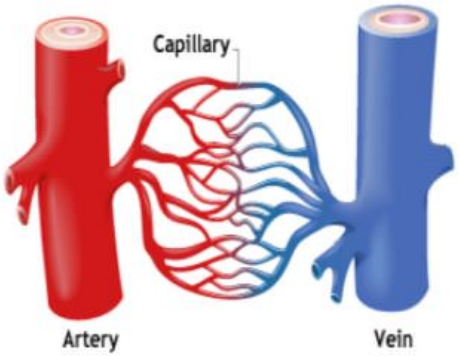
Veterinary Bioscience 1: Cardiovascular System

THE UNIVERSITY OF MELBOURNE

FACULTY OF VETERINARY & AGRICULTURAL SCIENCES



Blood vessels: structure and function

Dr Laura Dooley
laura.dooley@unimelb.edu.au

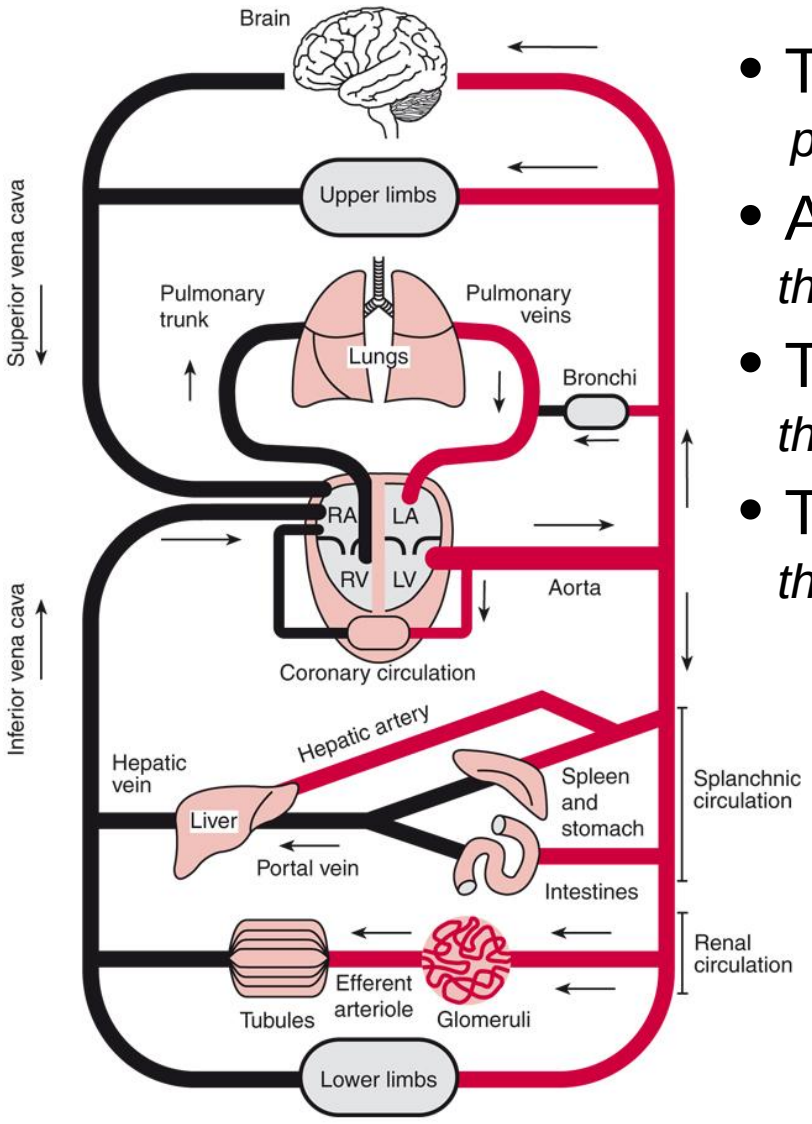
Vascular biology lectures

1. Structure and function of blood vessels
2. Vascular smooth muscle function
3. Special circulations

Intended learning outcomes

- Describe the basic components and structure of blood vessels
- Compare the structures of different types of arteries, veins & capillaries
- Describe the differences in blood flow velocity in different parts of the vascular bed, and relate these to their total cross sectional area
- Describe the pressure changes that occur as blood flows through a vascular bed, and relate these to the vascular resistance of various vascular segments
- Define total peripheral resistance (TPR) and explain the relationship between TPR and vascular resistance of each systemic organ
- Define vascular compliance and venous capacitance
- Describe the role of arterial compliance in storing energy for blood circulation
- Describe the relationships between arterial pressure, cardiac output and total peripheral resistance
- Explain the factors that contribute to venous return

Blood vessels: The big picture



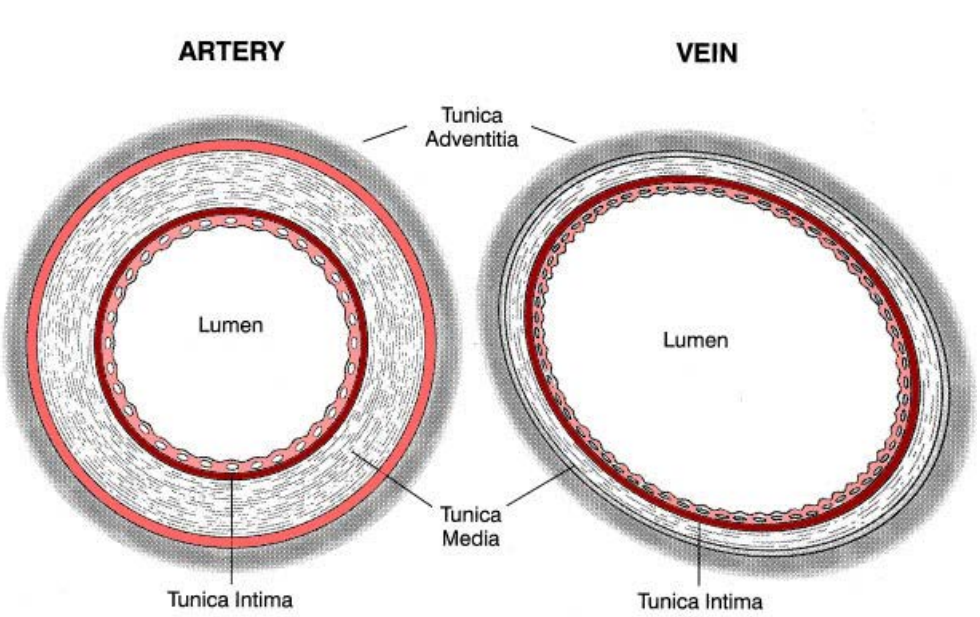
- The heart - the driving force
  propels blood around the body
- Arterial system
  the distribution channels
- The microcirculation
  the exchange vessels
- The venous system
  the blood reservoirs, return blood to the heart

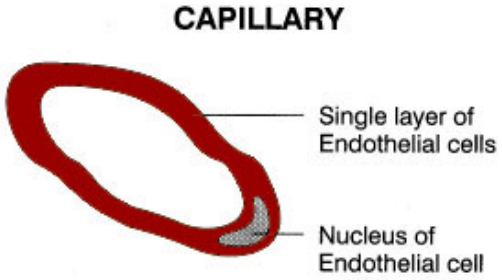
Blood flows only in one direction!

Blood vessel wall structure

Three layers:

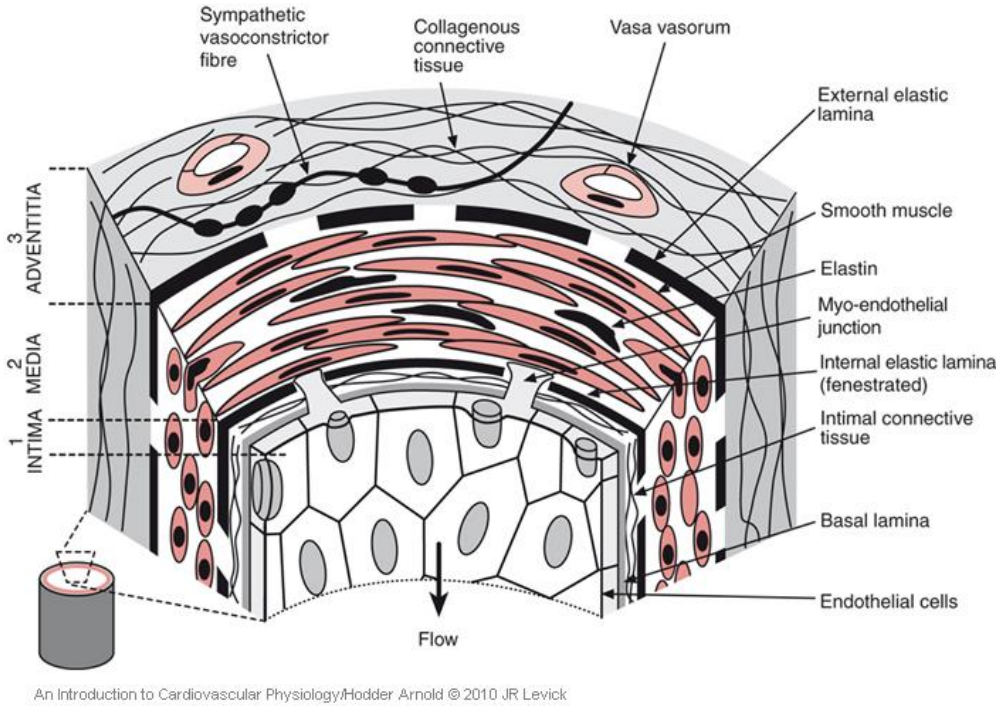
1. *Tunica intima* – inner layer
   - Function: barrier to prevent plasma escaping, secretes vasoactive mediators
2. *Tunica media* – middle layer
   - Function: mechanical strength and contractile power
3. *Tunica adventitia* – outer layer
   - Function: tethers vessel to surrounding tissues





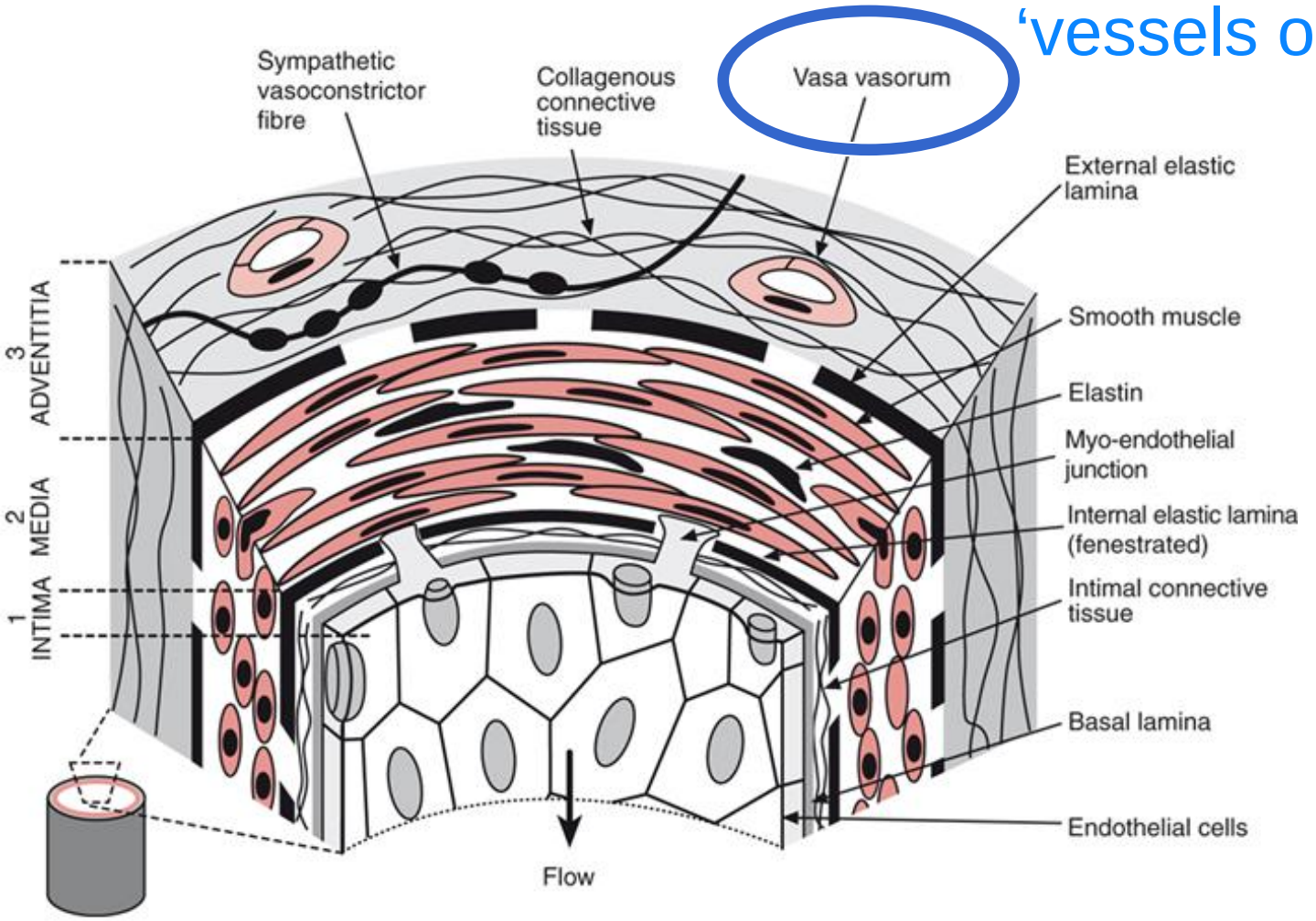
Arterial wall structure

- *Tunica intima*
  - Flattened endothelial cell layer
  - Basement membrane
  - Thin sub-endothelial c.t. layer
  - Internal elastic lamina
- *Tunica media*
  - SMC and elastic fibres in concentric layers
  - External elastic lamina
- *Tunica adventitia*
  - Connective tissue blends with surrounding tissue
  - Contains small blood vessels (in larger aa.)



Arterial wall structure

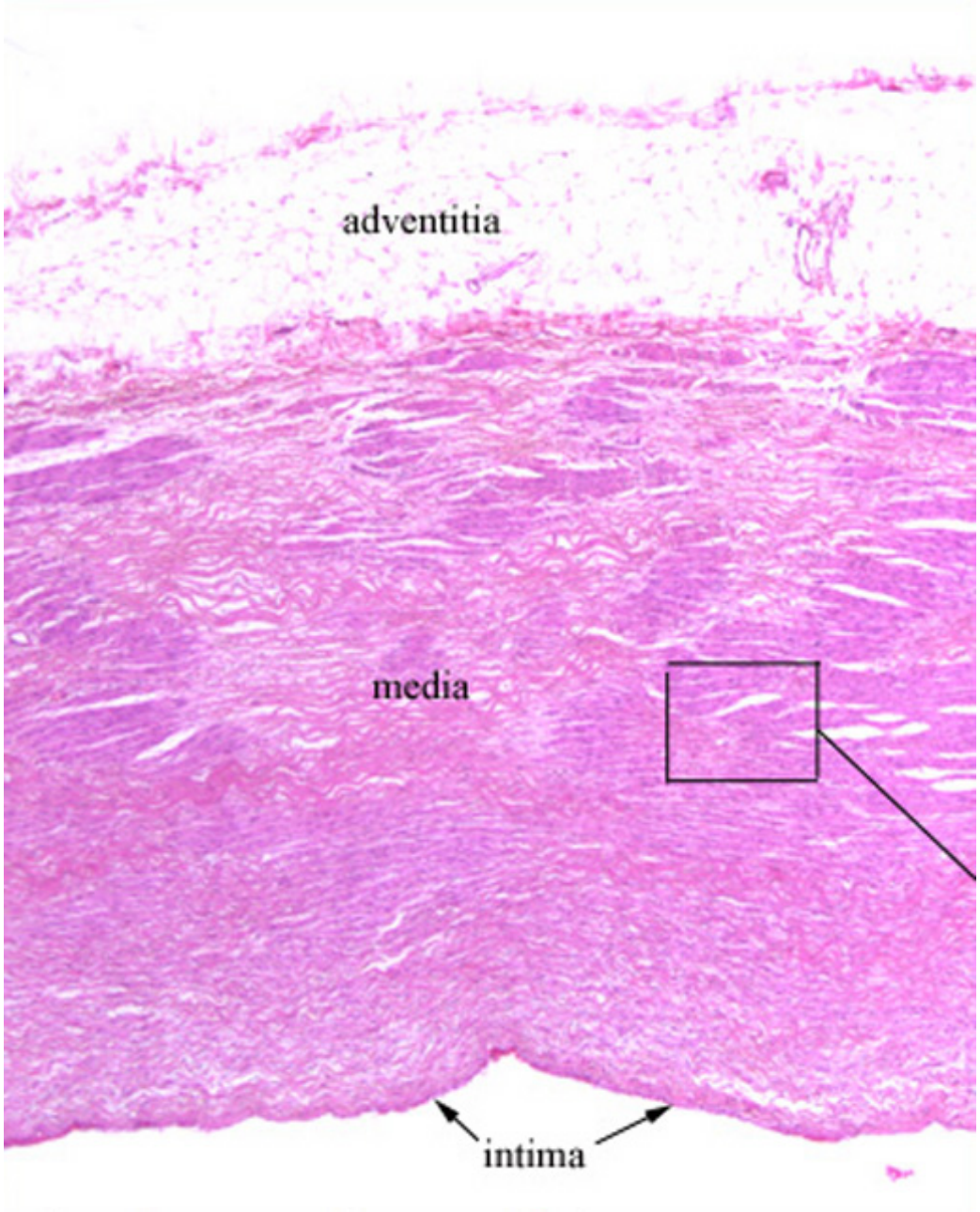
‘vessels of vessels’

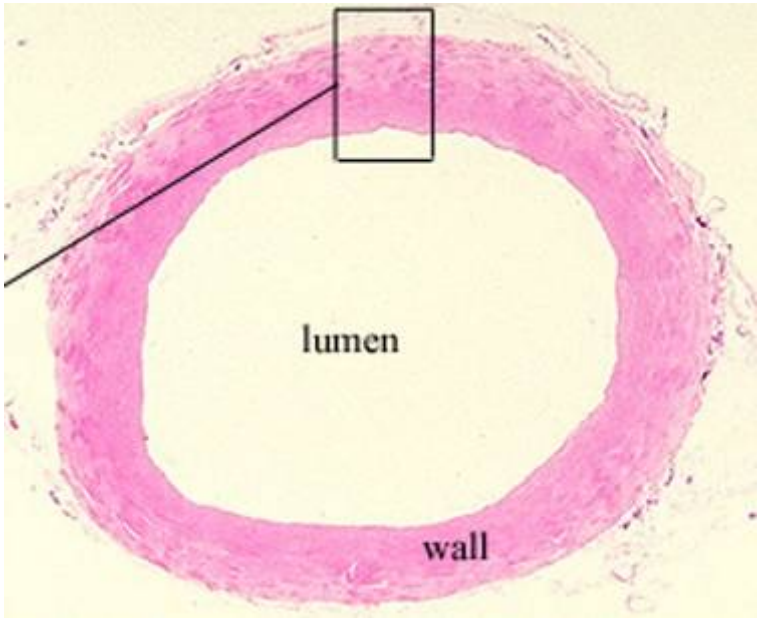


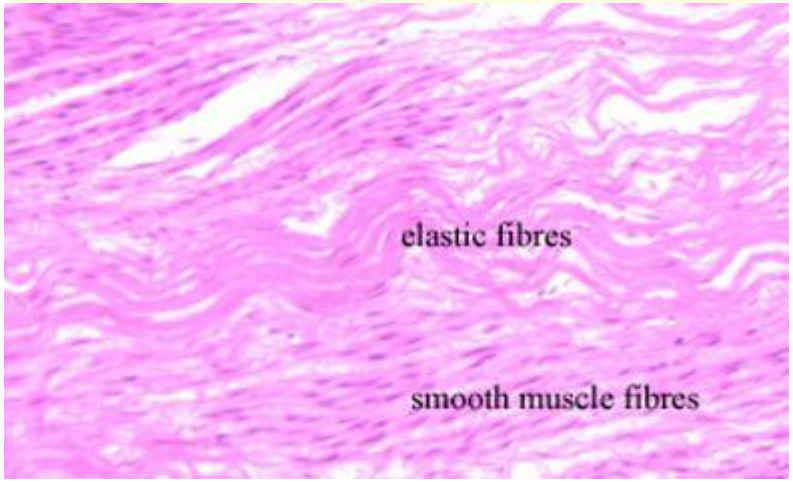
An Introduction to Cardiovascular Physiology/Hodder Arnold © 2010 JR Levick

Functional significance of vessel wall components

- Smooth continuous endothelium
  - low frictional resistance
- Elastic lamina and elastic fibres
  - elasticity during pulsatile pressure changes
- Smooth muscle cells
  - regulate the internal calibre of the vessel lumen
- Collagen fibres
  - Protection against stresses


adventitia
media
intima


lumen
wall


elastic fibres
smooth muscle fibres

Blood vessels: anatomical groupings

There are **9 main types**:

1. Elastic arteries
2. Muscular arteries
3. Arterioles
4. Metarterioles
5. Capillaries
6. Sinusoids
7. Postcapillary venules
8. Muscular venules
9. Veins

Exchange vessels

Blood vessels: functional groups

Each vessel has at least one extra role besides conducting blood!

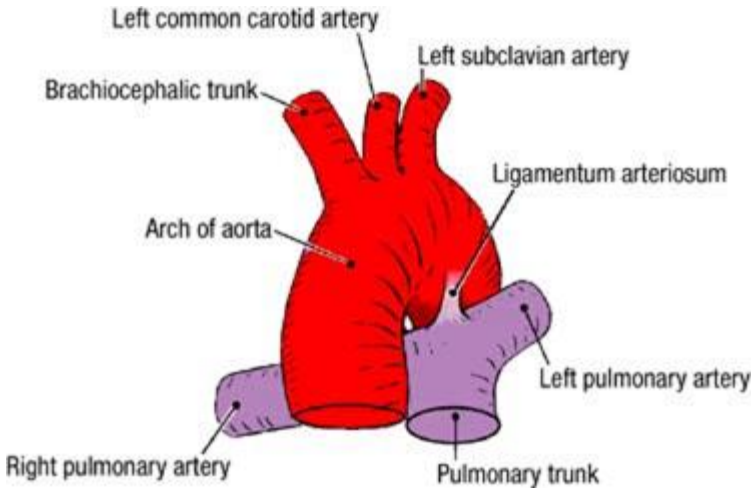
Functional groups

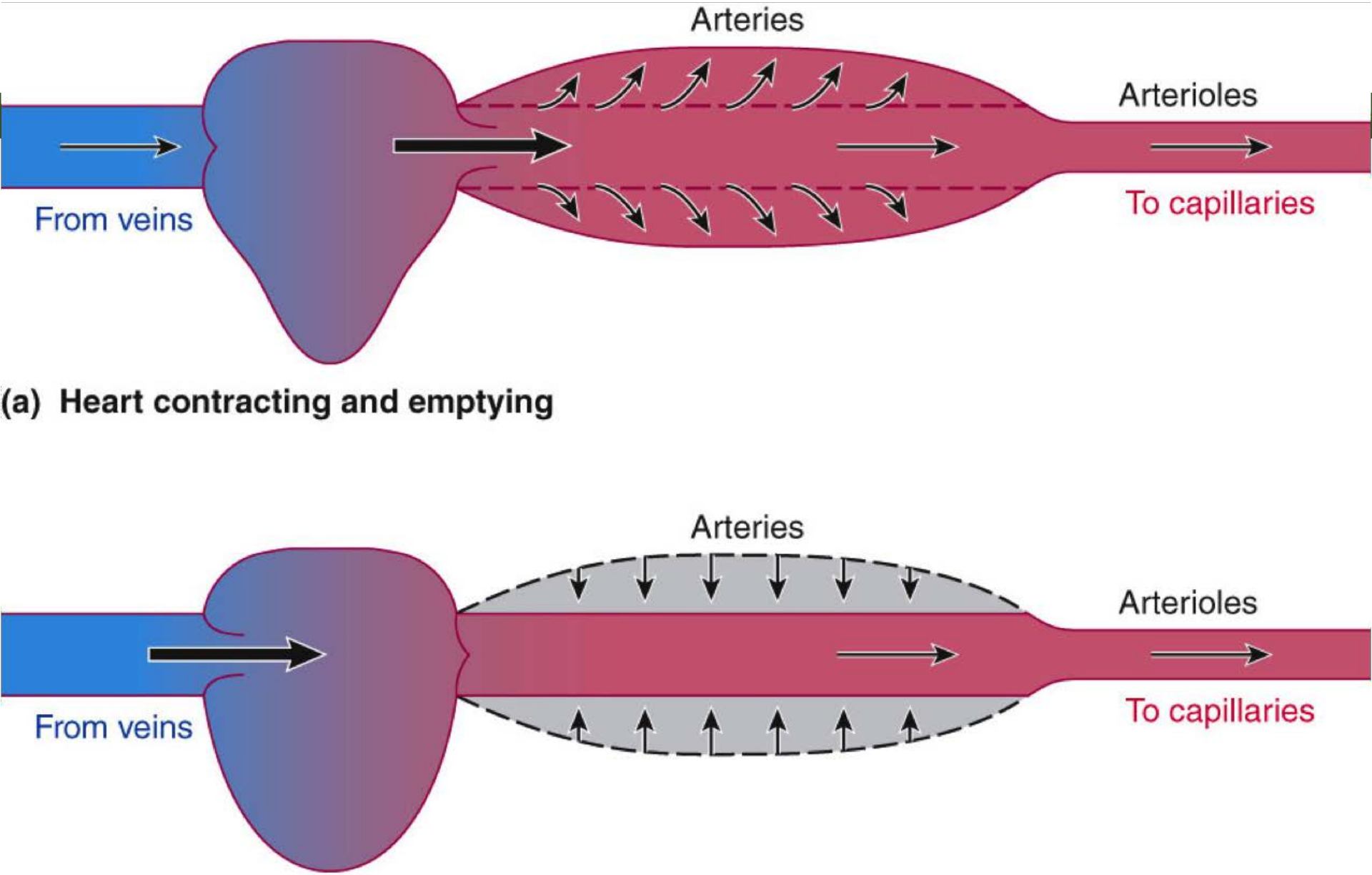
1. Conducting arteries
2. Distributing arteries
3. Resistance vessels
4. Exchange vessels
5. Capacitance (reservoir) vessels

Blood vessels: functional groups

1. Conducting arteries

- Elastic arteries – large and thick-walled
- Very distensible → lots of elastin in their wall
- Recoil when stretched:
    - Temporary blood storage vessels
    - Arterial pressure maintained despite intermittent ejection of blood from the heart
- Most *compliant* arteries
- e.g. aorta, pulmonary, brachiocephalic, subclavian and common carotid aa.




Arteries
Arterioles
From veins
To capillaries
(a) Heart contracting and emptying
Arteries
Arterioles
From veins
To capillaries
(b) Heart relaxing and filling

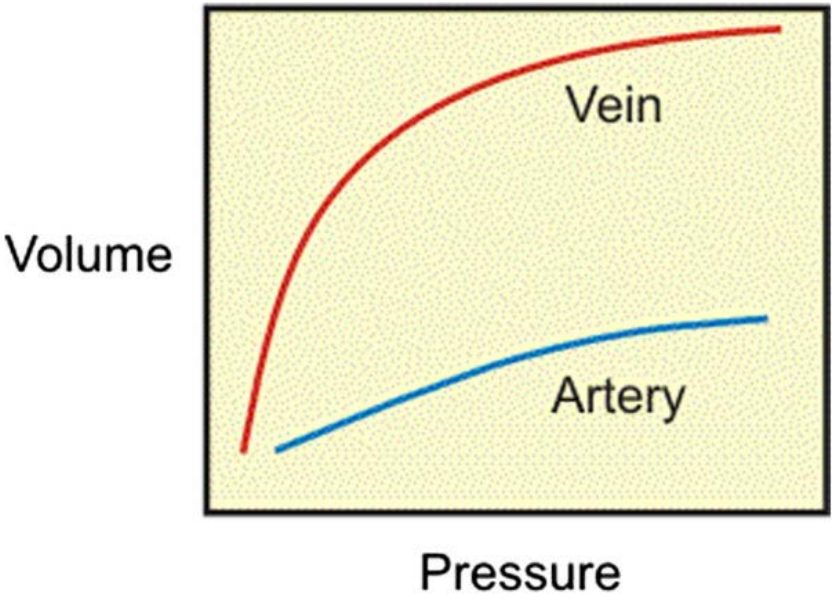
Elastic properties of vessels

- Very important for cardiovascular function
- Compliance: degree of volume change when distending pressure increases

$$C = \Delta V / \Delta P$$

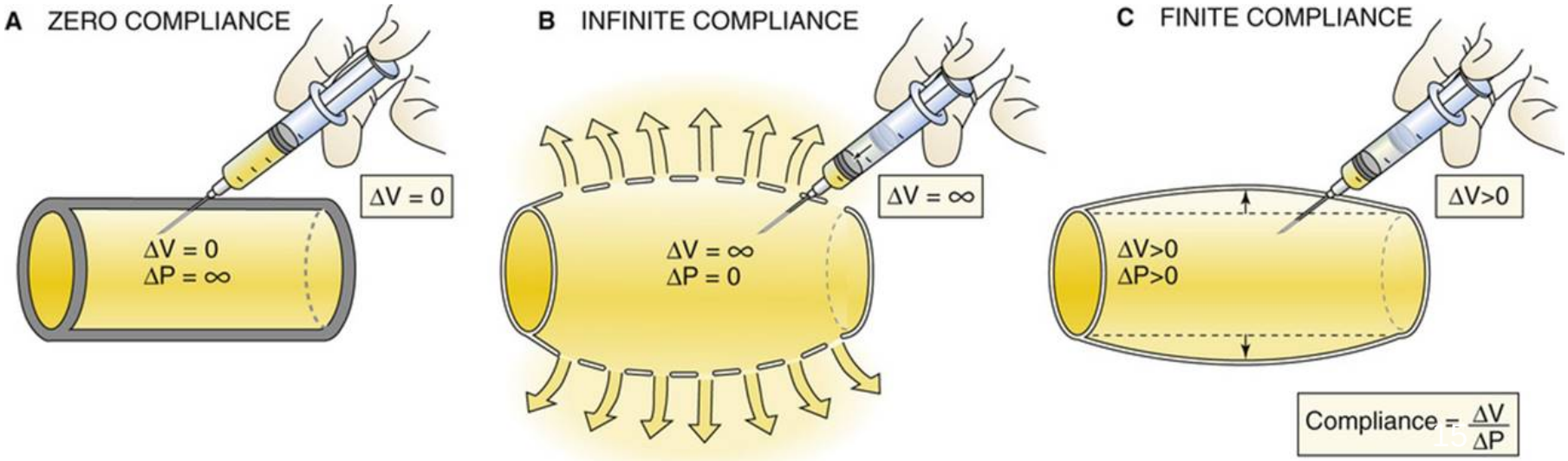
- Veins are more compliant than arteries
- Small ↑ in venous P → large ↑ in venous volume

- Veins are capacitance vessels – their compliance and volume means that they can hold ~70% of blood volume



Arterial compliance

- Important in converting pulsatile flow from heart → steady flow through peripheral vascular beds
- Elastic arteries act as a pressure reservoir – elastic recoil continues driving blood forward during diastole
- Arterial compliance decreases with age (esp. humans)



Blood vessels: functional groups

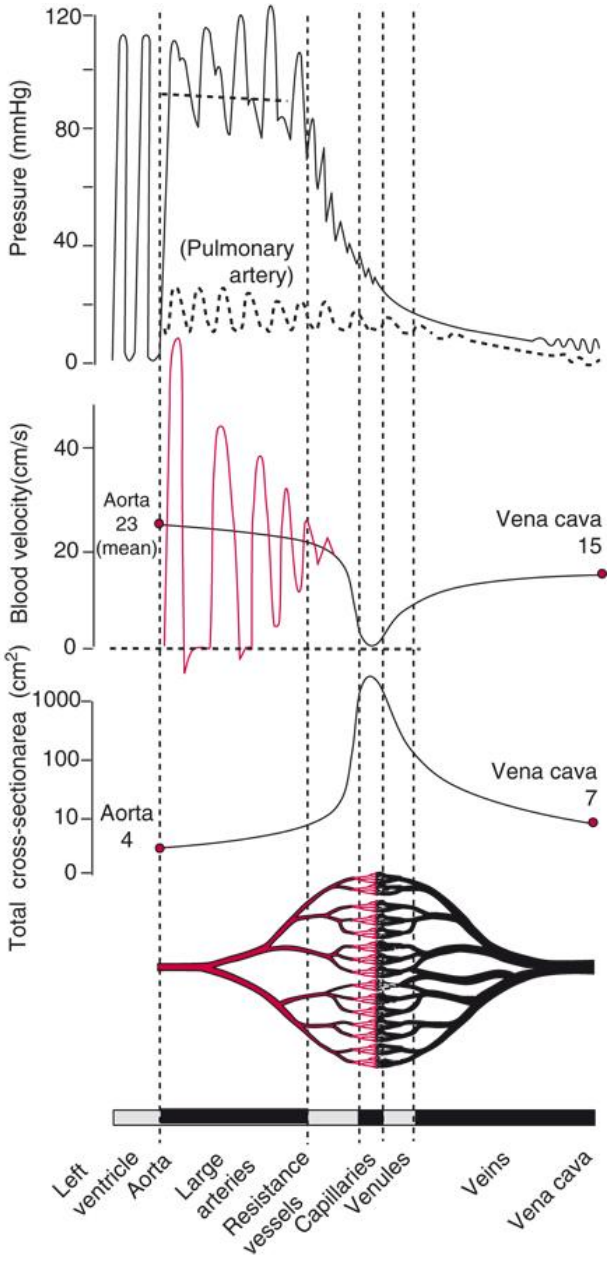
2. Distributing arteries

- Muscular arteries
- Tunica media has more smooth muscle (relative to lumen size) than conducting arteries
- Primary role to conduct flow to smaller arteries
- Rich sympathetic innervation: can change diameter actively
- Includes most arteries, e.g. *internal carotid, femoral, cranial mesenteric aa.*

Blood vessels: functional groups

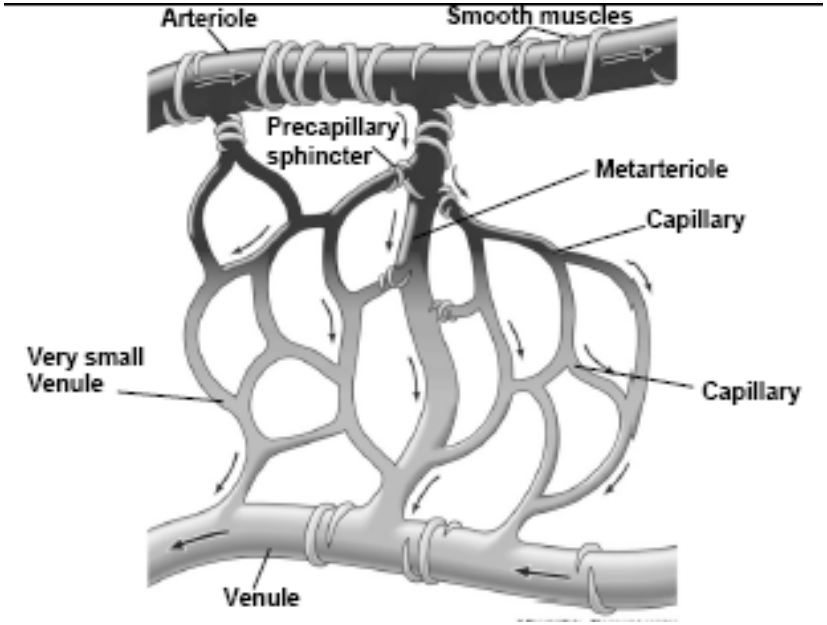
3. Resistance vessels

- Control local blood flow to tissues – ‘the tap’
- Main source of peripheral resistance, control arterial pressure
- Includes all arterioles and metarterioles
- Major fall in blood pressure occurs across the resistance vessels



The microcirculation

- Invisible to the naked eye



- Includes:
  - Arterioles
  - Metarterioles

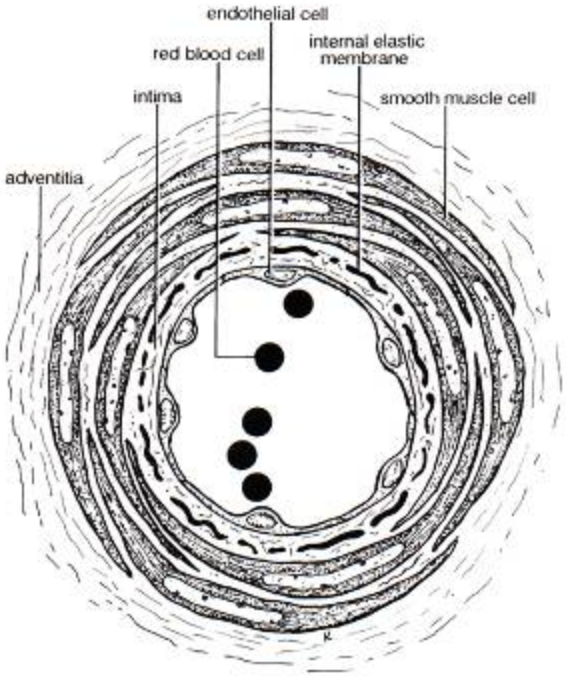
  } Resistance vessels

  - Capillaries
  - Post-capillary venules
  - Sinusoids

  } Exchange vessels

Arterioles

- Regulate total peripheral resistance
- Control flow of blood to capillary beds (together with metarterioles)



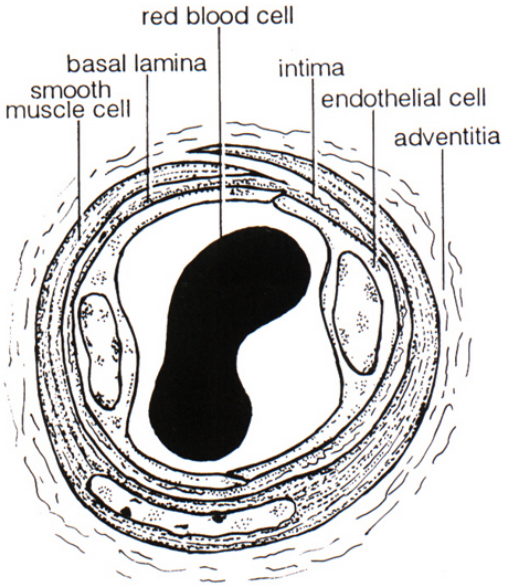
- Wall structure:
  - *Tunica intima*
    - Non-fenestrated endothelium
    - Supported by basement membrane and a few c.t. cells
  - *Tunica media*
    - Only 1-2 layers of smooth muscle cells
  - *Tunica adventitia*
    - Composed of loose c.t.

Metarterioles

- Regulate total peripheral resistance
- Cooperate with smaller arterioles to control flow of blood to capillary beds

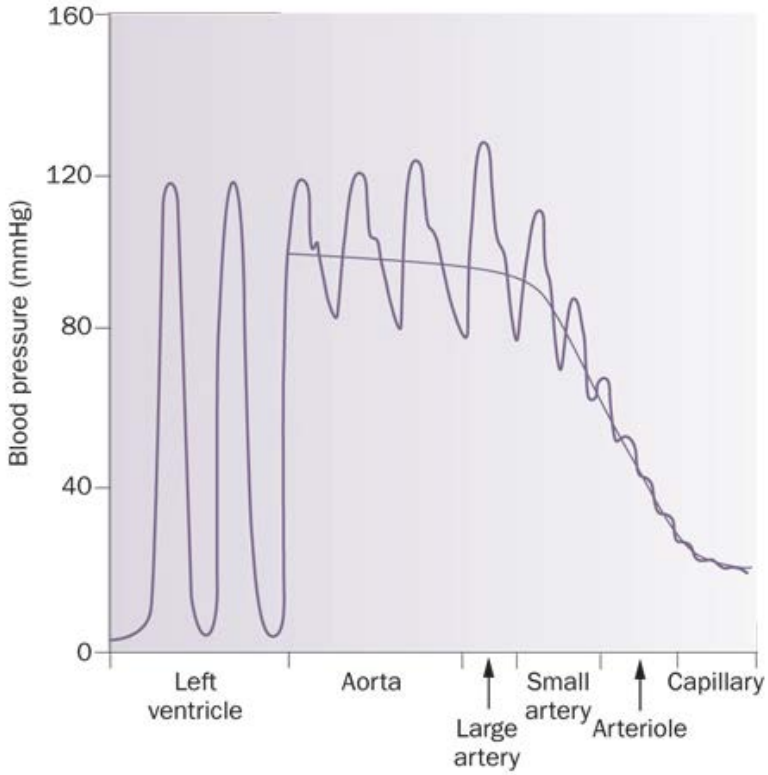
- Wall structure:
  - *Tunica intima*
    - Single layer of non-fenestrated endothelium
    - Supported by a basement membrane and a few c.t. fibres
  - *Tunica media*
    - Varies from single intermittent layer of smooth muscle cells to none being present
  - *Tunica adventitia* – poorly recognised

Metarteriole



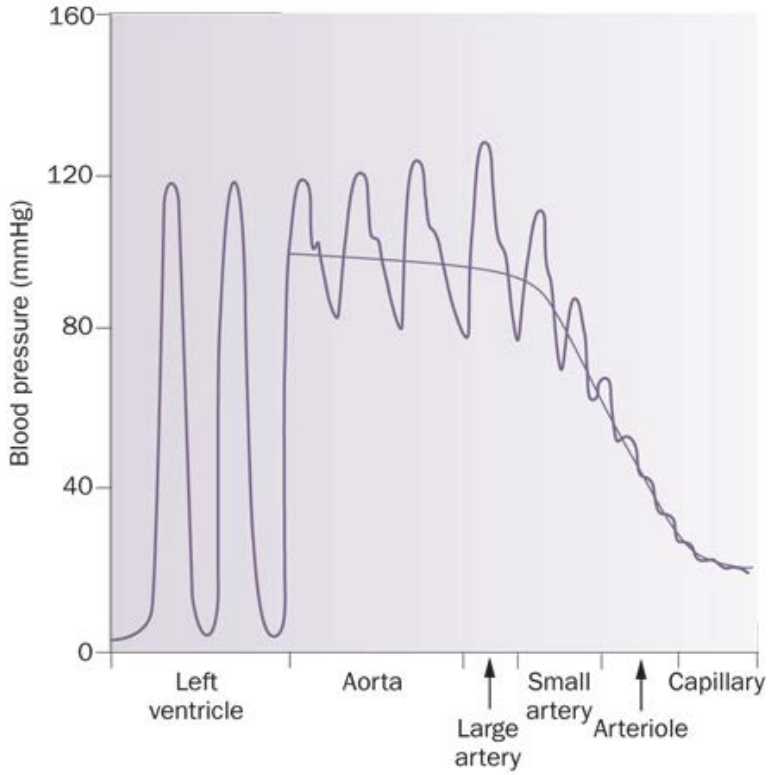
Peripheral vascular resistance

- Blood pressure ↓ in consecutive segments of the vascular tree
- Largest drop in arteriolar segment
- Pulsatile flow also disappears here

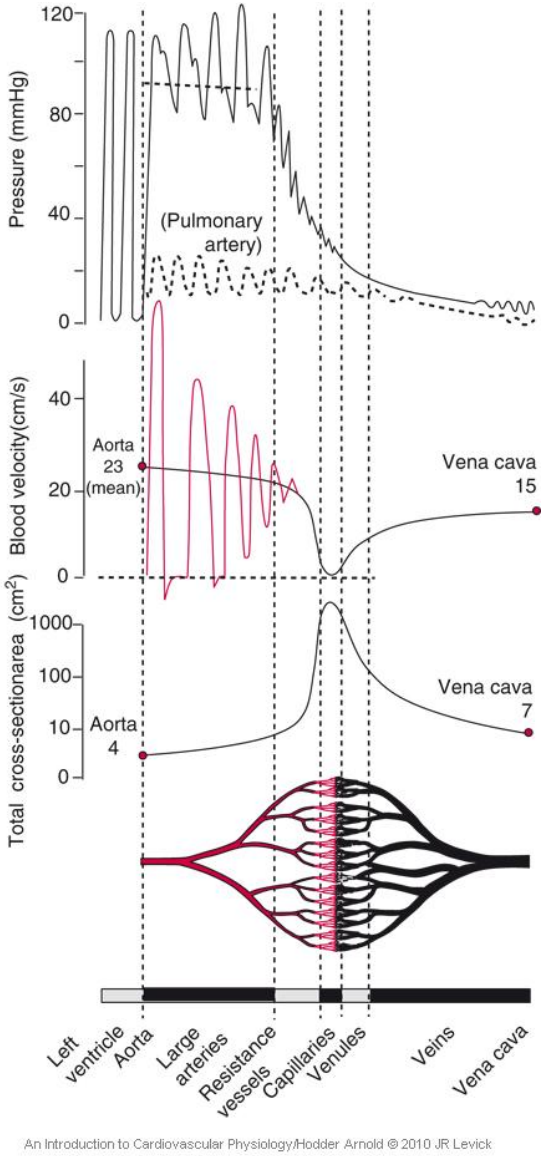


Peripheral vascular resistance

- Resistance is the opposite to flow
- Flow = $\frac{\text{pressure difference}}{\text{resistance}}$
- Resistance = difference in mean pressure needed to drive one unit of flow (↑ resistance = ↑difference)
- Biggest pressure drop occurs across arterioles → main site of resistance to blood flow (‘resistance vessels’)



Resistance vessels



↓ Blood pressure, loss of pulsatile flow

↓ Blood flow velocity

↑ Cross-sectional area

(reaches maximum in exchange vessels)

Rate of blood flow (L/min) remains the same across all vascular segments

Total peripheral resistance

The *other* TPR

- Total peripheral resistance is the resistance to flow through the entire systemic circulation

- TPR = $\frac{\text{(mean aortic pressure – vena caval pressure)}}{\text{cardiac output}}$

- Mean aortic pressure (Pa) = CO x TPR
  (*vena caval pressure close to zero*)

TPR is an important determinant of arterial pressure

Determinants of arterial pressure

- Mean arterial pressure: average pressure driving blood through organs
- MAP = CO x TPR (from flow eqn)
- [CO = stroke volume x heart rate]
- MAP = diastolic pressure + ⅓ pulse pressure

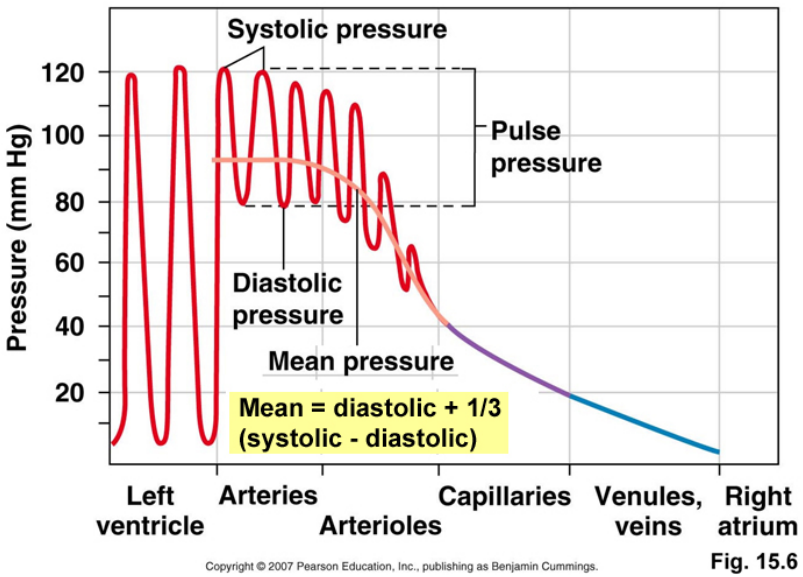
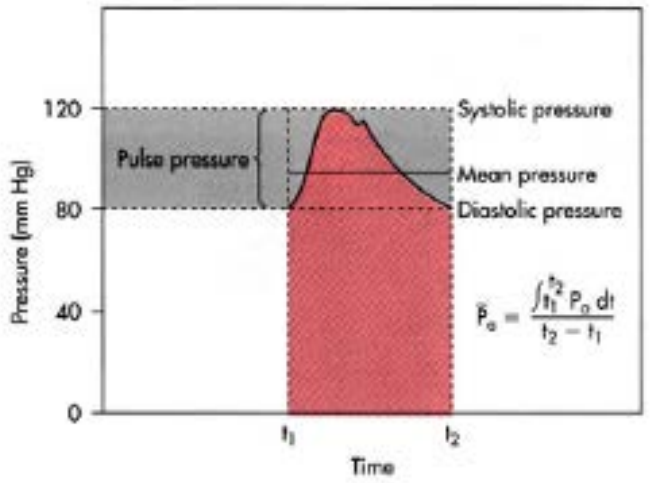
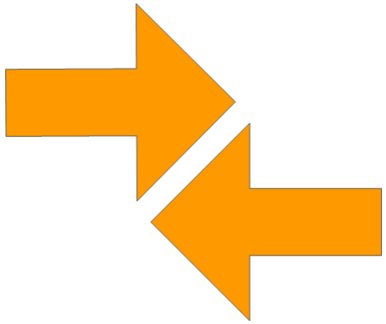


Fig. 15.6

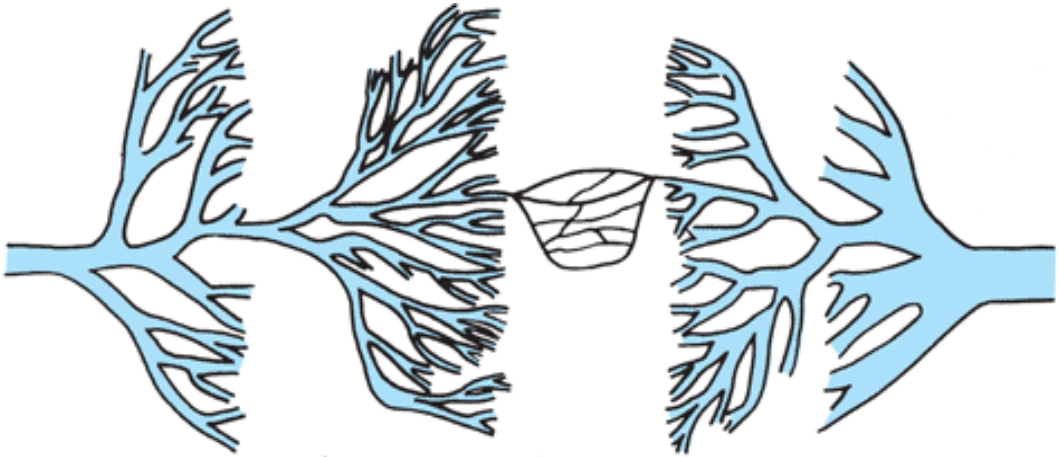


Blood vessels: functional groups

4. Exchange vessels

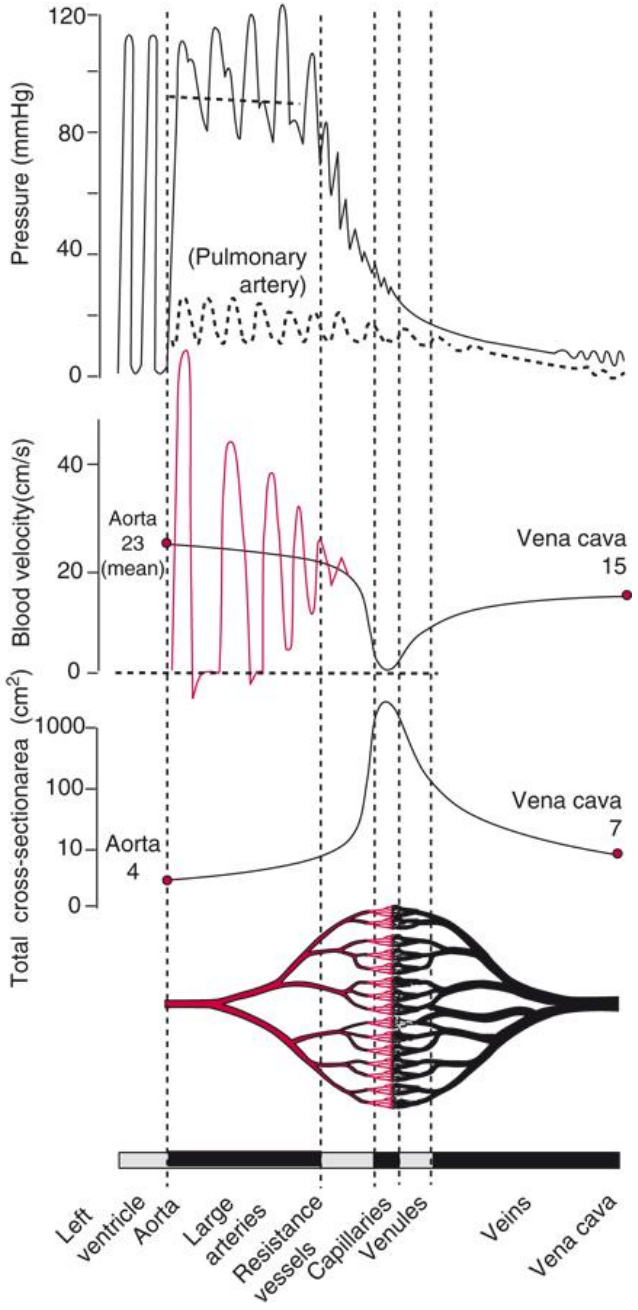


- Metabolic exchange takes place across walls: oxygen, carbon dioxide and metabolites
- Low resistance, high cross-sectional area
- Includes capillaries, sinusoids and post-capillary venules



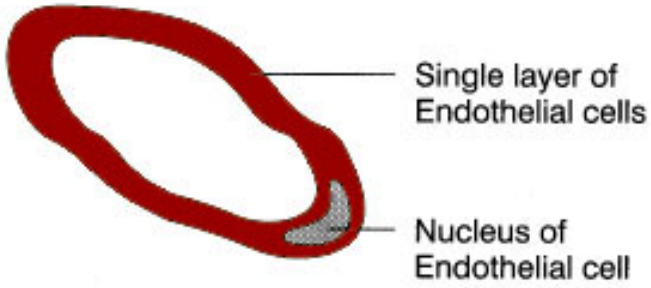
	ARTERIES		ARTERIOLES	CAPILLARIES	VENULES	VEINS	
	Aorta						Venae cavae
internal diameter	2.5 cm	0.4 cm	30 μm	5μm	70 μm	0.5 cm	3 cm
wall thickness	2 mm	1 mm	20 μm	1 μm	7μm	0.5 mm	1.5 mm
number	1	160	5×10^7	10^{10}	10^8	200	2
total cross-sectional area	4.5 cm^2	20 cm^2	400 cm^2	4500 cm^2	4000 cm^2	40 cm^2	18 cm^2

one-way valves



Capillaries

- Classification based on:
  - Position in the vascular bed
  - Nature of endothelial lining
- Wall structure
  - Two essential components:
    1. Thin endothelial cell layer
    2. Basement membrane
  - External to this:
    - Sparse network of c.t.
    - Often a pericyte

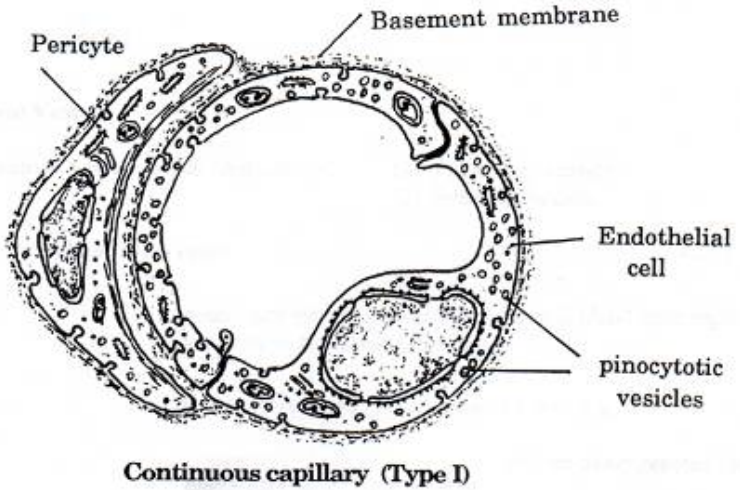


Capillaries

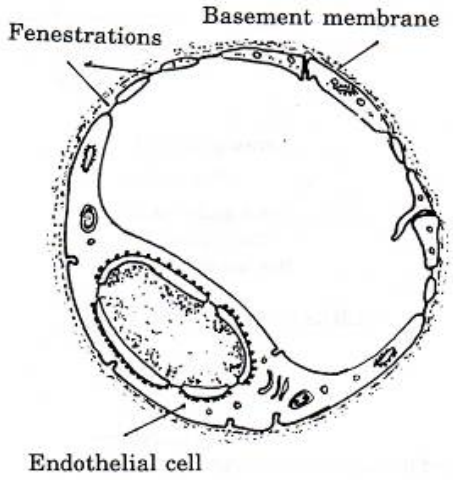
Classification based on:

- Position in vascular bed
- Nature of endothelial lining
  - Continuous with thick endothelium
  - Continuous with thin endothelium
  - Fenestrated

    e.g. Glomerular capillaries of kidney

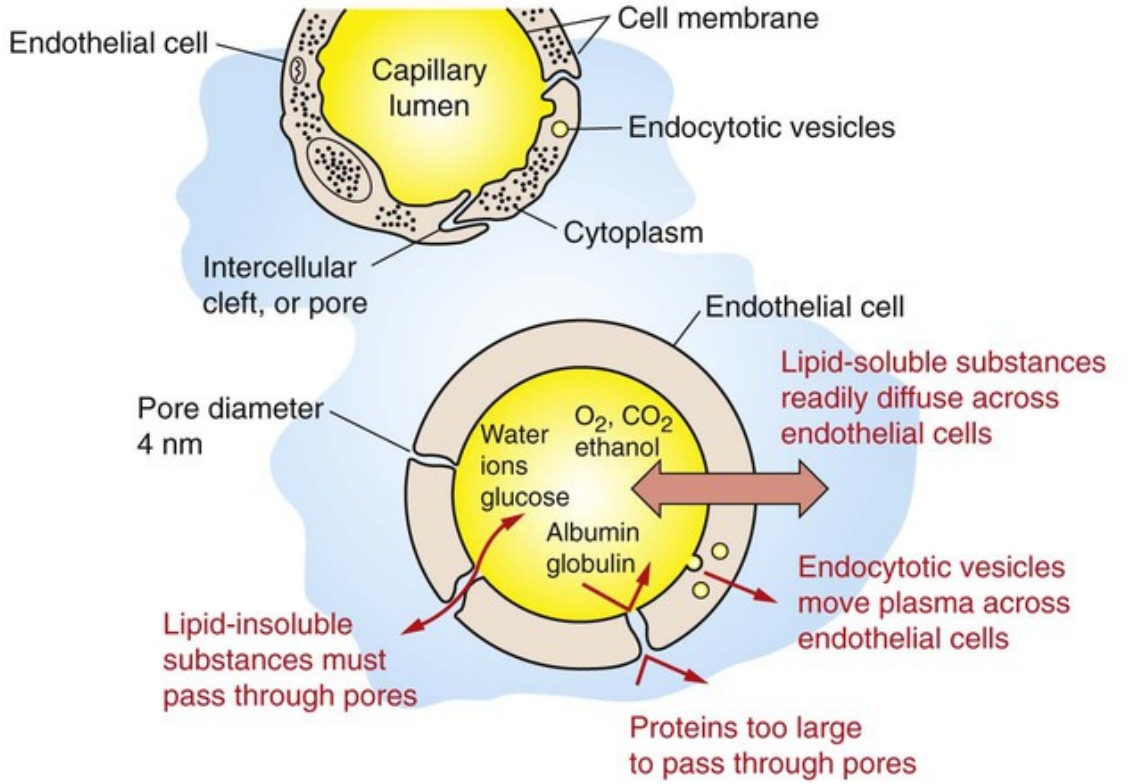


Continuous capillary (Type I)

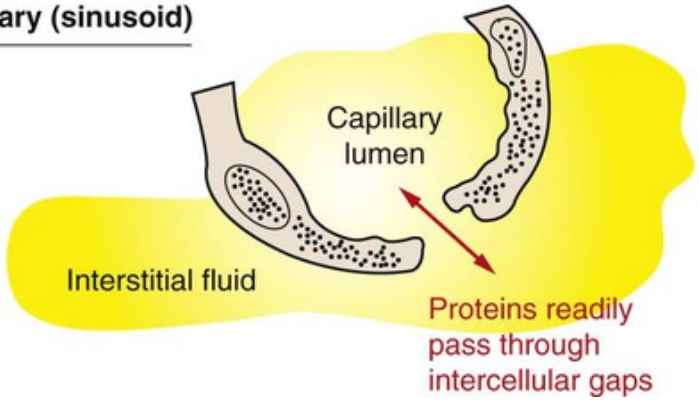


Fenestrated capillary (Type II)

Typical continuous capillary



Discontinuous capillary (sinusoid)

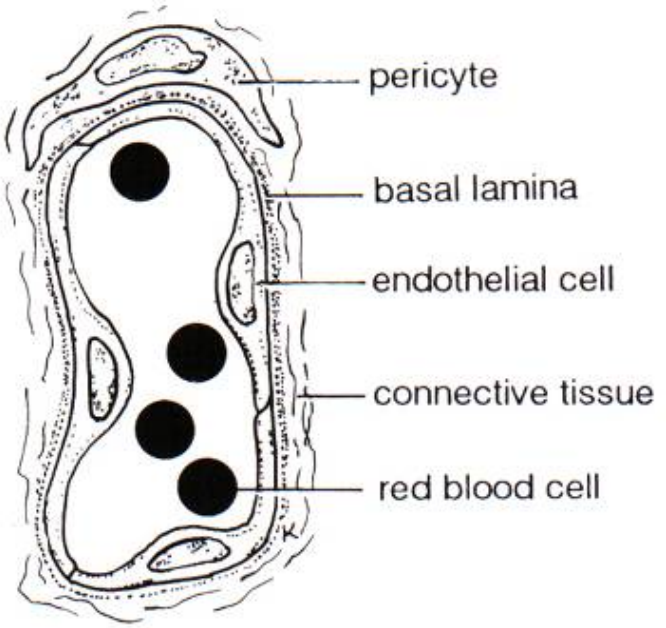


Sinusoid

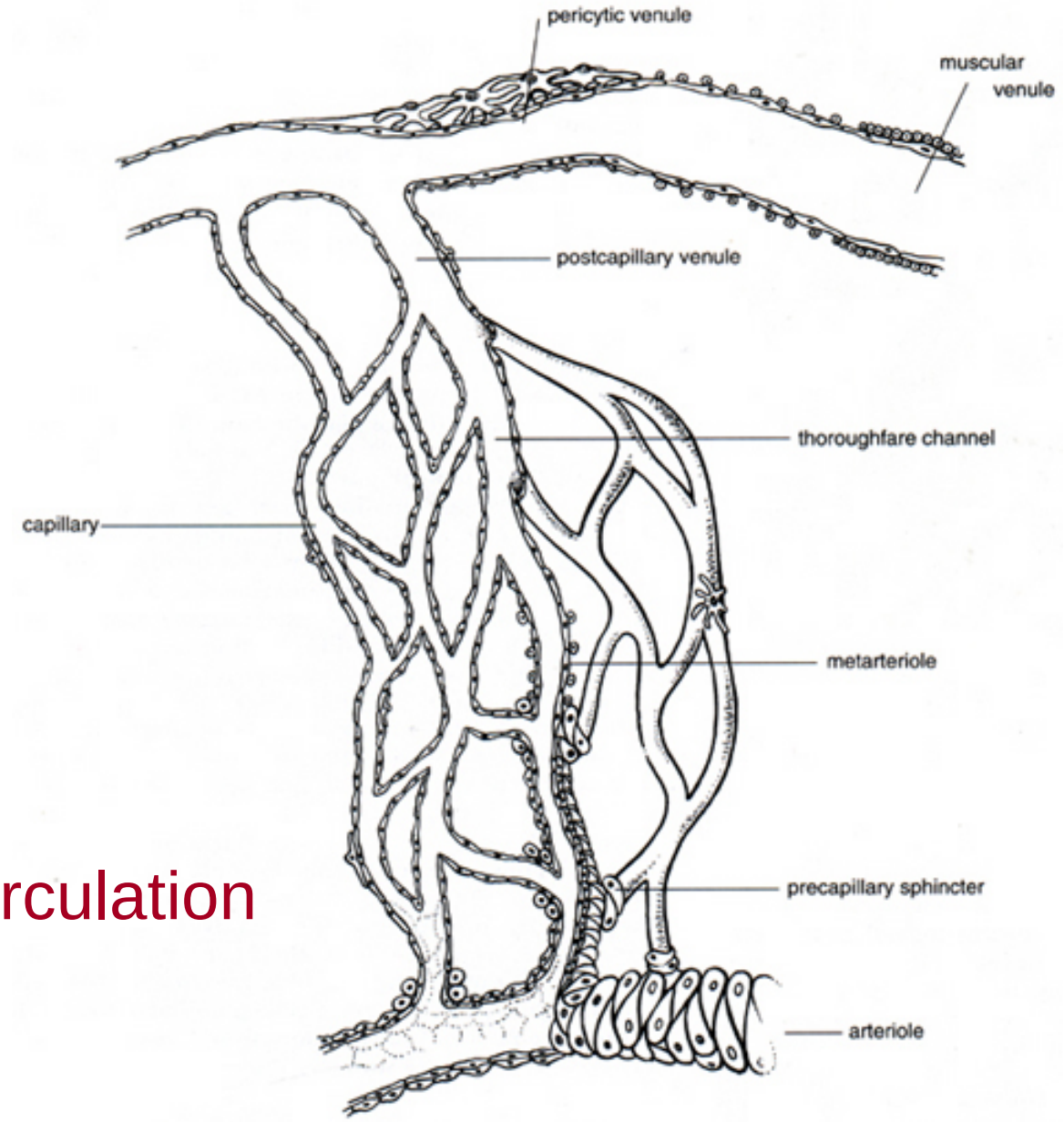
- Exchange vessel
- Endothelial channel
- Irregular bulging vessel
  - Greater capacity than slender capillary
- Wall structure:
  - Discontinuous endothelial lining
  - Endothelial cells – multiple fenestrations
  - Basement membrane – fragmentary or absent
- Enable interchange of fluids and macromolecules and easy movement of cells across the endothelium
- Characteristic of haemopoietic tissues and the liver

Post-capillary venules

- Exchange vessels
- Resemble large capillary
- Drain several capillaries
- Wall structure:
  - Continuous endothelial cell layer
  - Supported by basal lamina
  - Surrounded by a few pericytes, some c.t.
  - No or few smooth muscle cells
  - Joins between cells ‘leaky’ - promotes migration of WBC



Microcirculation



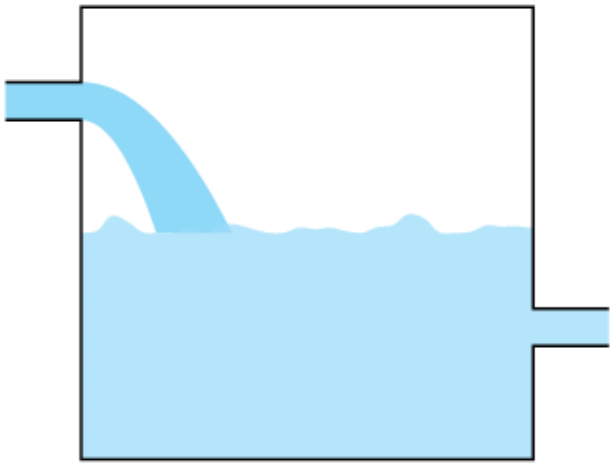
Arteriovenous shunts

- Simple arteriovenous shunt
  - Connects arteriole with a muscular venule
  - Thick ring of smooth muscle cells in walls
    - Sphincter-like action
- Thoroughfare channel
  - Connects metarteriole to post-capillary venule
- Glomeriform arteriovenous anastomosis
  - Role in thermoregulation
  - *We will return to these in the special circulations lecture*

Blood vessels: functional groups

5. Capacitance (reservoir) vessels

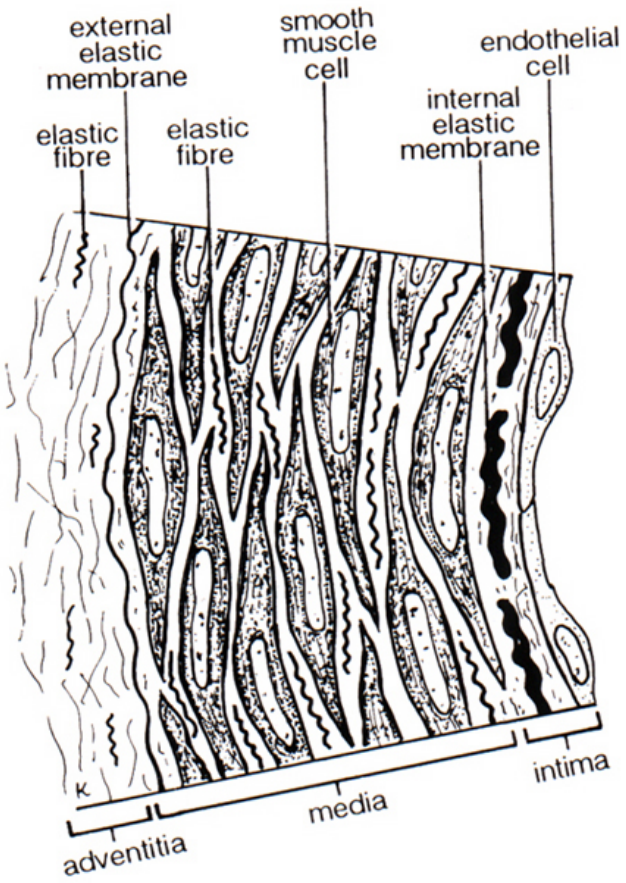
- Large volume and low pressure
- Return blood to heart
- Includes all muscular venules and veins



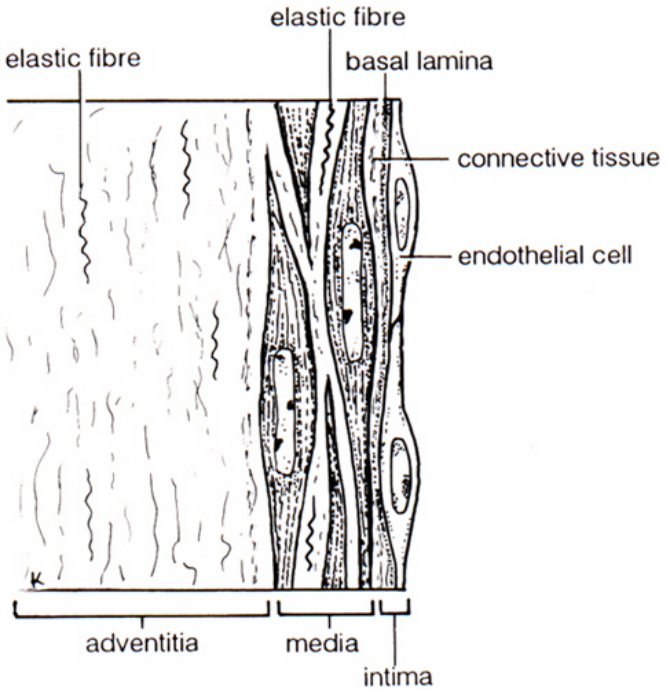
Wall structure of veins

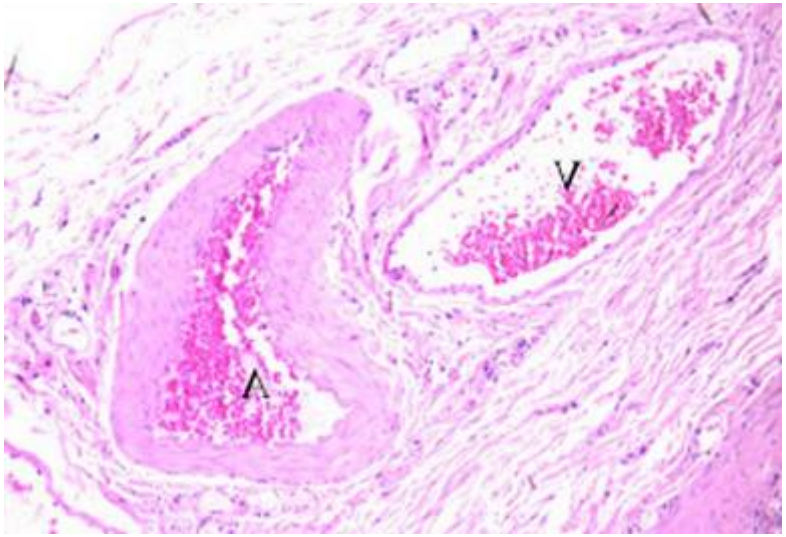
- *Tunica intima*
  - Same as arteries except no internal elastic lamina
- *Tunica media*
  - Relatively small amounts of SMC and elastic fibres
  - Usually abundant collagen fibres
  - No external elastic lamina
- *Tunica adventitia*
  - Many large collagen fibres in the c.t.
  - Often the thickest layer

Small muscular artery



Small vein





Veins: capacitance vessels

- Veins are: thin-walled, contractile and voluminous
- Contain about 2/3 of the total blood pool
- Act as a reservoir of blood
- Crucial role in stabilising and regulating venous return of blood to the heart

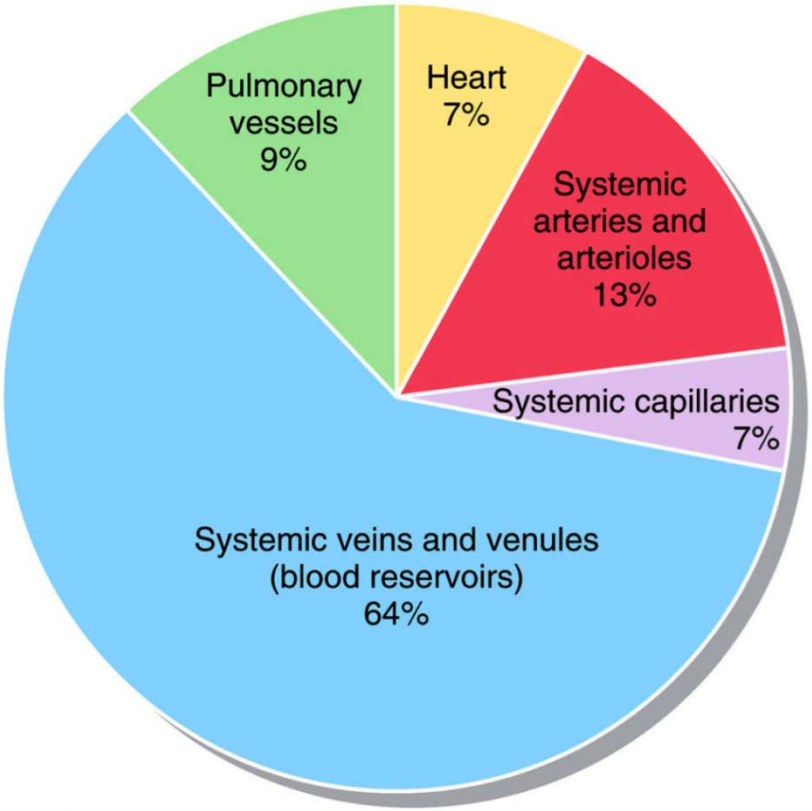


Figure 21.06 Tortora - PAP 12/e

Venous tone

Venous tone influences cardiac filling and stroke volume

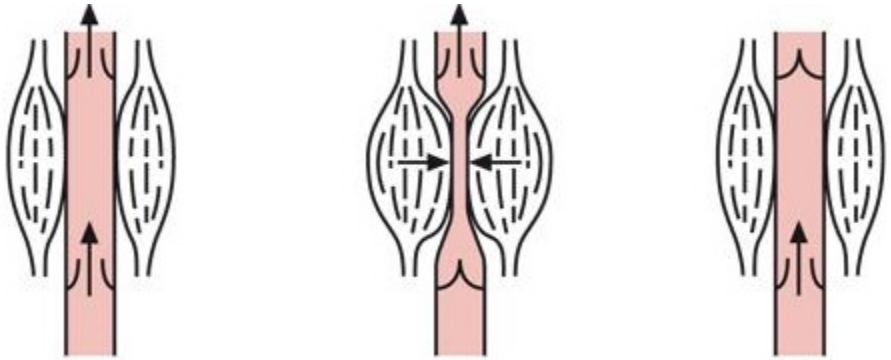
- Largest volume of blood is stored in veins of systemic organs (peripheral venous pool)
- Blood also stored in great veins of thorax and R atrium (central venous pool)
- Constriction of peripheral veins: blood moves peripheral → central venous pool
- This increases cardiac filling and stroke volume

Venous return

Factors controlling venous return:

- Smooth muscle contraction
  - sympathetic NS
- Skeletal muscle pump effect
- One-way valves
- Thoracic and cardiac pressure

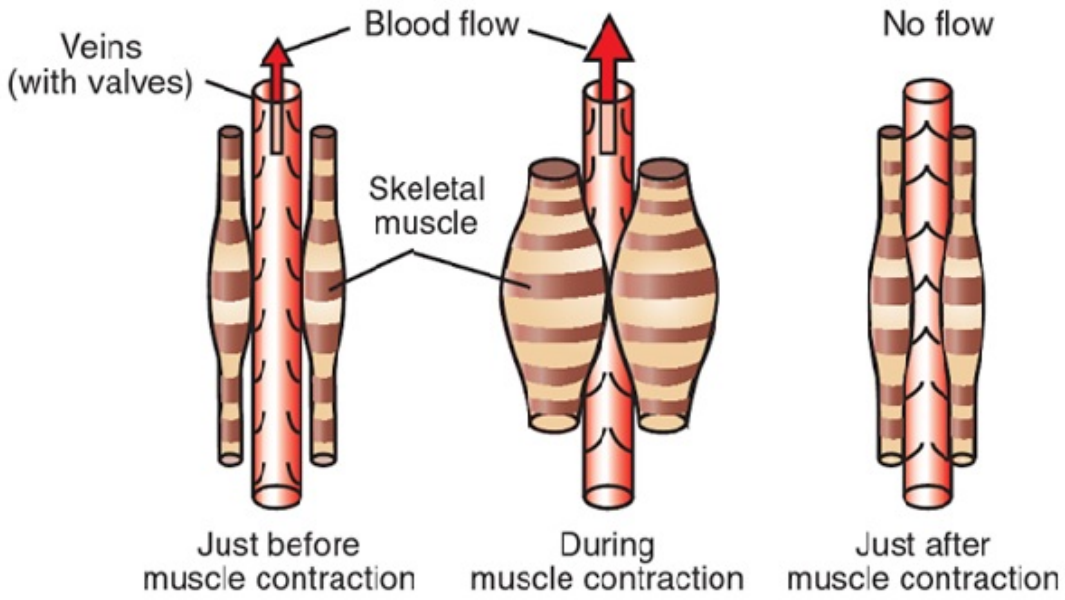
(includes pressure gradient between veins and heart)



Valves

Valves in the lumen of veins

- Composed of two cusps
- Valves present in medium sized veins – especially in limbs
- Reduce the hydrostatic pressure and aids the '*muscle pump*'



Summary

- Blood vessel structure
  - » Three layers: *tunica intima, media, adventitia*
  - » Differences in anatomy across vessel groups driven by function
- Blood vessel functional groups
  - » Conducting, distributing, resistance, exchange, capacitance
- Key functional concepts
  - » Compliance
  - » Total Peripheral Resistance (TPR)
  - » Venous capacitance and control of venous return