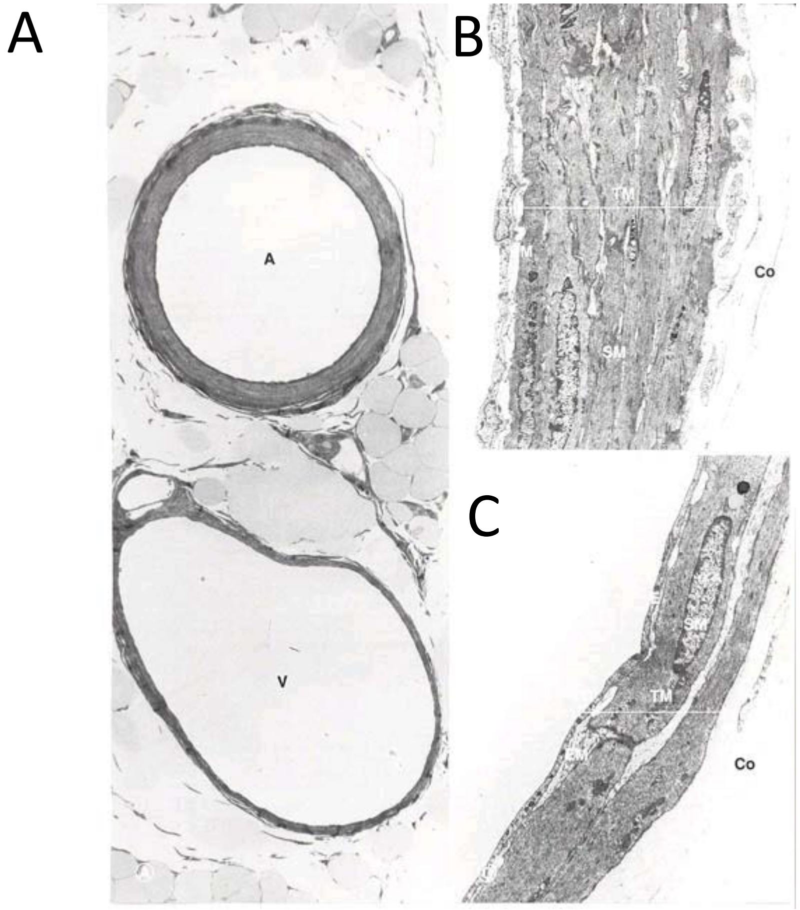
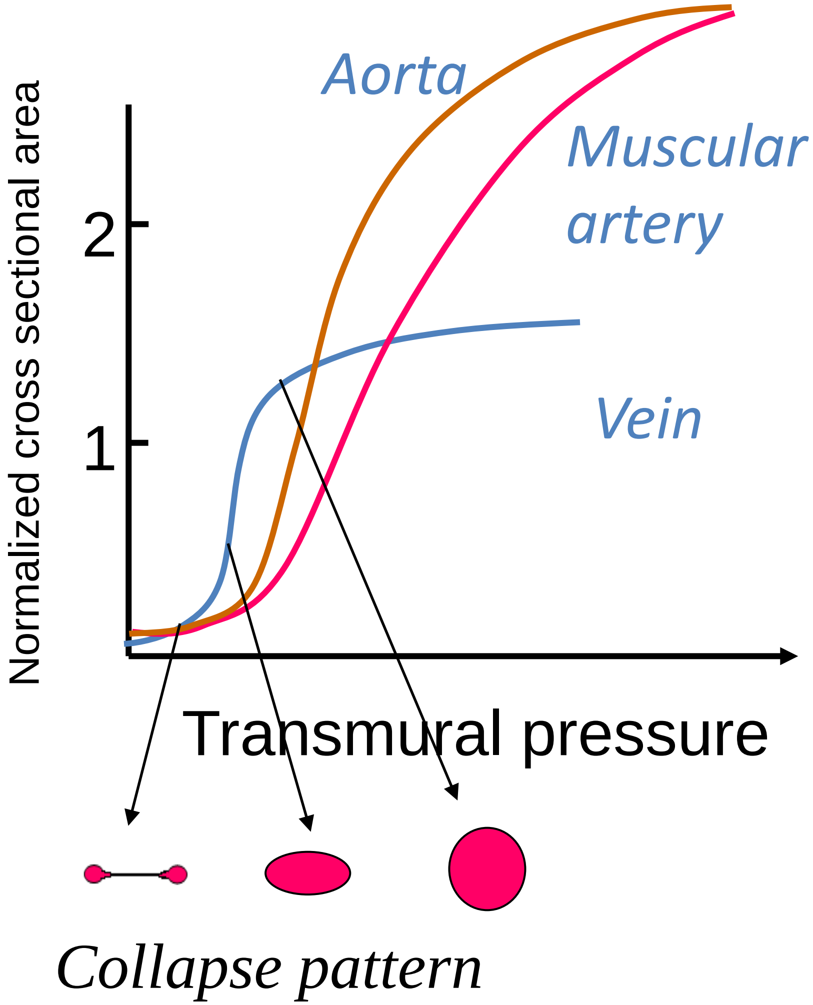


Figure A. Light micrograph of a cross section through a medium-sized artery and vein from the Testis of the squirrel monkey. A, artery; V, vein. 438 X
Figures B and C. Electron micrographs of cross sections taken through the walls of the same artery (Figure B) and vein (Figure C shown in Figure A. Co, Collagen fibrils; E, endothelial cell; EM, Internal Elastic Membrane; F, Fibroblast; N, nerve; SM, smooth muscle; TA, tunica Adventitia; TI, Tunica Intima; TM, Tunica Media. Figure B, 3,300X; Figure C, 8,900 X

- Veins are less muscular, layers less well defined than arteries
- Limb veins contain semi-lunar valves to prevent backflow (no valves in central veins and veins in the head)

Elastic properties of different vessel types



- All vessels show non-linear stress-strain relationships (due to combination of collagen + elastin)
- Veins are highly compliant <u>but</u> over a narrow pressure range
- Elastic arteries are more compliant than muscular arteries

Recommended reading

- Levick JR. An introduction to Cardiovascular Physiology, Hodder Arnold; 2003, ISBN: 0340809213
- Vogel S. Vital Circuits, Oxford University Press, 1991, ISBN 0195082699 (PBK)