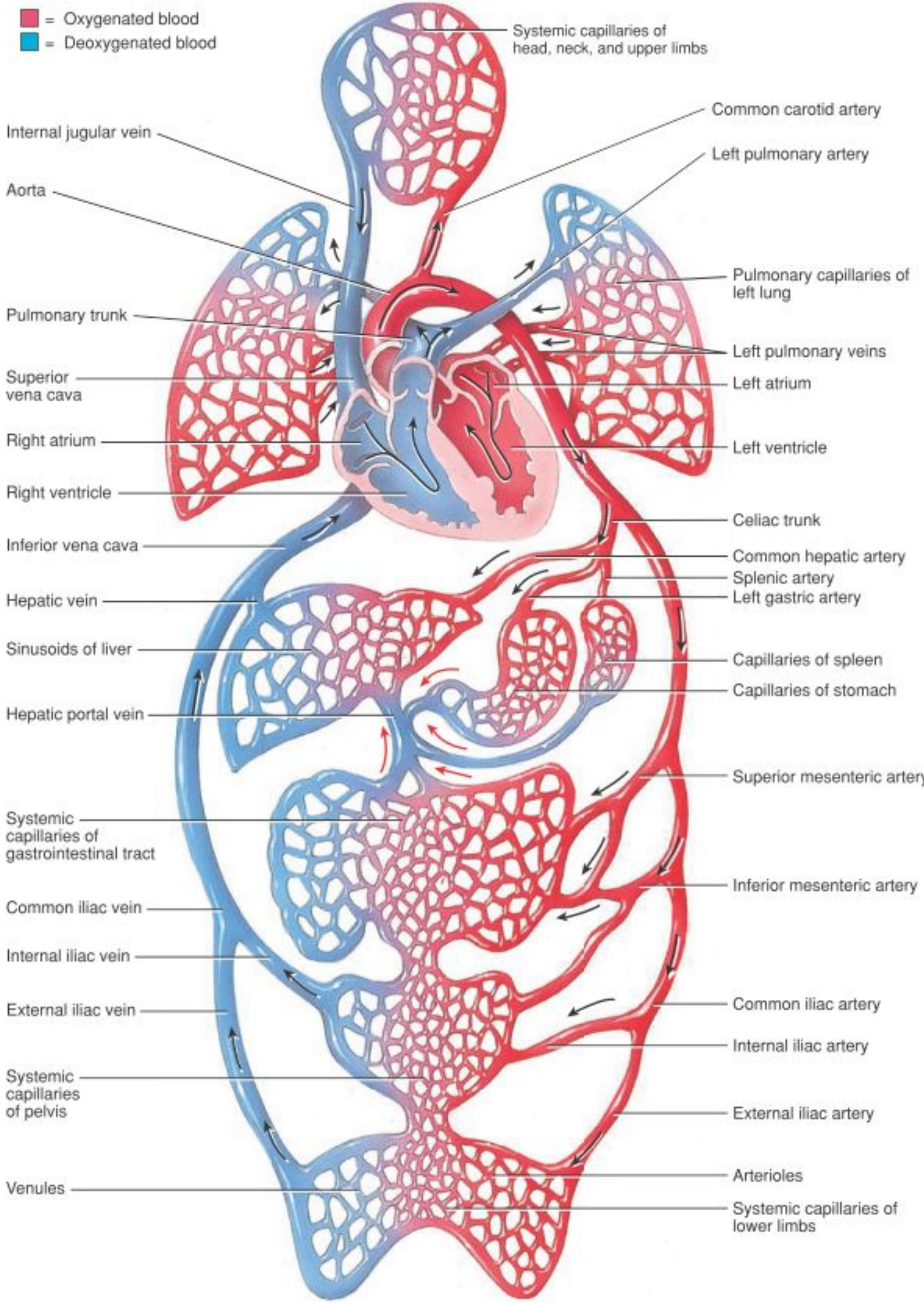
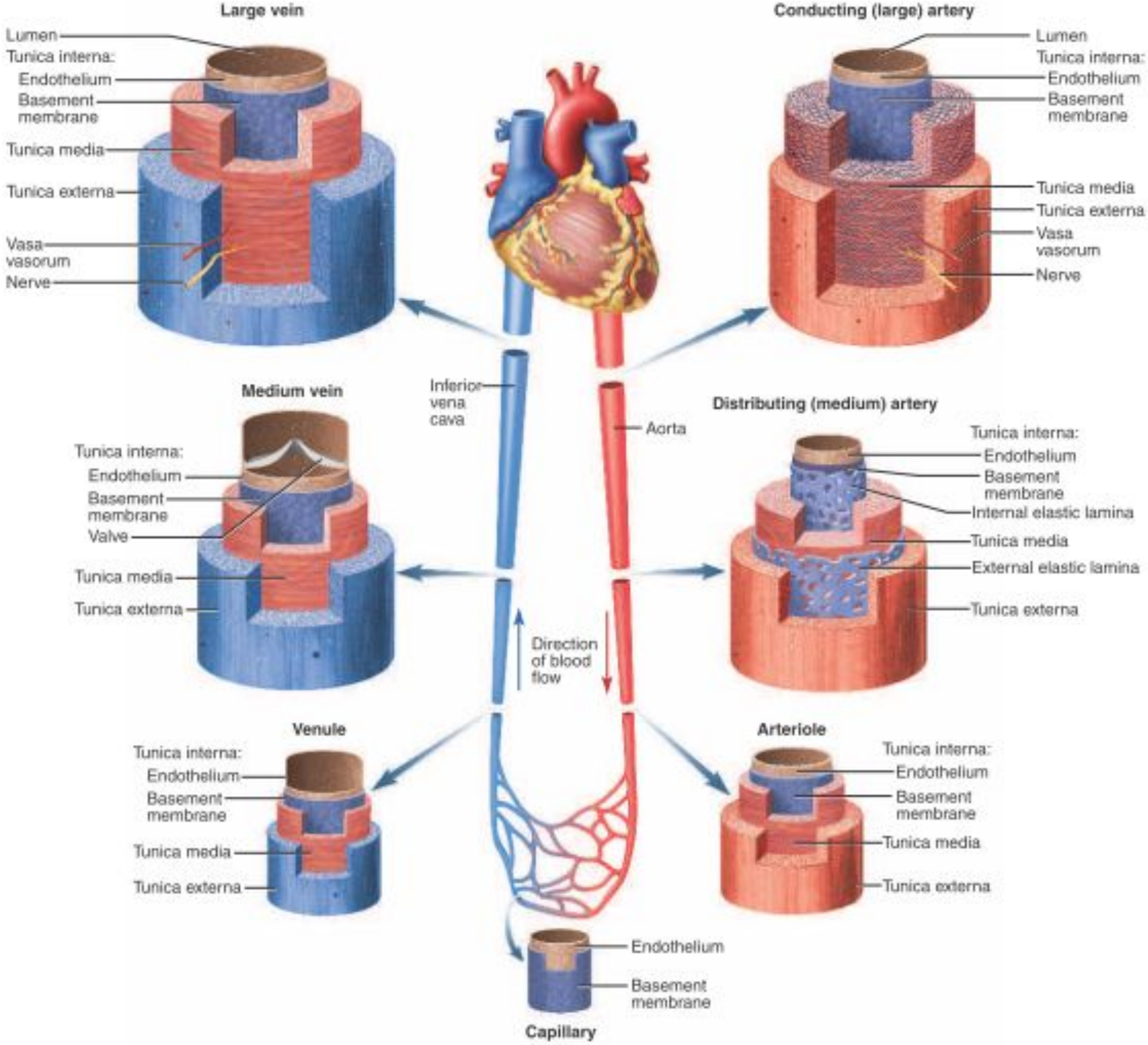
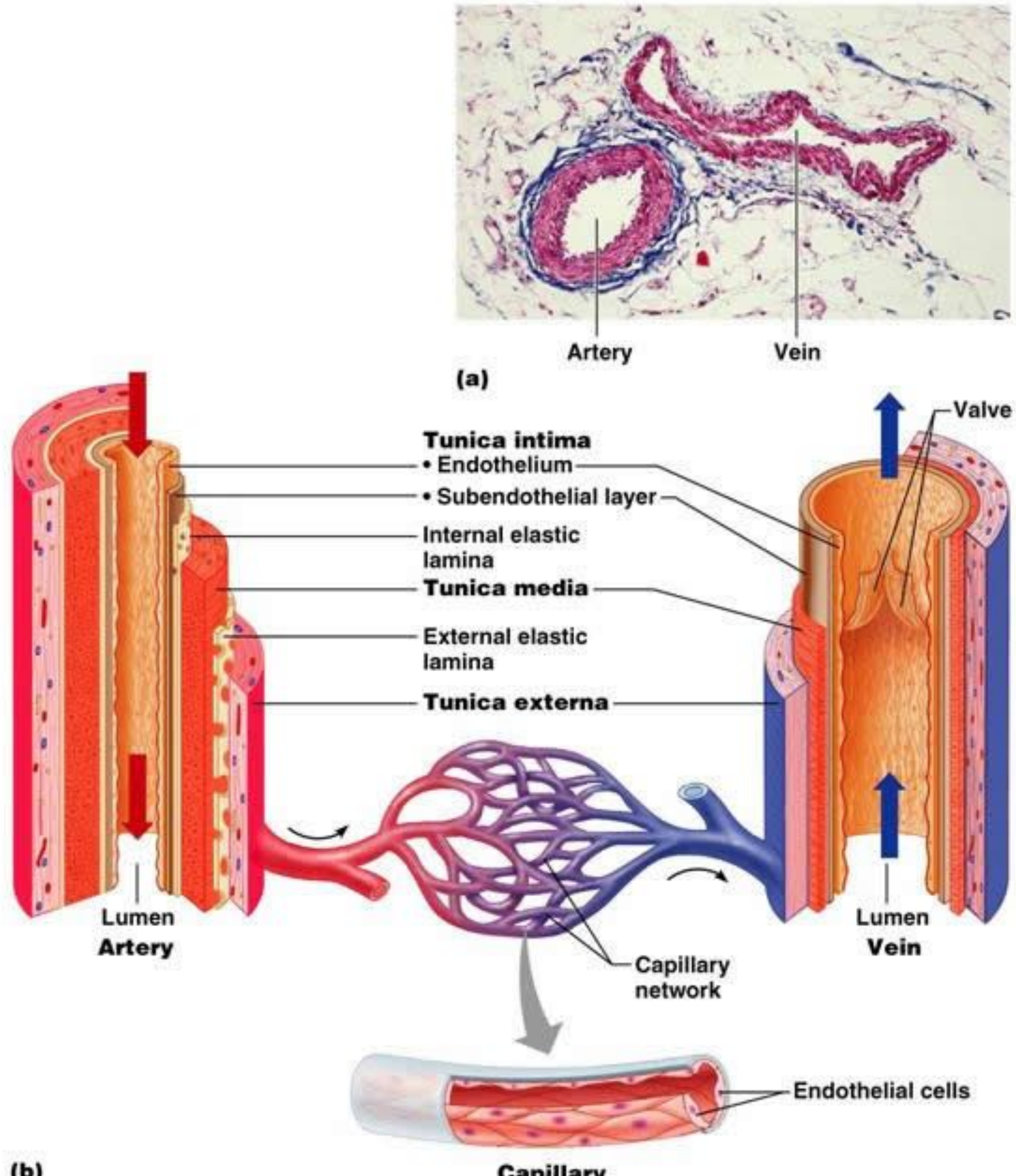
Движение крови по сосудам. Кровяное давление

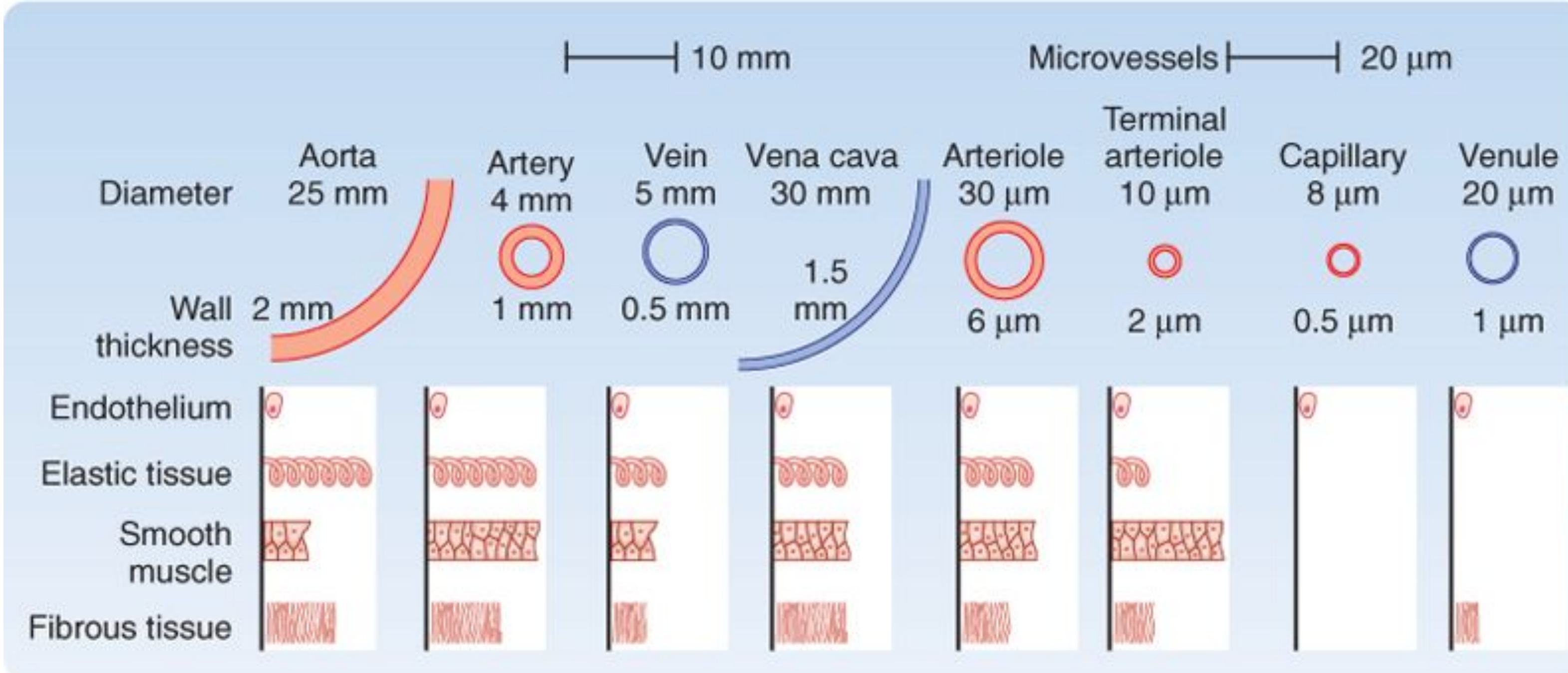


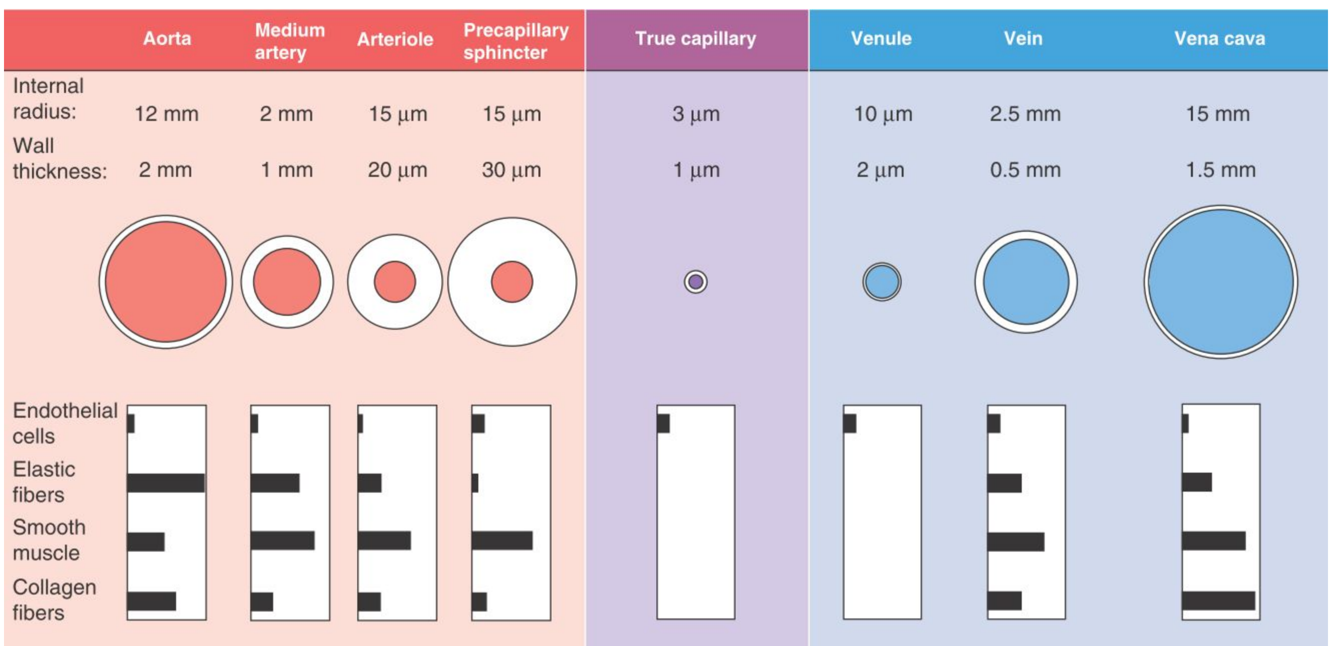
= Oxygenated blood
= Deoxygenated blood
Systemic capillaries of head, neck, and upper limbs
Common carotid artery
Left pulmonary artery
Internal jugular vein
Aorta
Pulmonary capillaries of left lung
Pulmonary trunk
Left pulmonary veins
Superior vena cava
Left atrium
Right atrium
Left ventricle
Right ventricle
Celiac trunk
Inferior vena cava
Common hepatic artery
Splenic artery
Left gastric artery
Hepatic vein
Sinusoids of liver
Capillaries of spleen
Capillaries of stomach
Hepatic portal vein
Superior mesenteric artery
Systemic capillaries of gastrointestinal tract
Inferior mesenteric artery
Common iliac vein
Internal iliac vein
Common iliac artery
External iliac vein
Internal iliac artery
Systemic capillaries of pelvis
External iliac artery
Arterioles
Venules
Systemic capillaries of lower limbs

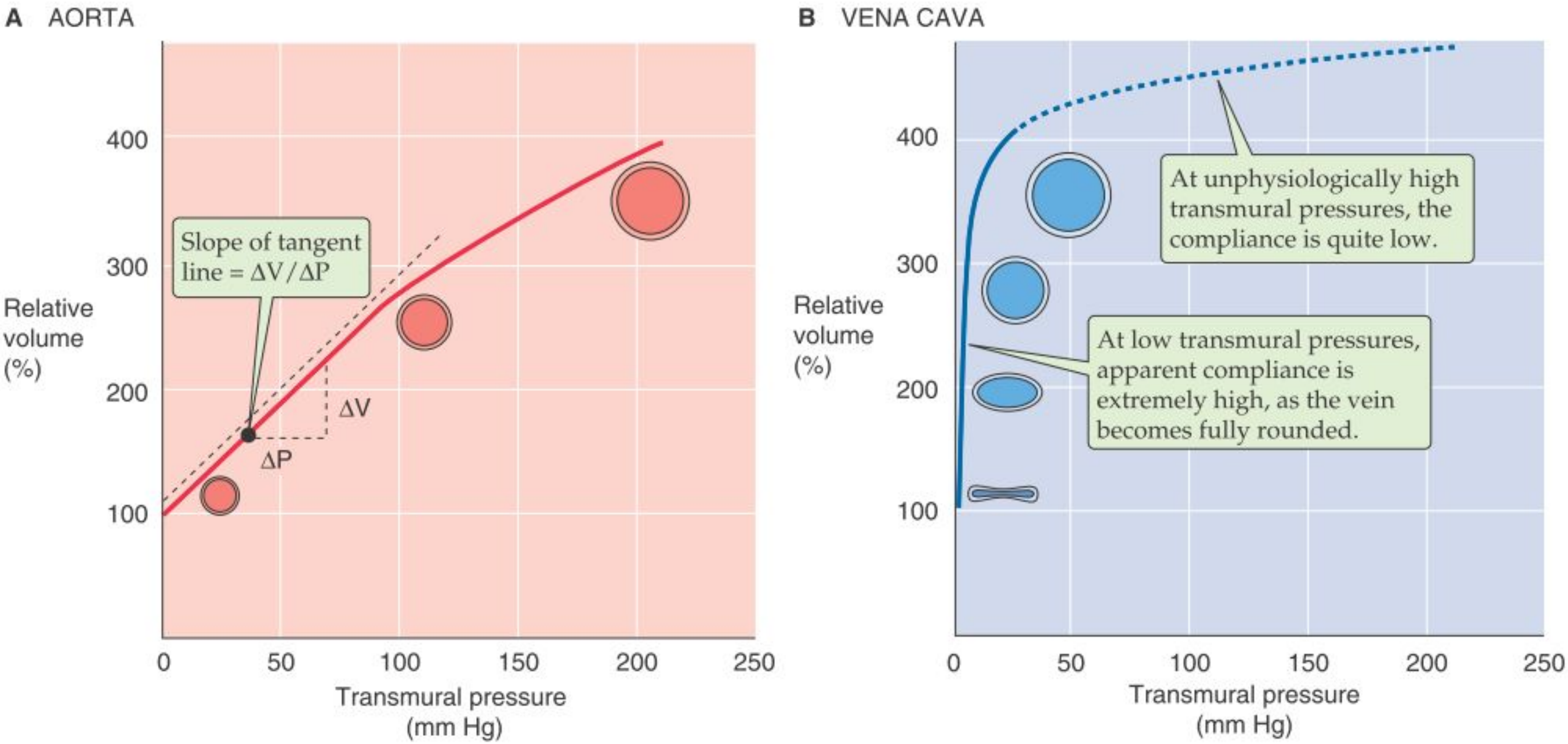


Large vein
Lumen
Tunica interna:
Endothelium
Basement membrane
Tunica media
Tunica externa
Vasa vasorum
Nerve
Conducting (large) artery
Lumen
Tunica interna:
Endothelium
Basement membrane
Tunica media
Tunica externa
Vasa vasorum
Nerve
Medium vein
Tunica interna:
Endothelium
Basement membrane
Valve
Tunica media
Tunica externa
Inferior vena cava
Aorta
Distributing (medium) artery
Tunica interna:
Endothelium
Basement membrane
Internal elastic lamina
Tunica media
External elastic lamina
Tunica externa
Direction of blood flow
Venule
Tunica interna:
Endothelium
Basement membrane
Tunica media
Tunica externa
Arteriole
Tunica interna:
Endothelium
Basement membrane
Tunica media
Tunica externa
Endothelium
Basement membrane
Capillary

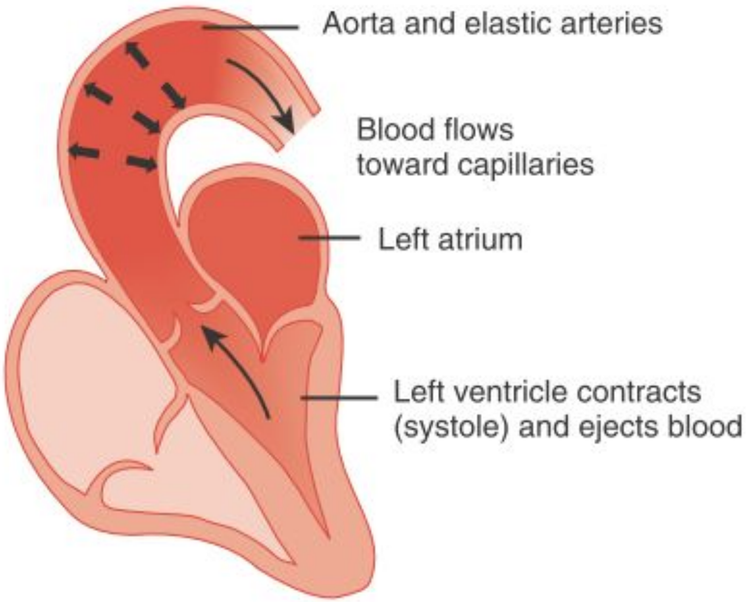

Artery
Vein
(a)
Valve
Tunica intima
• Endothelium
• Subendothelial layer
Internal elastic
lamina
Tunica media
External elastic
lamina
Tunica externa
Lumen
Artery
Lumen
Vein
Capillary
network
Endothelial cells
(b)
Capillary


10 mm
Microvessels
20 µm
Diameter
Wall thickness
Aorta 25 mm
2 mm
Artery 4 mm
1 mm
Vein 5 mm
0.5 mm
Vena cava 30 mm
1.5 mm
Arteriole 30 µm
6 µm
Terminal arteriole 10 µm
2 µm
Capillary 8 µm
0.5 µm
Venule 20 µm
1 µm
Endothelium
Elastic tissue
Smooth muscle
Fibrous tissue

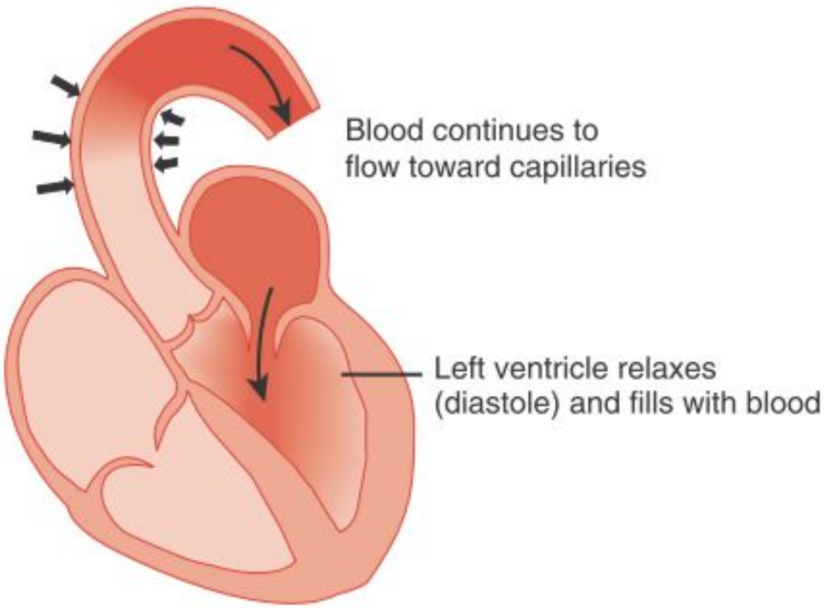

Aorta
Medium artery
Arteriole
Precapillary sphincter
True capillary
Venule
Vein
Vena cava
Internal radius:
12 mm
2 mm
15 µm
15 µm
3 µm
10 µm
2.5 mm
15 mm
Wall thickness:
2 mm
1 mm
20 µm
30 µm
1 µm
2 µm
0.5 mm
1.5 mm
Endothelial cells
Elastic fibers
Smooth muscle
Collagen fibers



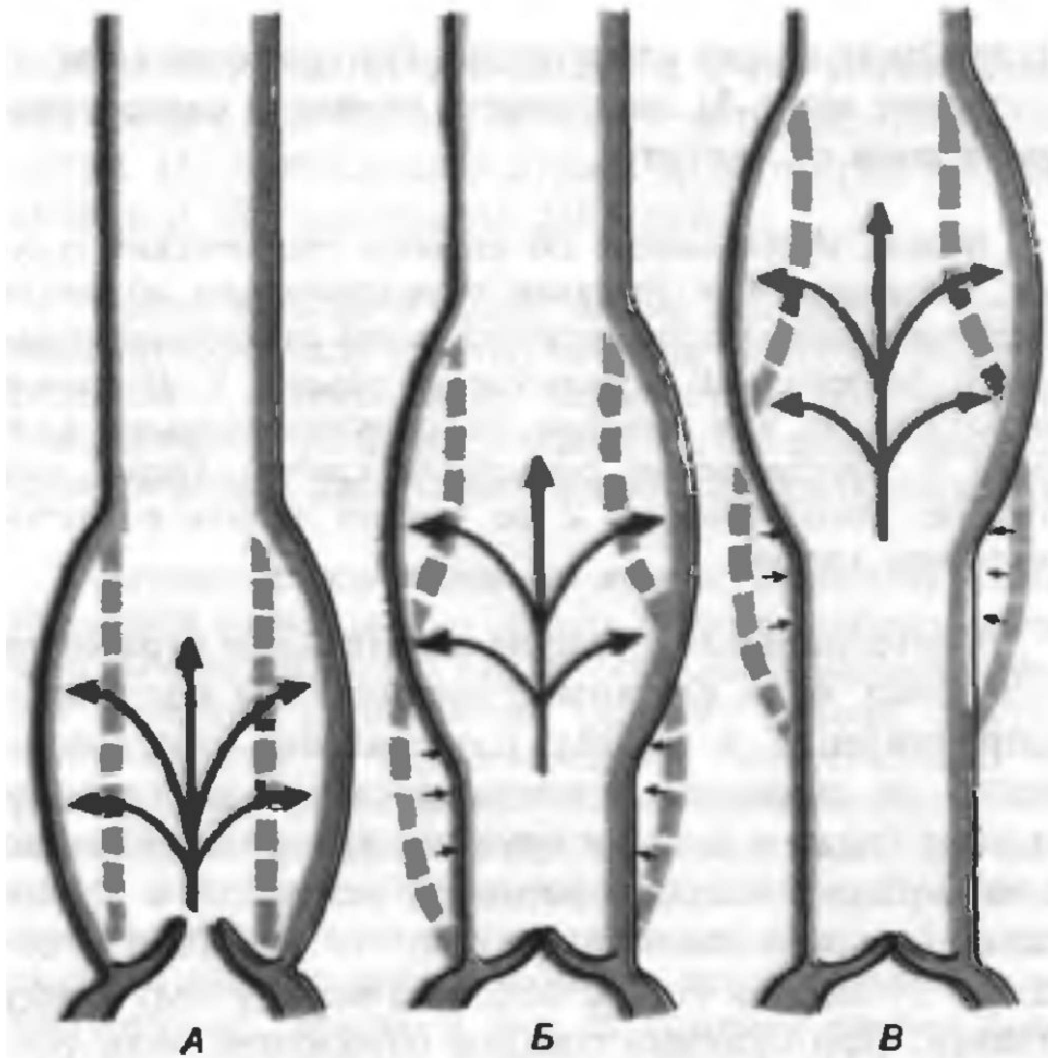
A AORTA
Relative volume (%)
400
300
200
100
0
50
100
150
200
250
Transmural pressure (mm Hg)
Slope of tangent line = ΔV/ΔP
ΔV
ΔP
B VENA CAVA
Relative volume (%)
400
300
200
100
0
50
100
150
200
250
Transmural pressure (mm Hg)
At unphysiologically high transmural pressures, the compliance is quite low.
At low transmural pressures, apparent compliance is extremely high, as the vein becomes fully rounded.

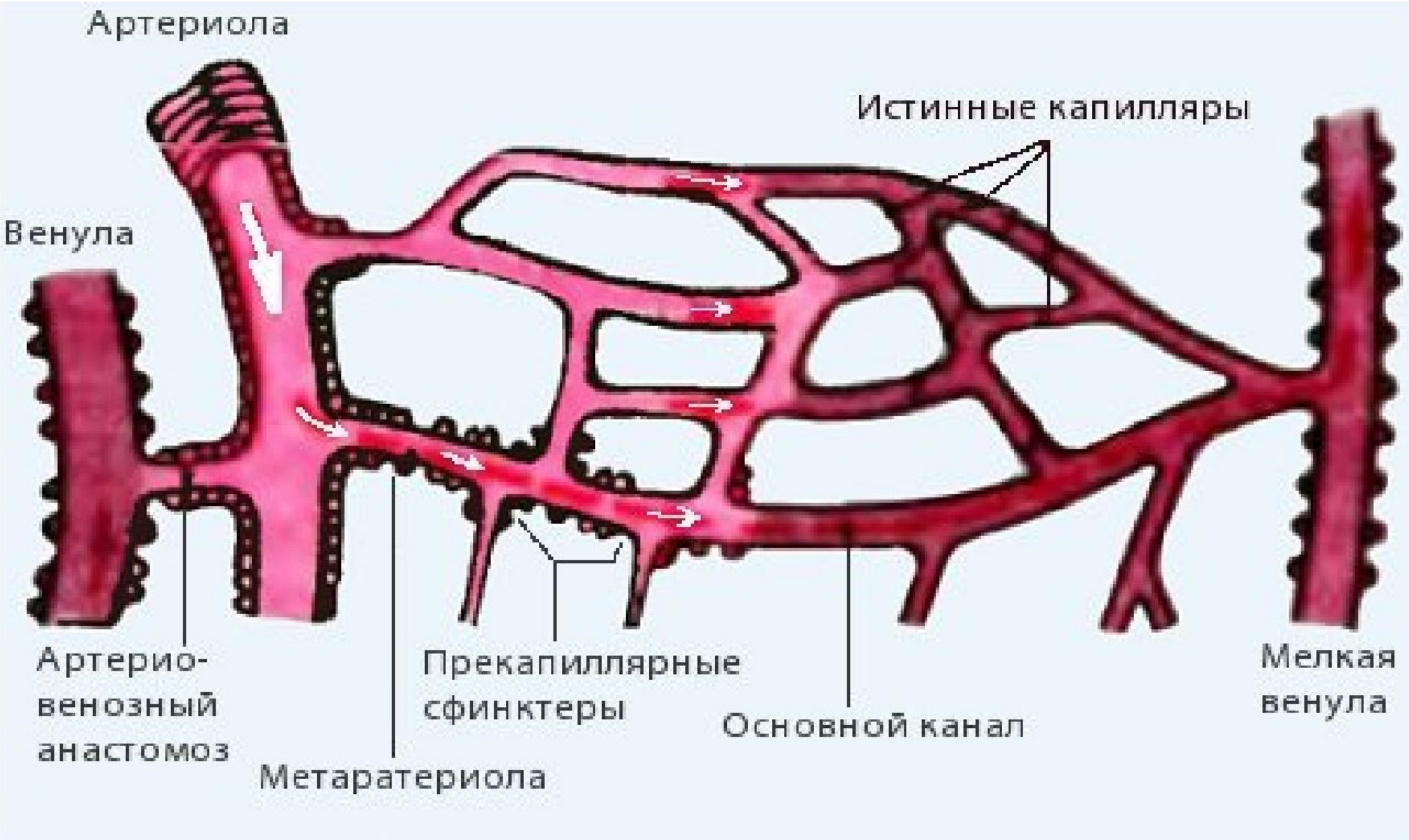


(a) Elastic aorta and arteries stretch during ventricular contraction



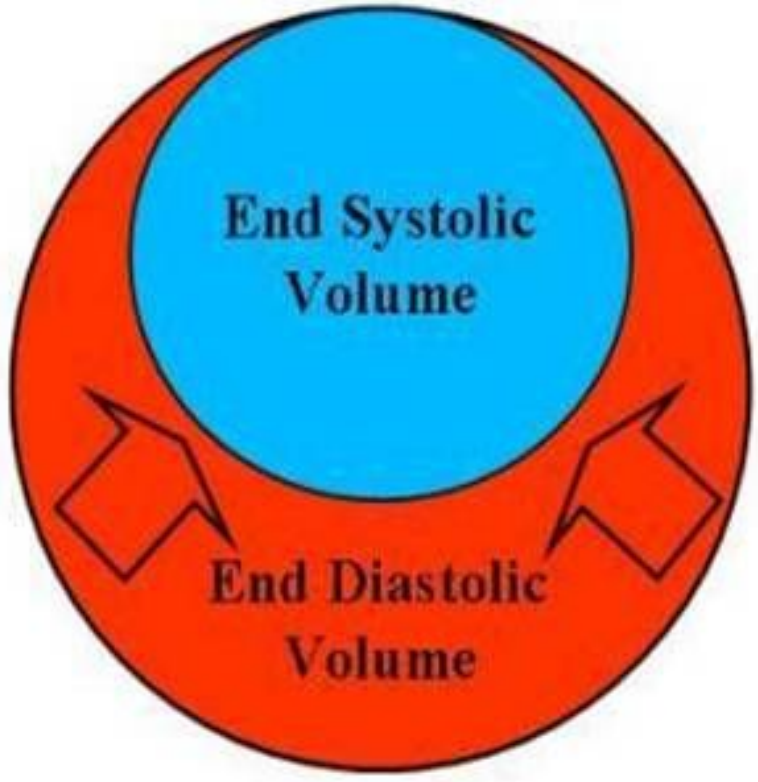
(b) Elastic aorta and arteries recoil during ventricular relaxation

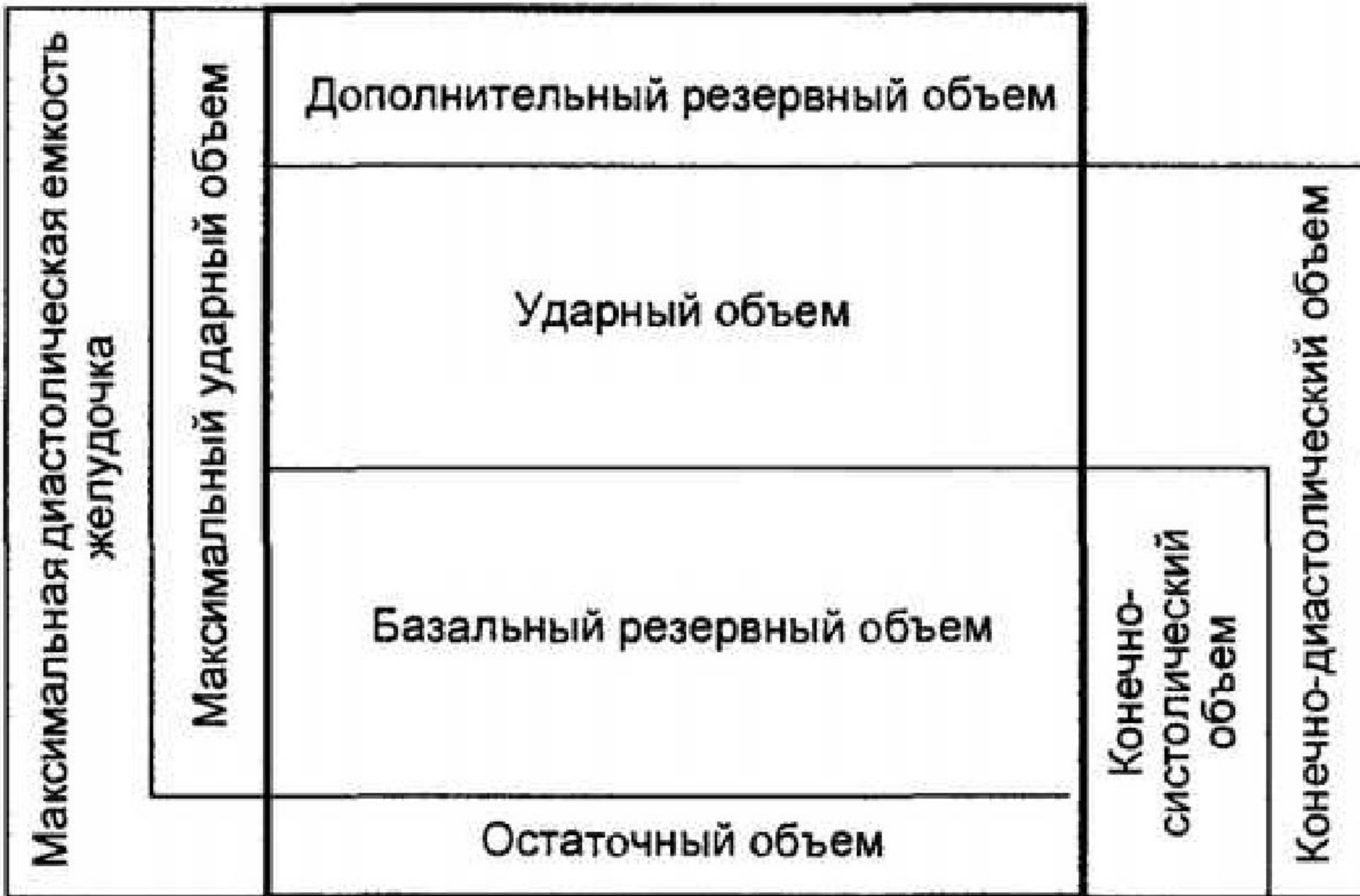



Артериола
Истинные капилляры
Венула
Артерио-
венозный
анастомоз
Метаратериола
Прекапиллярные
сфинктеры
Основной канал
Мелкая
венула

Left Ventricular Ejection Fraction

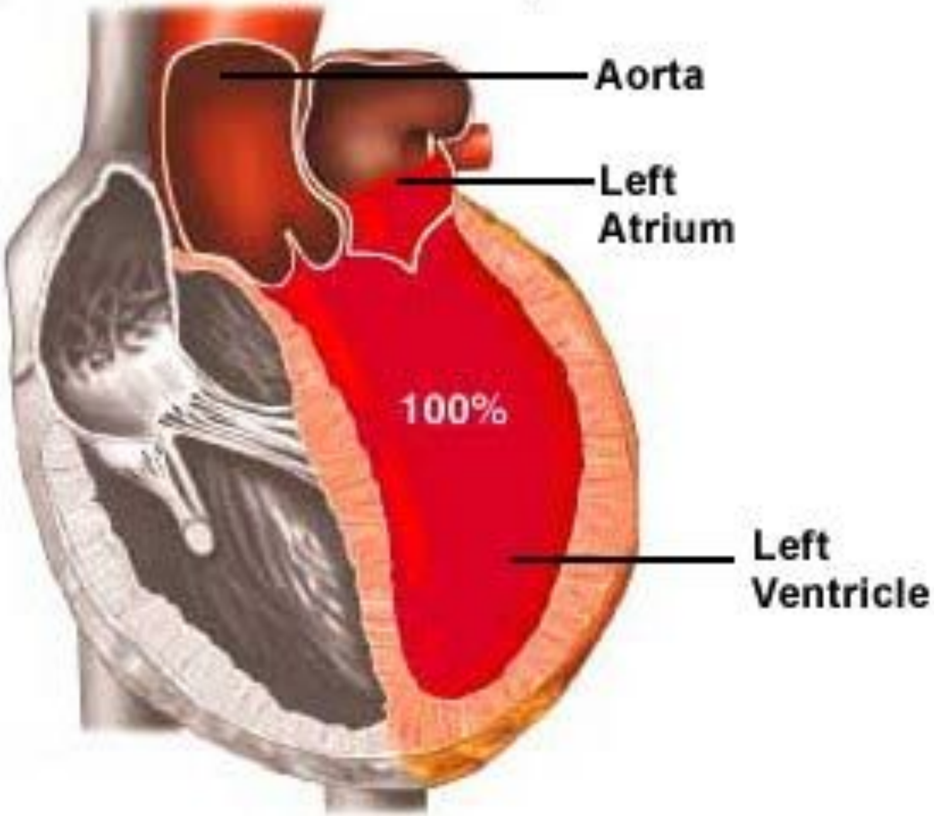
$$\text{LVEF} = \frac{\text{STROKE VOLUME = END DIASTOLIC VOLUME – END SYSTOLIC VOLUME}}{\text{END DIASTOLIC VOLUME}}$$




Максимальная диастолическая емкость желудочка
Максимальный ударный объем
Дополнительный резервный объем
Ударный объем
Базальный резервный объем
Остаточный объем
Конечно-систолический объем
Конечно-диастолический объем

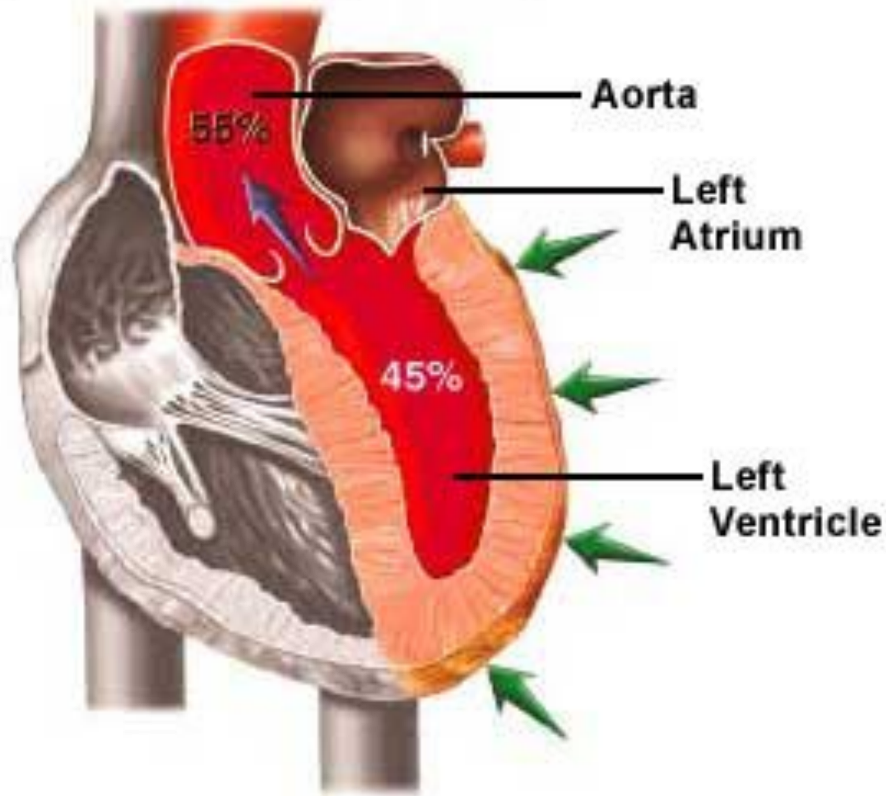
Normal Diastole

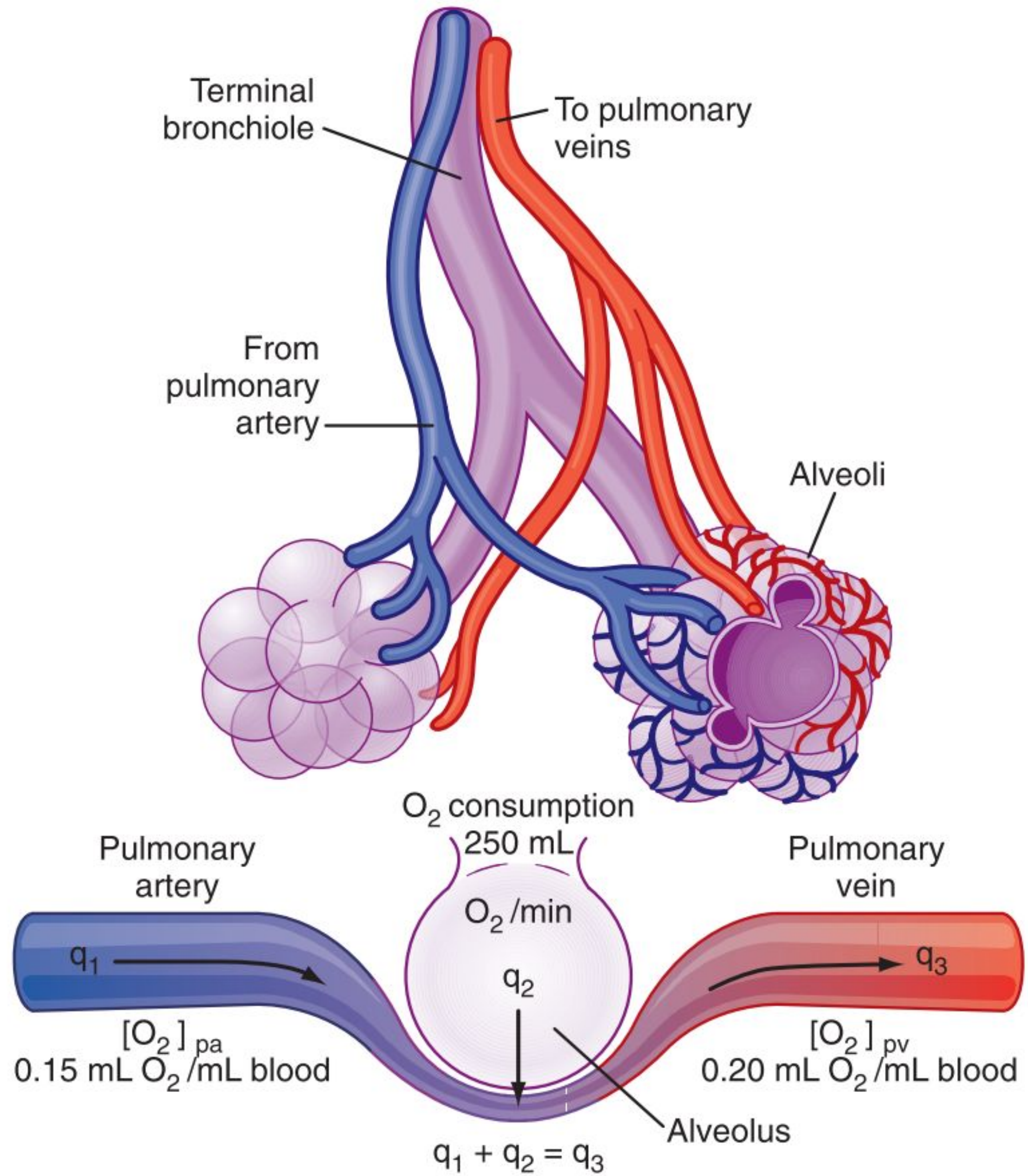
(Frontal, cut-away view of heart)



Normal Systole (Contraction)

Ejection Fraction approximately 0.55





Terminal bronchiole
To pulmonary veins
From pulmonary artery
Alveoli
O_2 consumption 250 mL O_2/min
Pulmonary artery
Pulmonary vein
q_1
q_2
q_3
$[O_2]_{pa}$ 0.15 mL O_2/mL blood
$[O_2]_{pv}$ 0.20 mL O_2/mL blood
Alveolus
$q_1 + q_2 = q_3$

e

- Систолический и минутный объем крови. Косвенный метод
- определения минутного объема крови по Фику

- МОК = СО × v = 70 мл ×75 уд./мин = 5000 мл/мин = 5л/мин

- Метод Фика (1870 г.)

- За 1 мин человек потребил 300 мл O_2
- Содержание O_2 в артериальной крови – 20 об%
- Содержание O_2 в венозной крови – 14 об%
- a-v = 6 об%

- 6 мл O_2 - 100 мл крови
- 300 мл O_2 - х мл

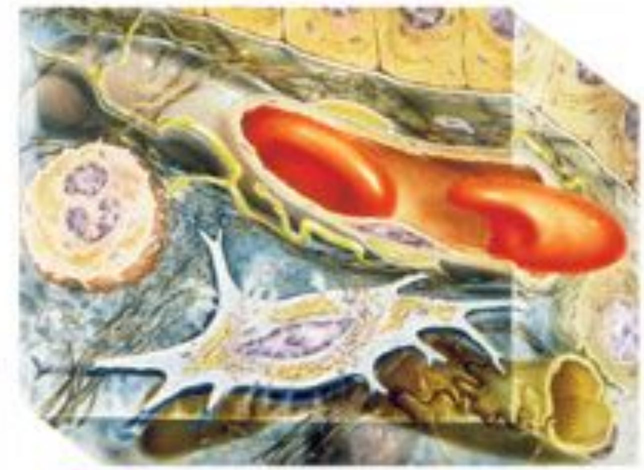
$$\text{МОК (x)} = \frac{300 \cdot 100}{6} = 5000 \text{ мл/мин} = 5 \text{ л/мин}$$

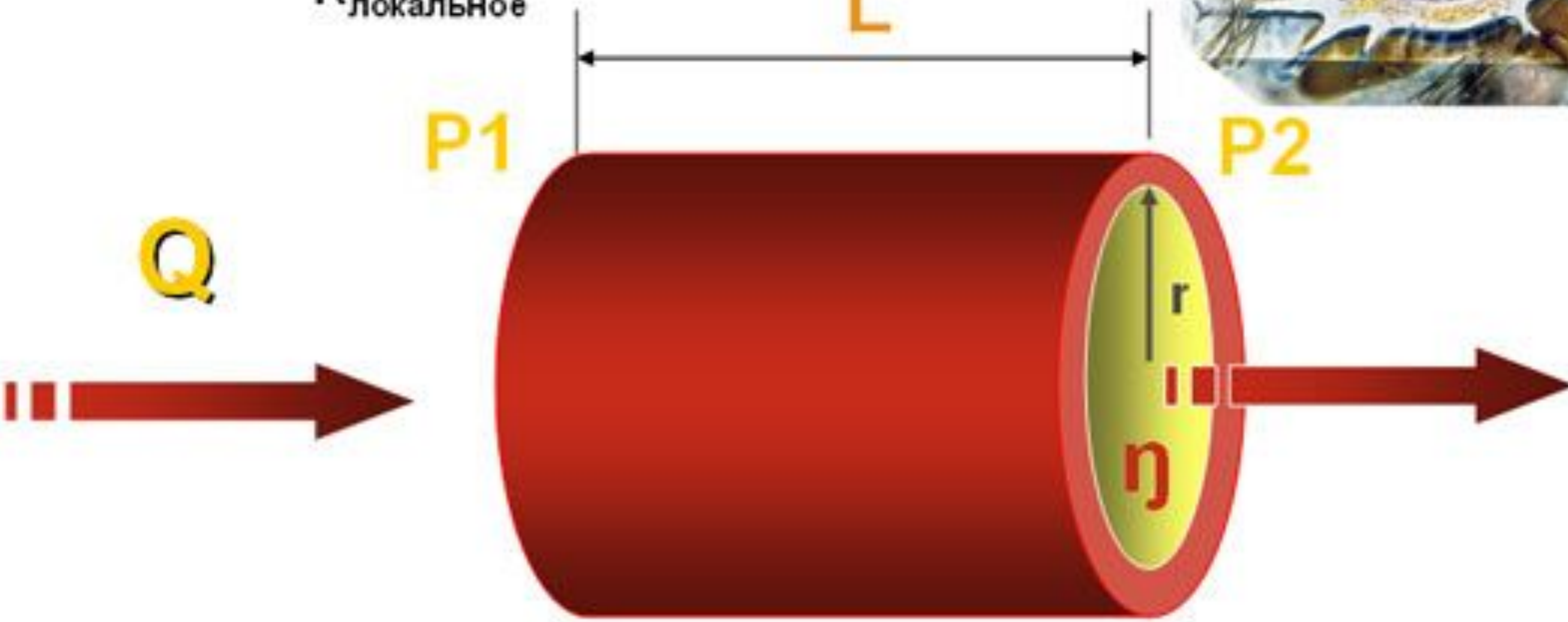
$E_п$=mgh=5 кг×10 м/с^2×0,1 м рт.ст ×13,6 =68 Нм (потенциальный компонент левого желудочка);

$E_п$ =mgh=5 кг × 10 м/с^2× 0,02 м рт.ст ×13,6=13,6 Нм (потенциальный компонент правого желудочка);

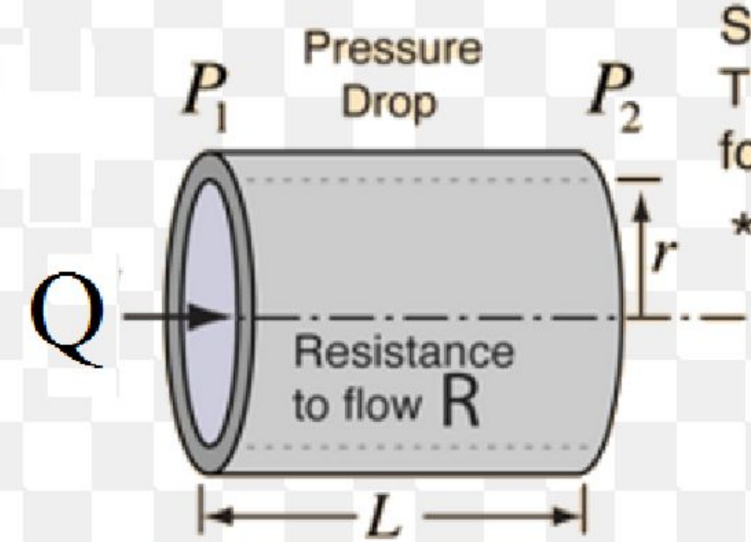
$E_к$ = mv^2/2 = 5 кг×(0,5м/с)^2/2= 0,64 Нм (кинетический компонент, одинаков для обоих желудочков)

$$Q = \frac{P_1 - P_2}{R_{локальное}}$$





$$R_{локальное} = 8L\eta \backslash \pi r^4$$



Suppose the original flowrate is 100 cm^3/sec. The effect of changes in the parameters is as follows:

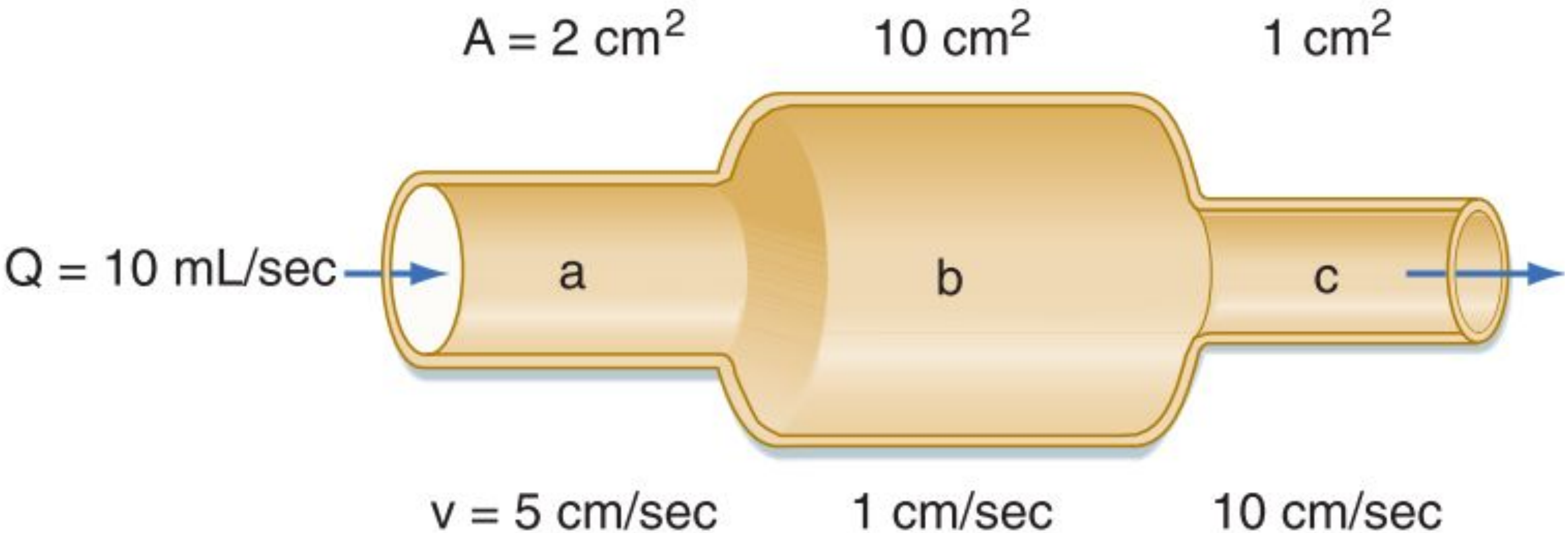
*Double length	⟹ 50	cm^3/sec
Double viscosity	⟹ 50	cm^3/sec
Double pressure	⟹ 200	cm^3/sec
Double radius	➡ 1600	cm^3/sec

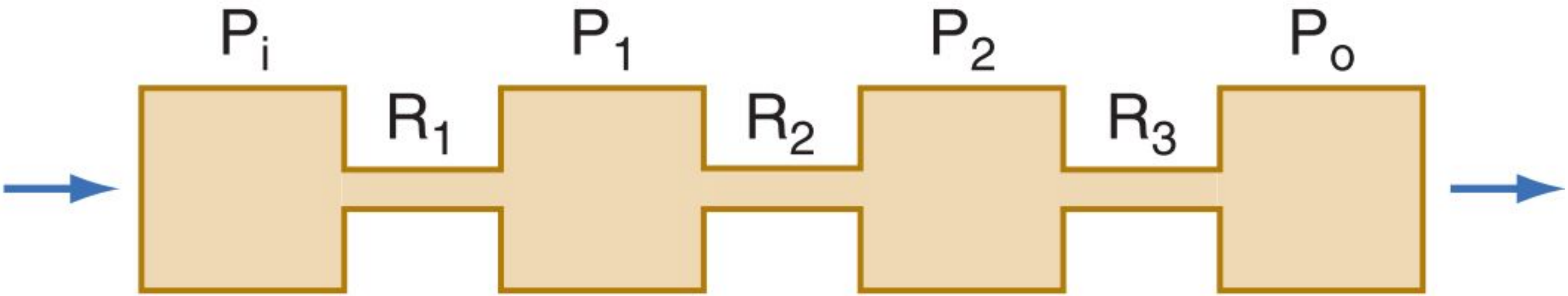
$$\mathcal{R} = \frac{8\eta L}{\pi r^4}$$ where η = viscosity

* With other parameters held at original values

$$\text{Volume Flowrate} = Q = \frac{P_1 - P_2}{\mathcal{R}} = \frac{\pi(\text{Pressure difference})(\text{radius})^4}{8(\text{viscosity})(\text{length})}$$

A 19% increase in radius will double the volume flowrate!

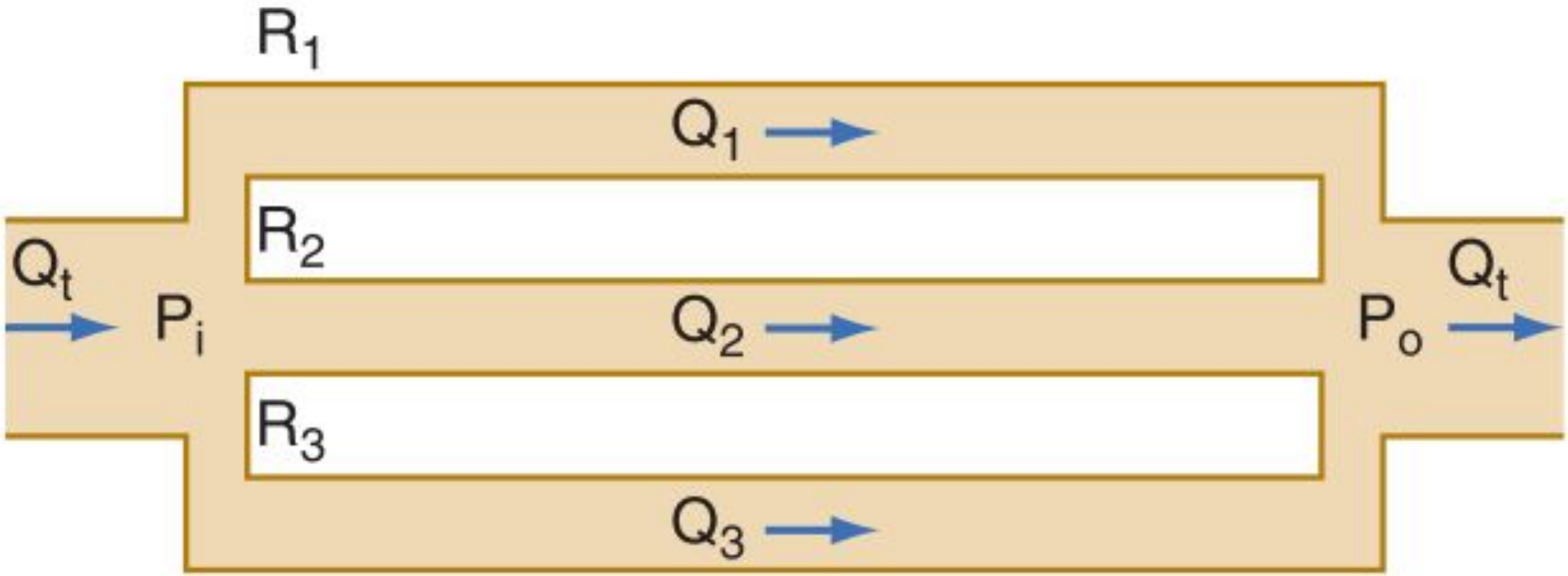

A = 2 cm2
10 cm2
1 cm2
Q = 10 mL/sec
a
b
c
v = 5 cm/sec
1 cm/sec
10 cm/sec



$$\text{(a) } P_i - P_o = (P_i - P_1) + (P_1 - P_2) + (P_2 - P_o)$$

$$\text{(b) } \frac{P_i - P_o}{Q} = \frac{(P_i - P_1)}{Q} + \frac{(P_1 - P_2)}{Q} + \frac{(P_2 - P_o)}{Q}$$

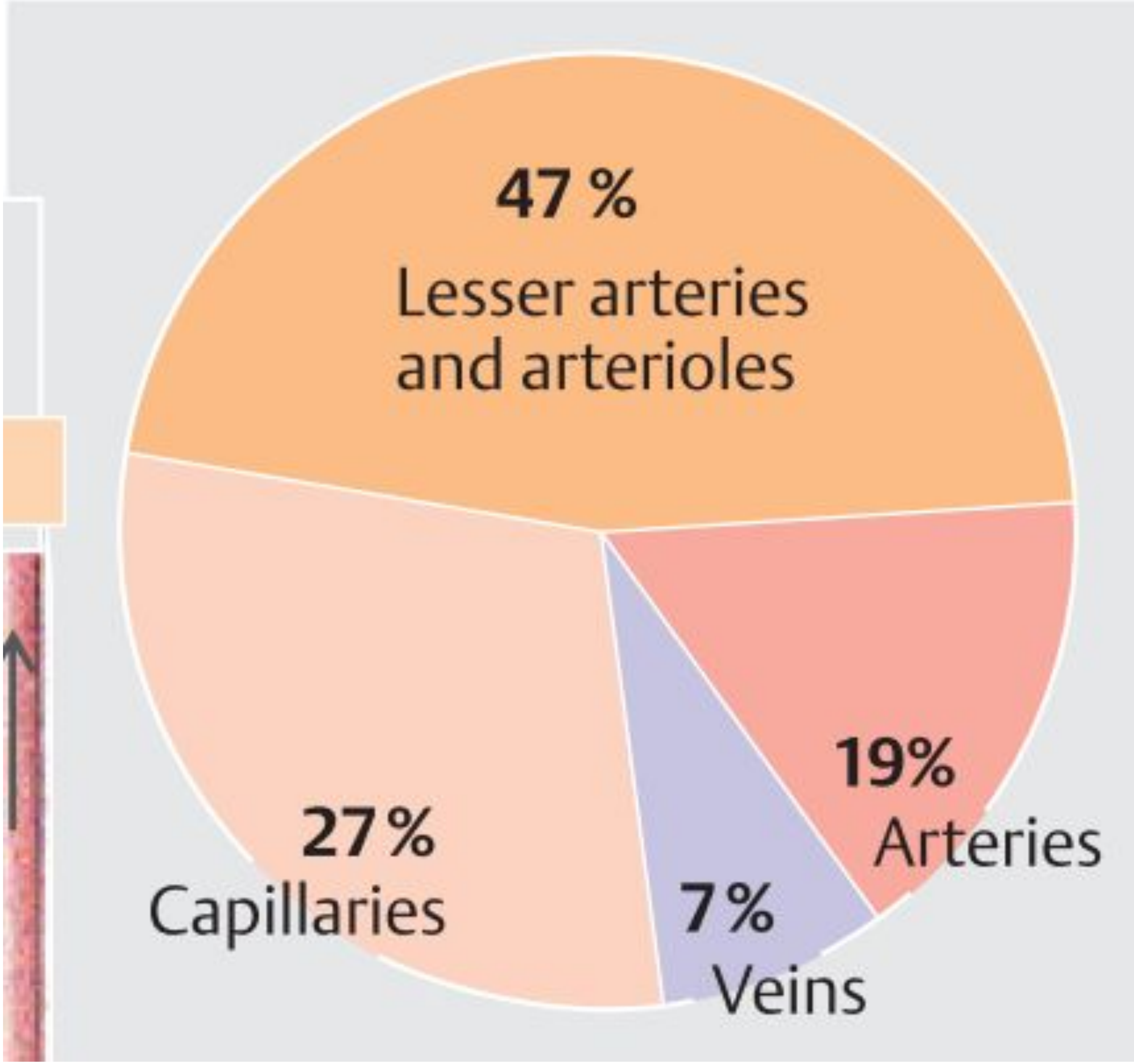
$$\text{(c) } R_t = R_1 + R_2 + R_3$$



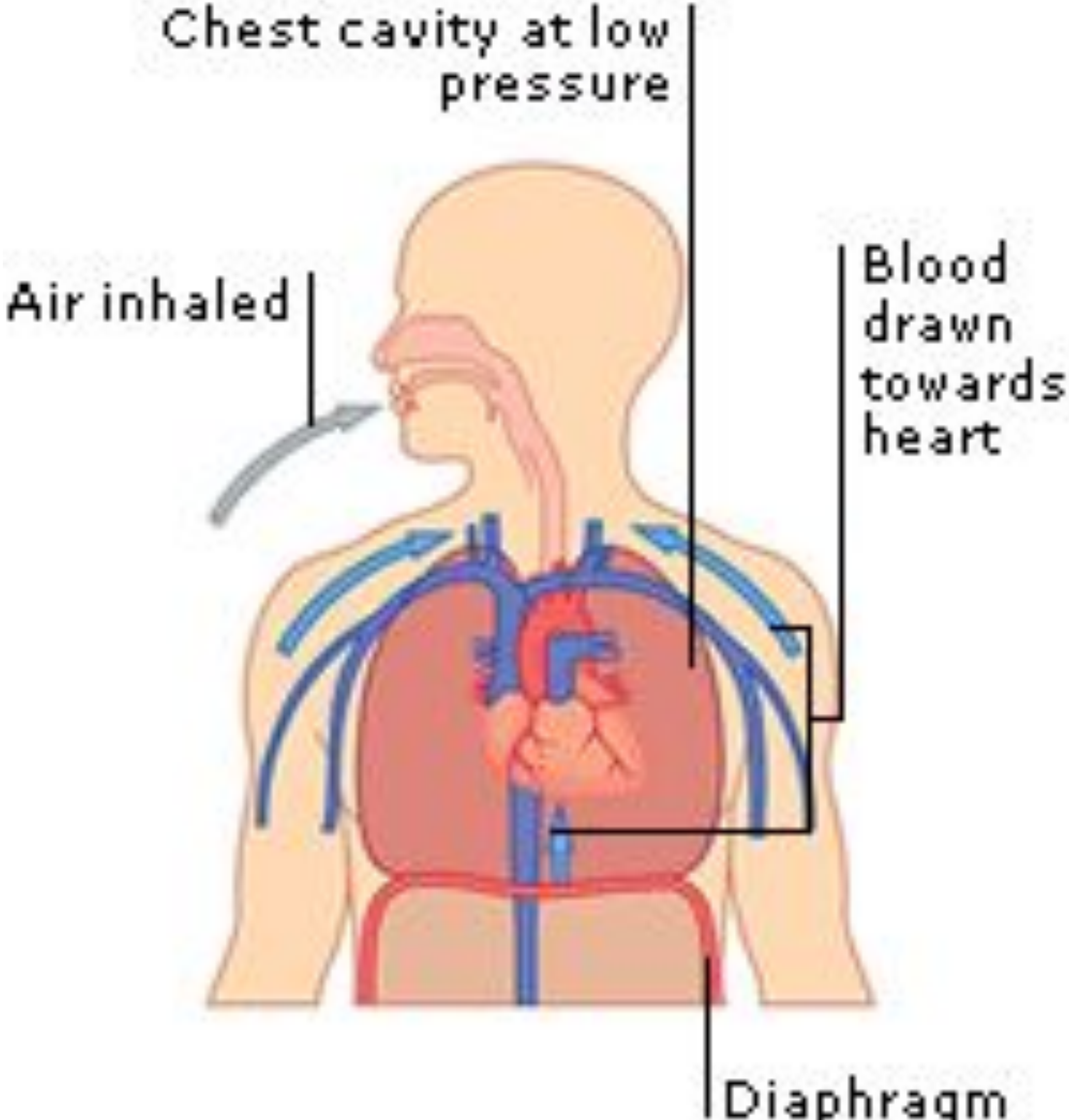
(a) $Q_t = Q_1 + Q_2 + Q_3$

(b) $$\frac{Q_t}{P_i - P_o} = \frac{Q_1}{(P_i - P_o)} + \frac{Q_2}{(P_i - P_o)} + \frac{Q_3}{(P_i - P_o)}$$

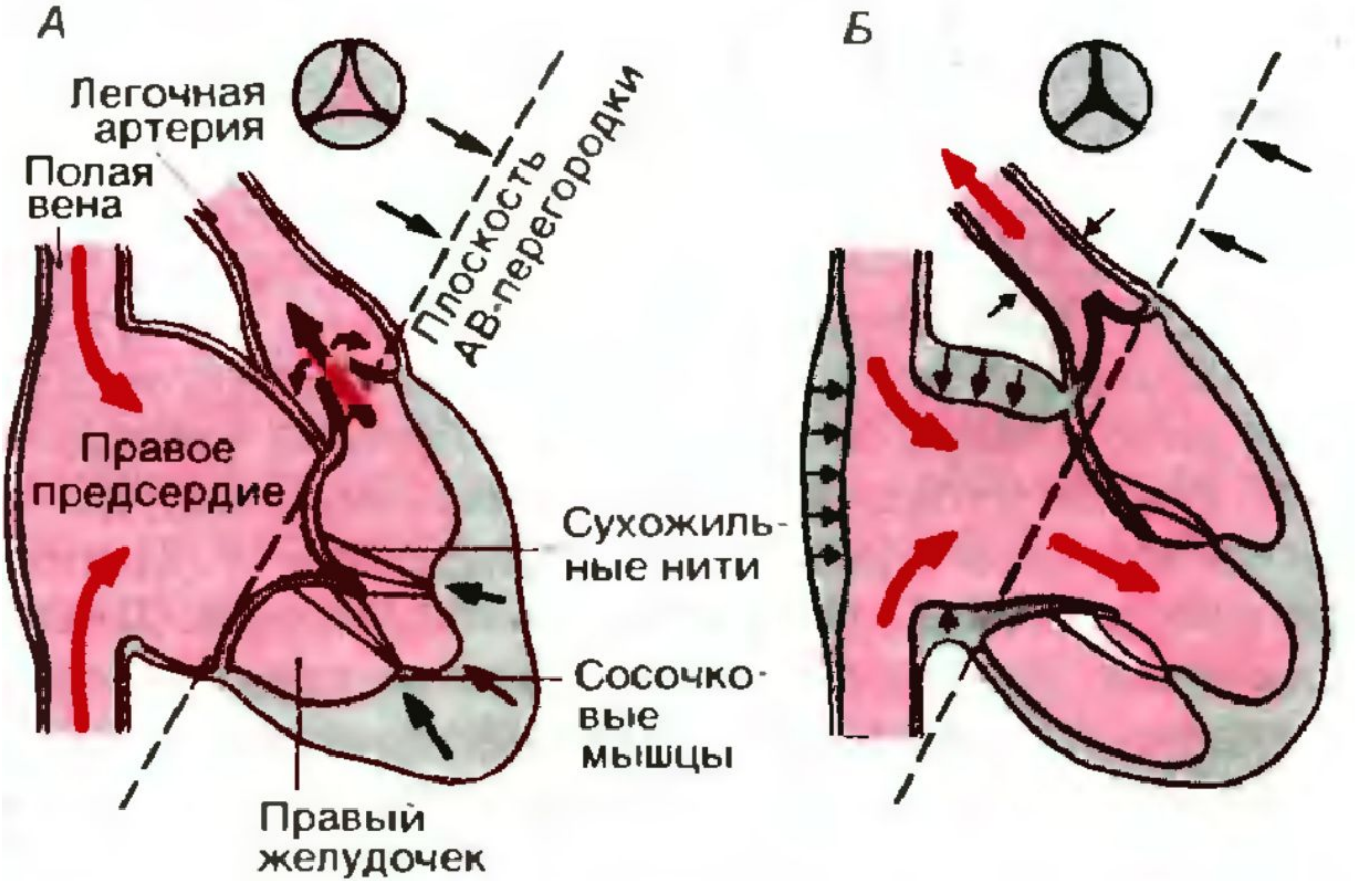
(c) $$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



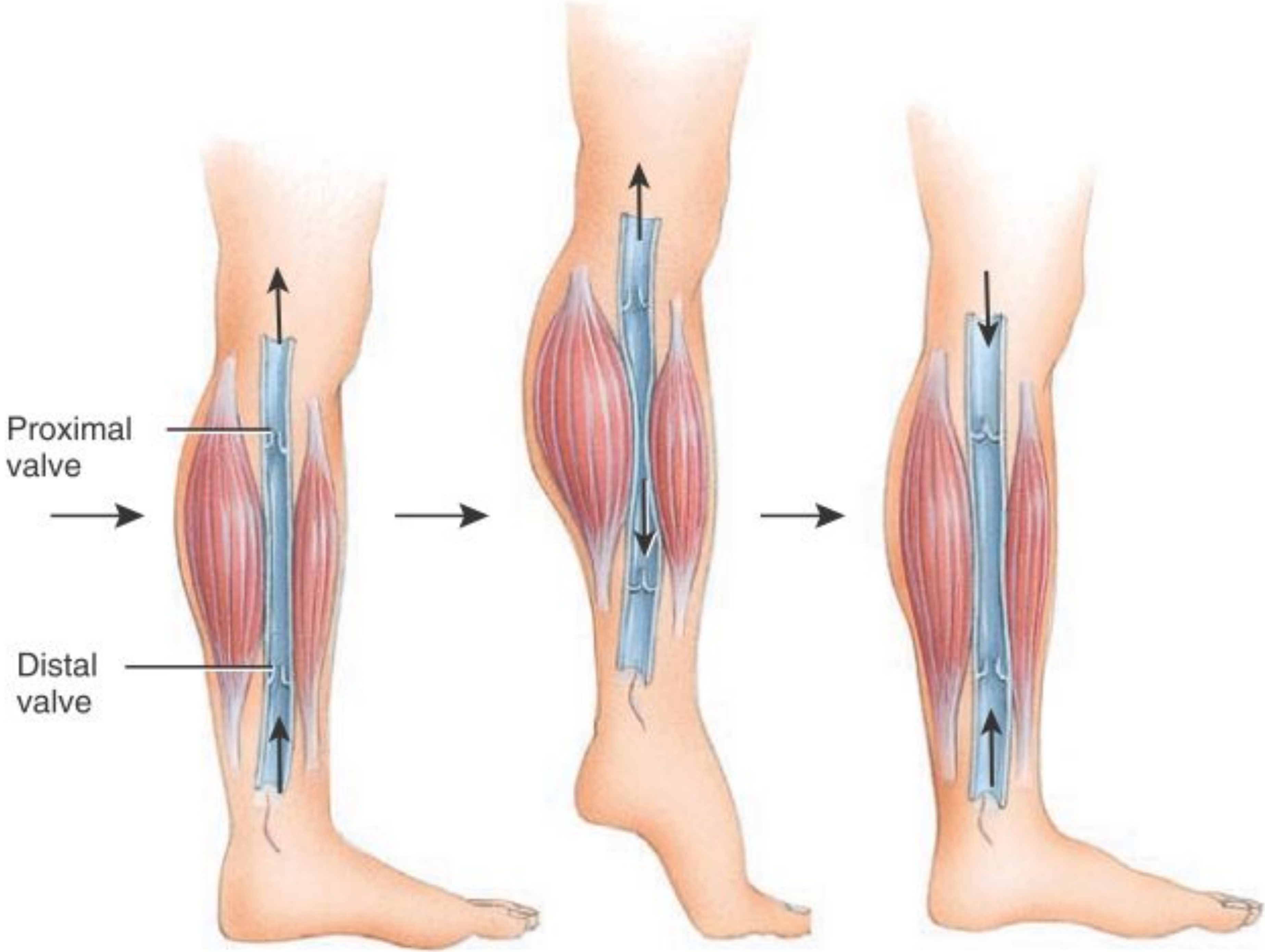
47 %
Lesser arteries and arterioles
19%
Arteries
7%
Veins
27%
Capillaries



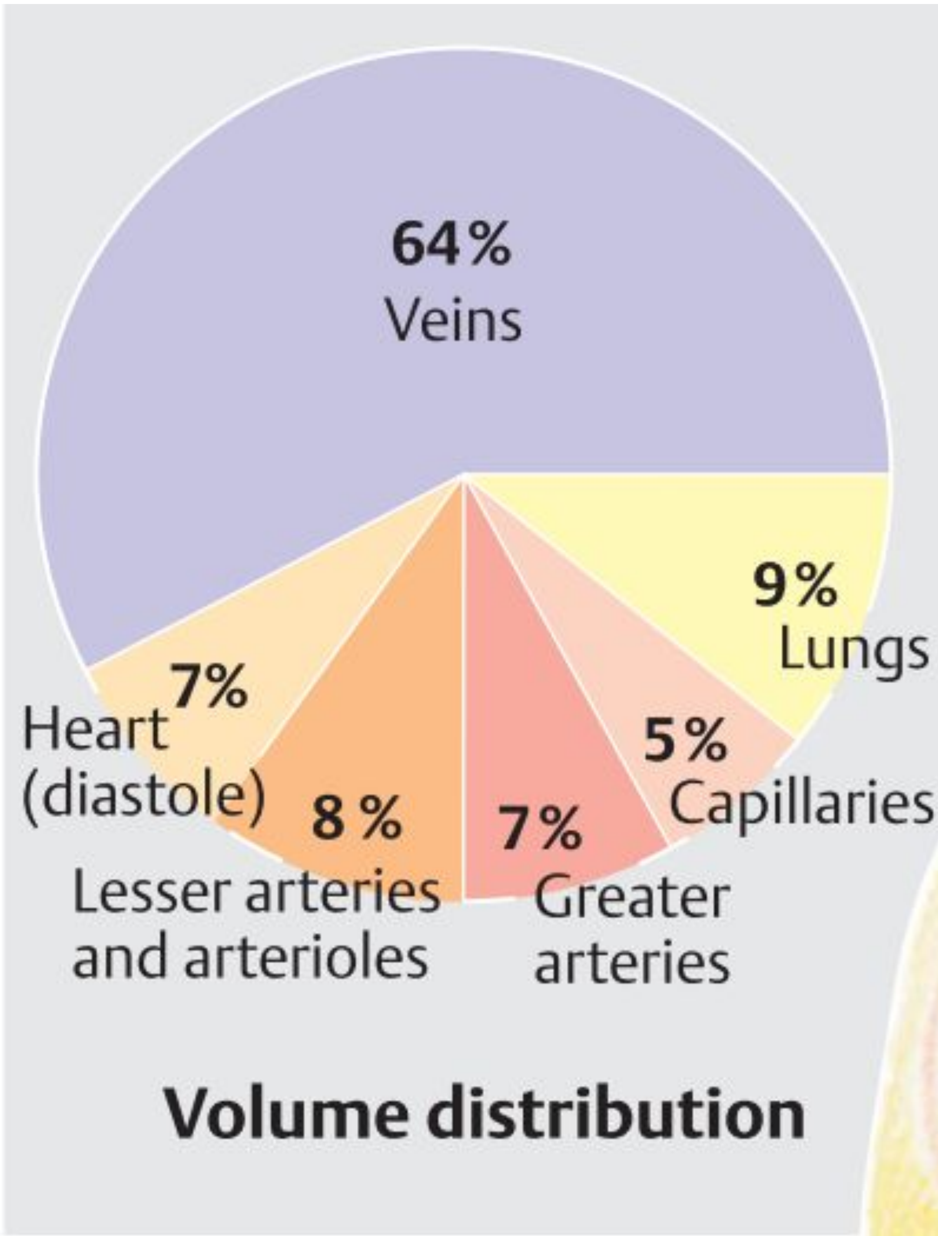
Chest cavity at low pressure
Air inhaled
Blood drawn towards heart
Diaphragm



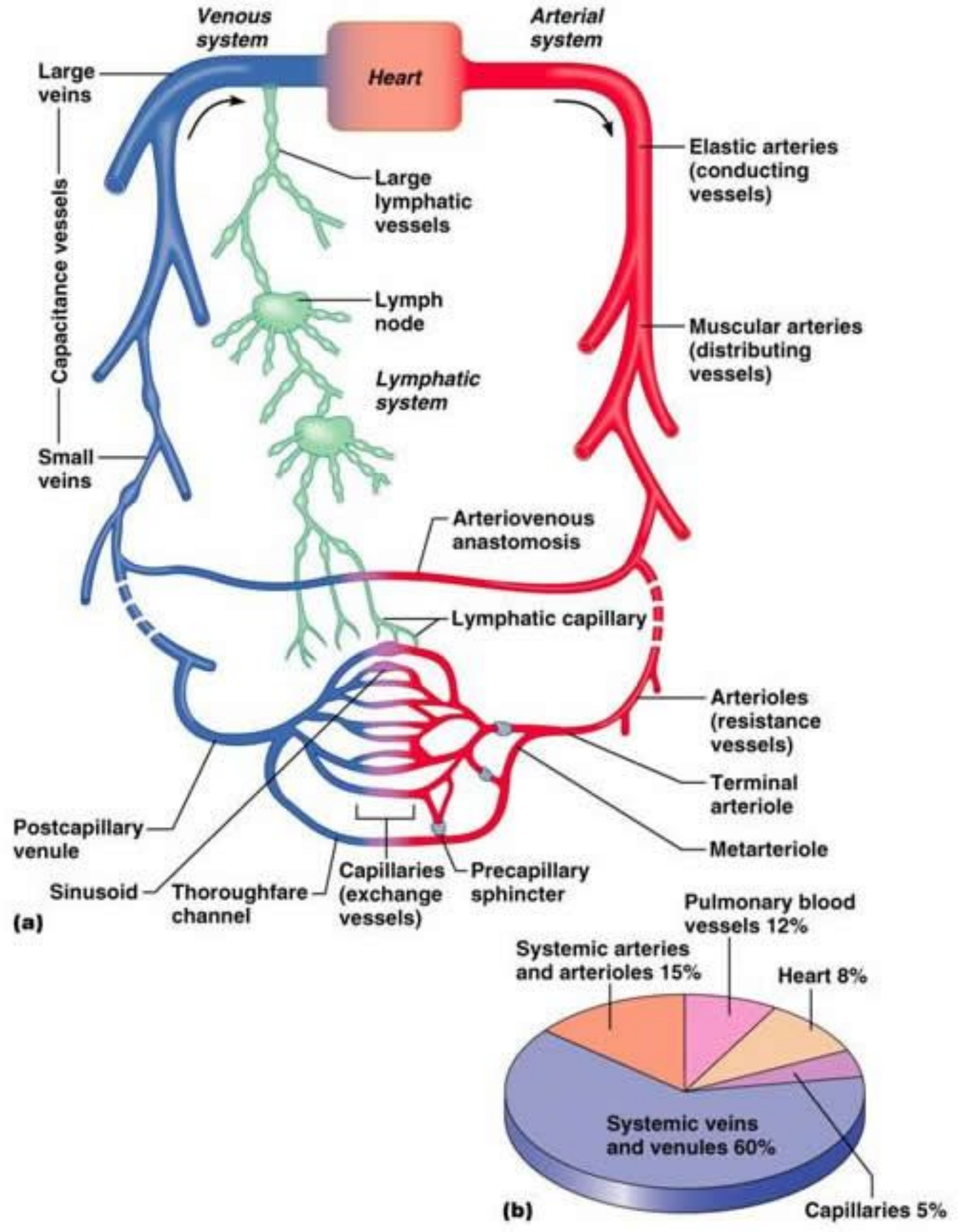
А
Б
Легочная артерия
Полая вена
Плоскость АВ-перегородки
Правое предсердие
Сухожильные нити
Сосочковые мышцы
Правый желудочек


Proximal
valve
Distal
valve

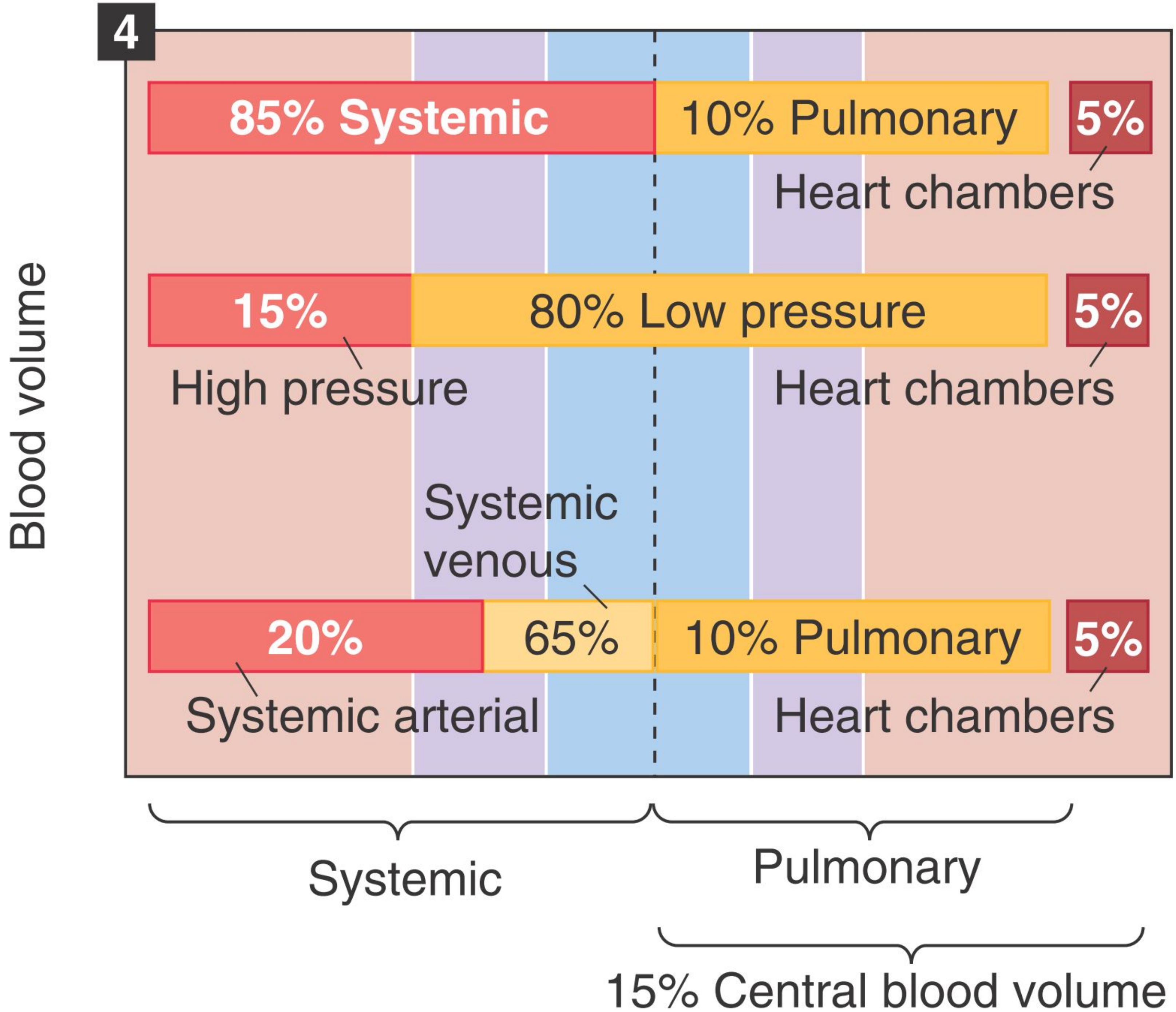
Отдел сердечно-сосудистой системы	Объем				
	мл		%		общий %
Сердце (и диастоле)	360		7,2		7,7
Легочное кроио-обращение					
Артерии	130	440	2,6		8,8
Капилляры	110		2,2		
Вены	200		4,0		
Системное кровообращение					
Аорта и крупные артерии	300	4200	6,0	14	84,0
Мелкие артерии	400		8,0		
Капилляры	300		6,0	64	
Мелкие вены	2300		46,0		
Крупные вены	900		18,0		
	5000				100,0

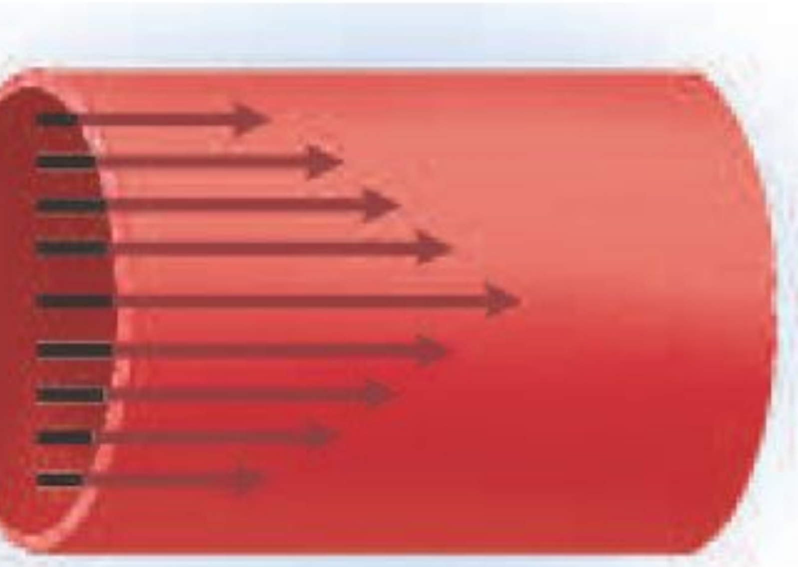


64% Veins
9% Lungs
7% Heart (diastole)
5% Capillaries
8% Lesser arteries and arterioles
7% Greater arteries
Volume distribution



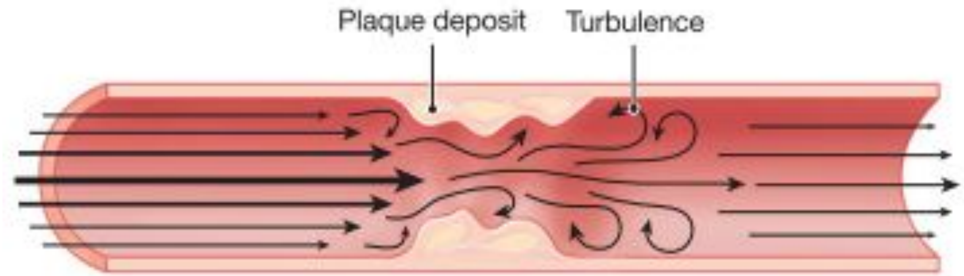
Venous system
Heart
Arterial system
Large veins
Capacitance vessels
Large lymphatic vessels
Elastic arteries (conducting vessels)
Lymph node
Lymphatic system
Muscular arteries (distributing vessels)
Small veins
Arteriovenous anastomosis
Lymphatic capillary
Arterioles (resistance vessels)
Terminal arteriole
Metarteriole
Postcapillary venule
Sinusoid
Thoroughfare channel
Capillaries (exchange vessels)
Precapillary sphincter
(a)
Pulmonary blood vessels 12%
Systemic arteries and arterioles 15%
Heart 8%
Systemic veins and venules 60%
Capillaries 5%
(b)


4
Blood volume
85% Systemic
10% Pulmonary
5%
Heart chambers
15%
80% Low pressure
5%
High pressure
Heart chambers
Systemic
venous
20%
65%
10% Pulmonary
5%
Systemic arterial
Heart chambers
Systemic
Pulmonary
15% Central blood volume



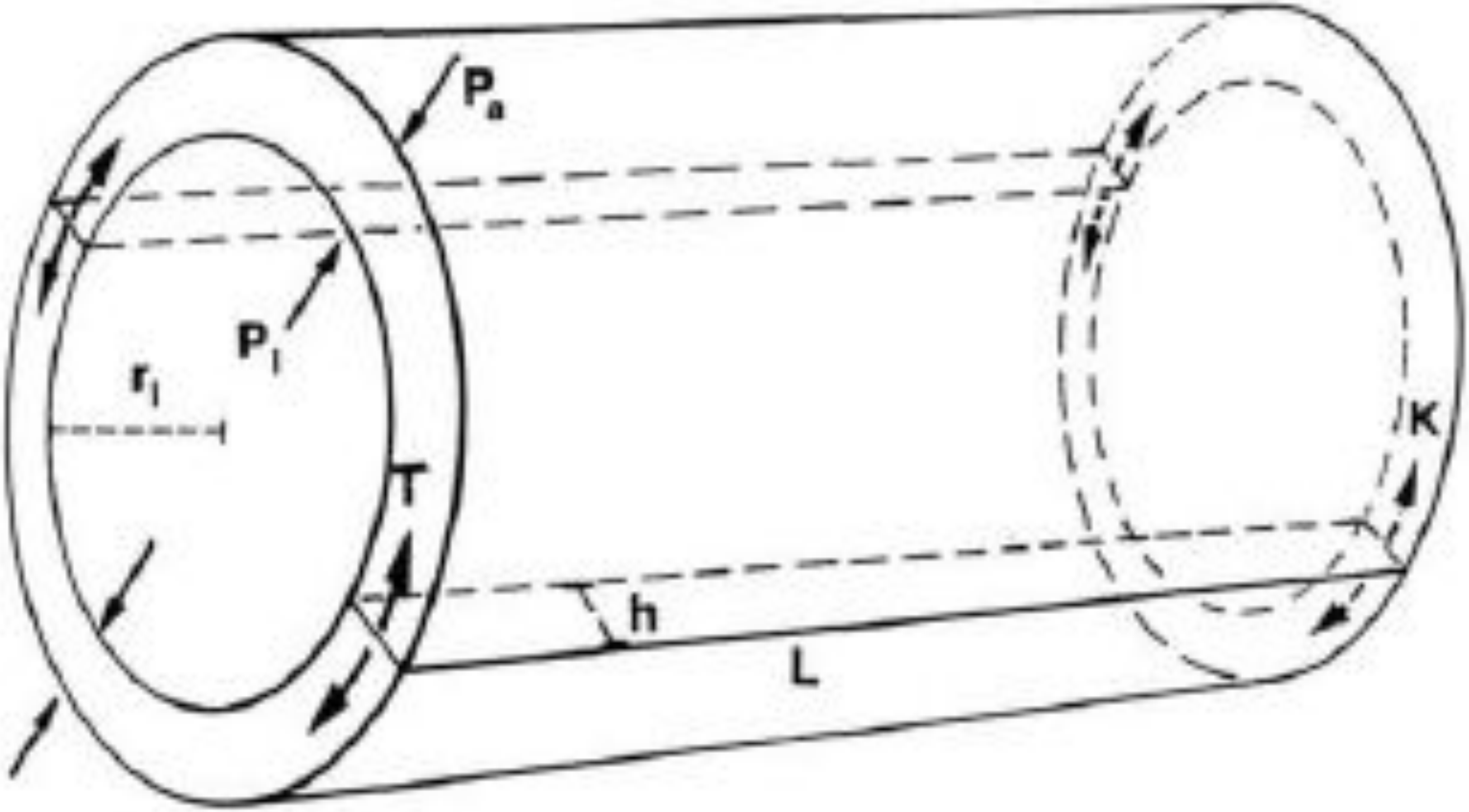
)

)

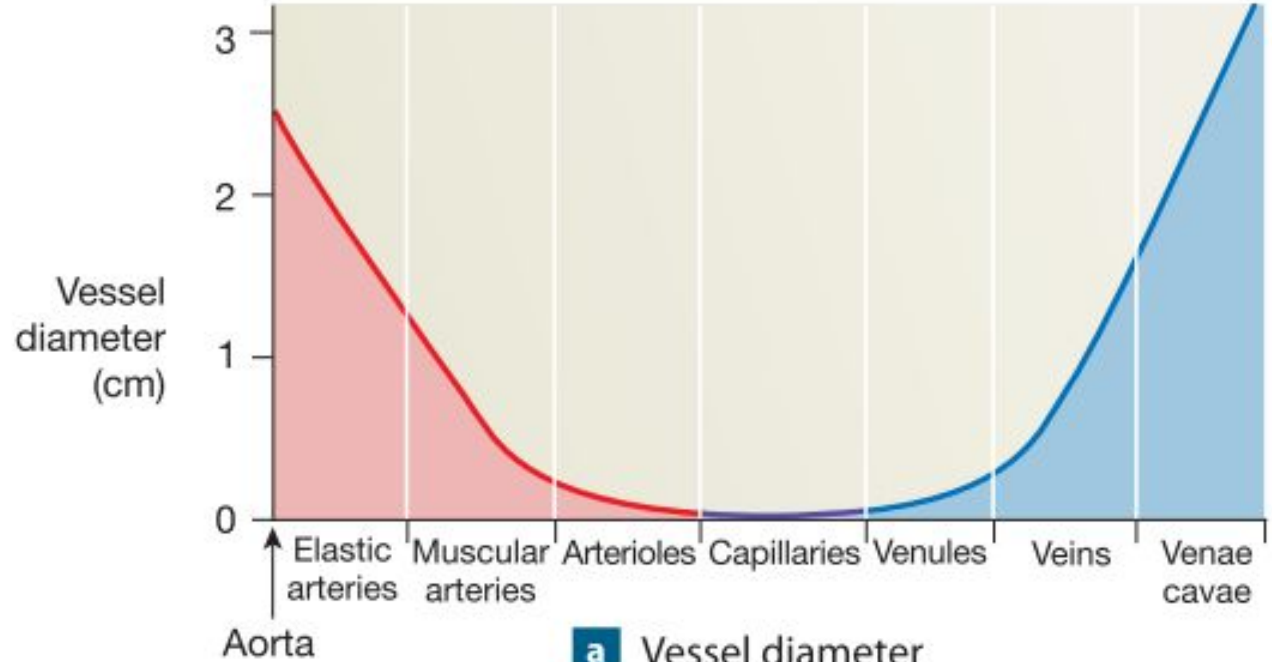


Turbulence

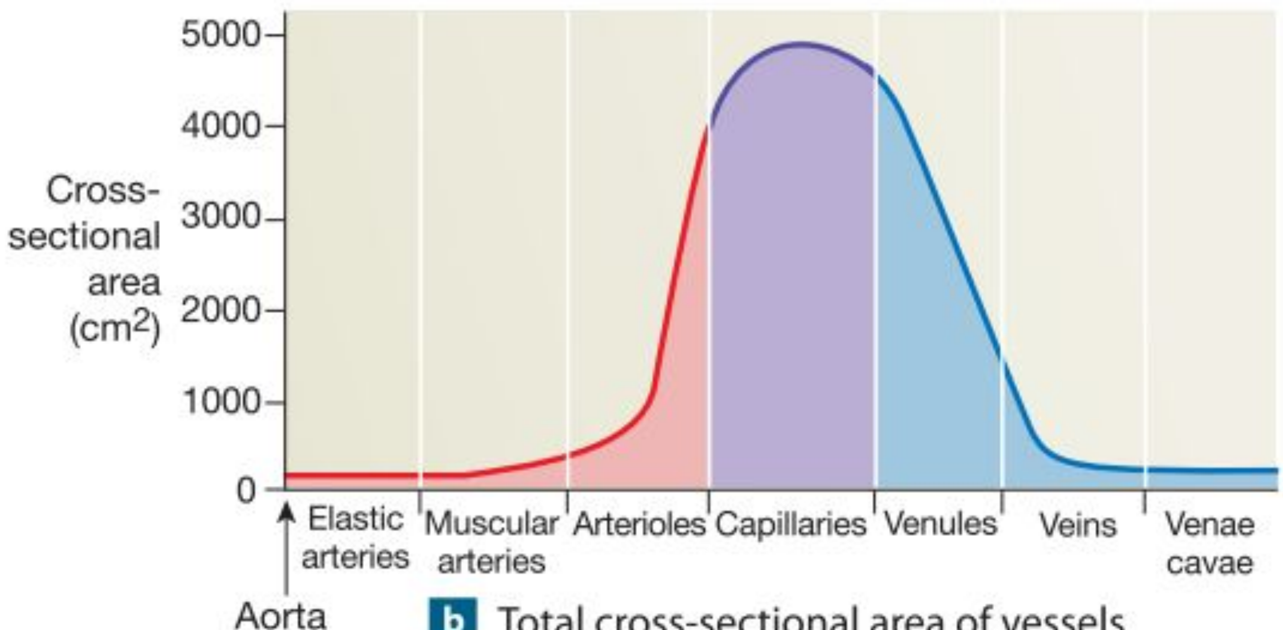
$$Re = \frac{2r \cdot \bar{v} \cdot \rho}{\eta}$$



$$T_h = P_t \cdot \frac{r_B}{h}$$

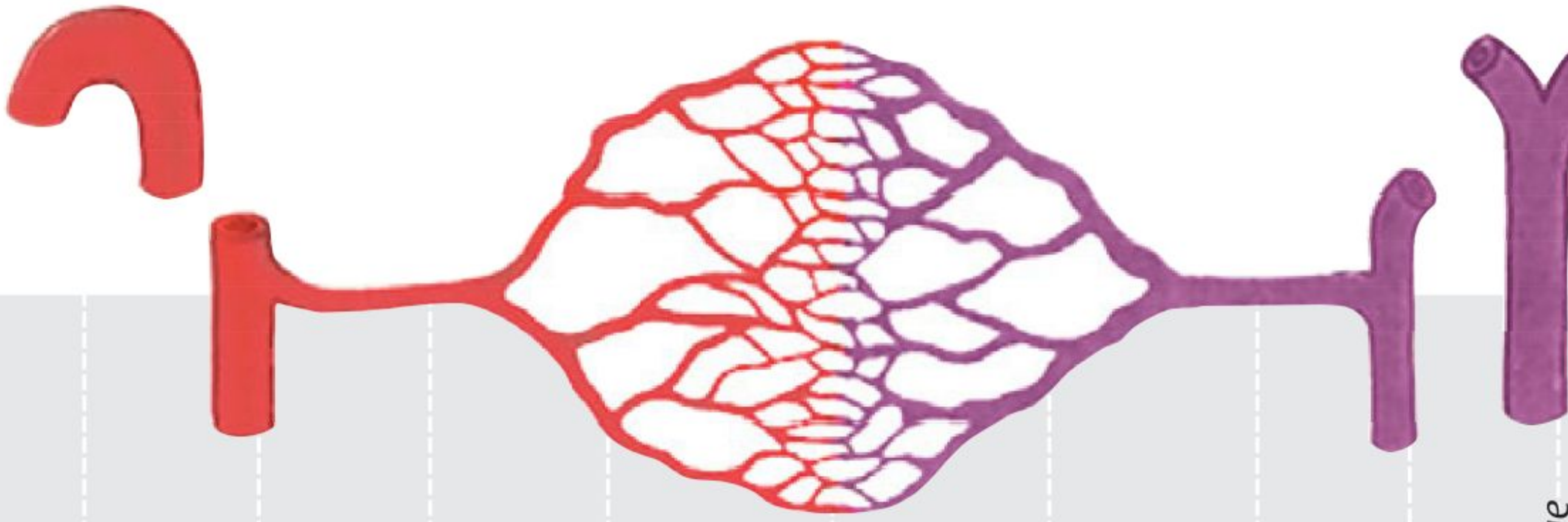


a Vessel diameter

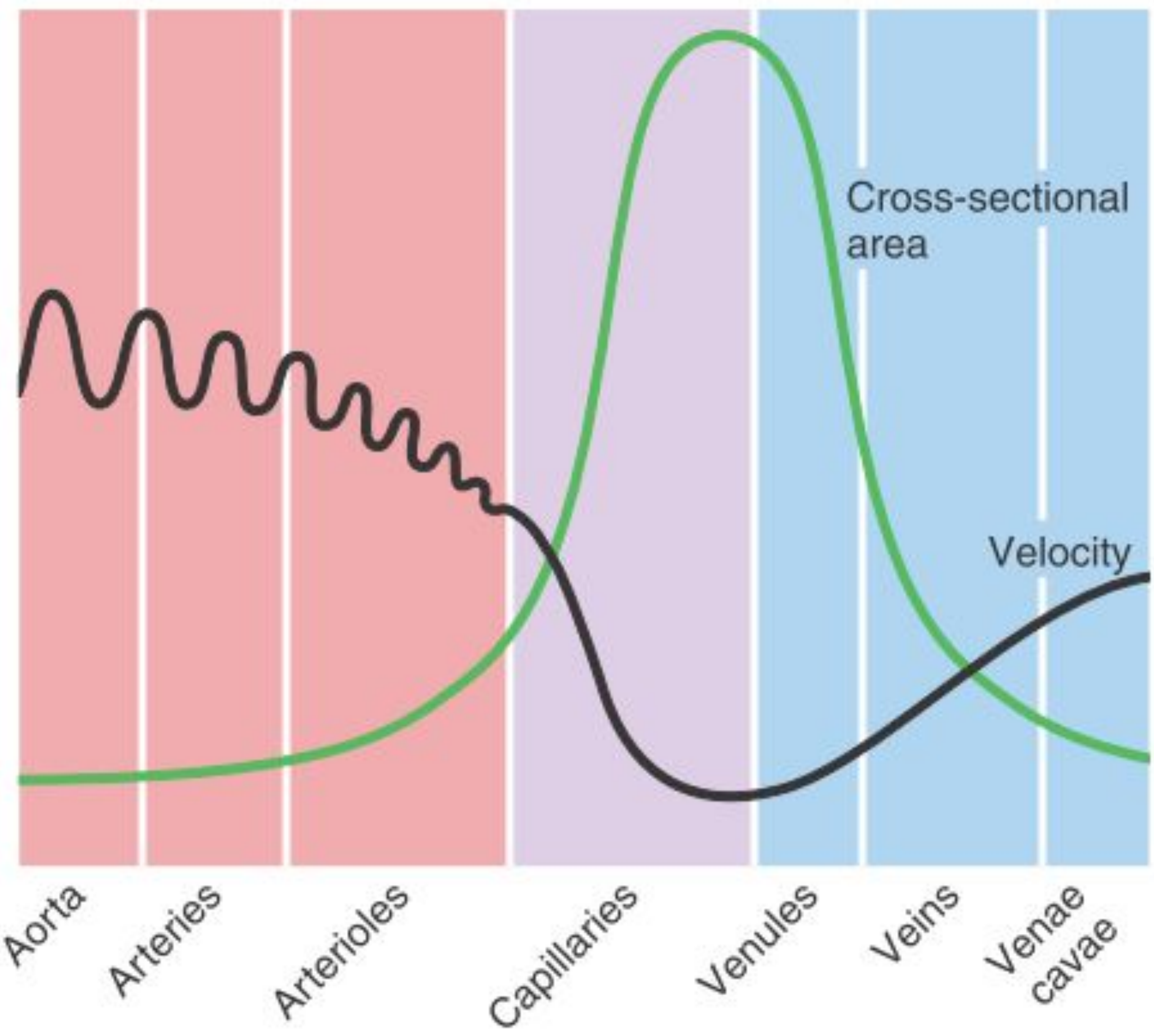


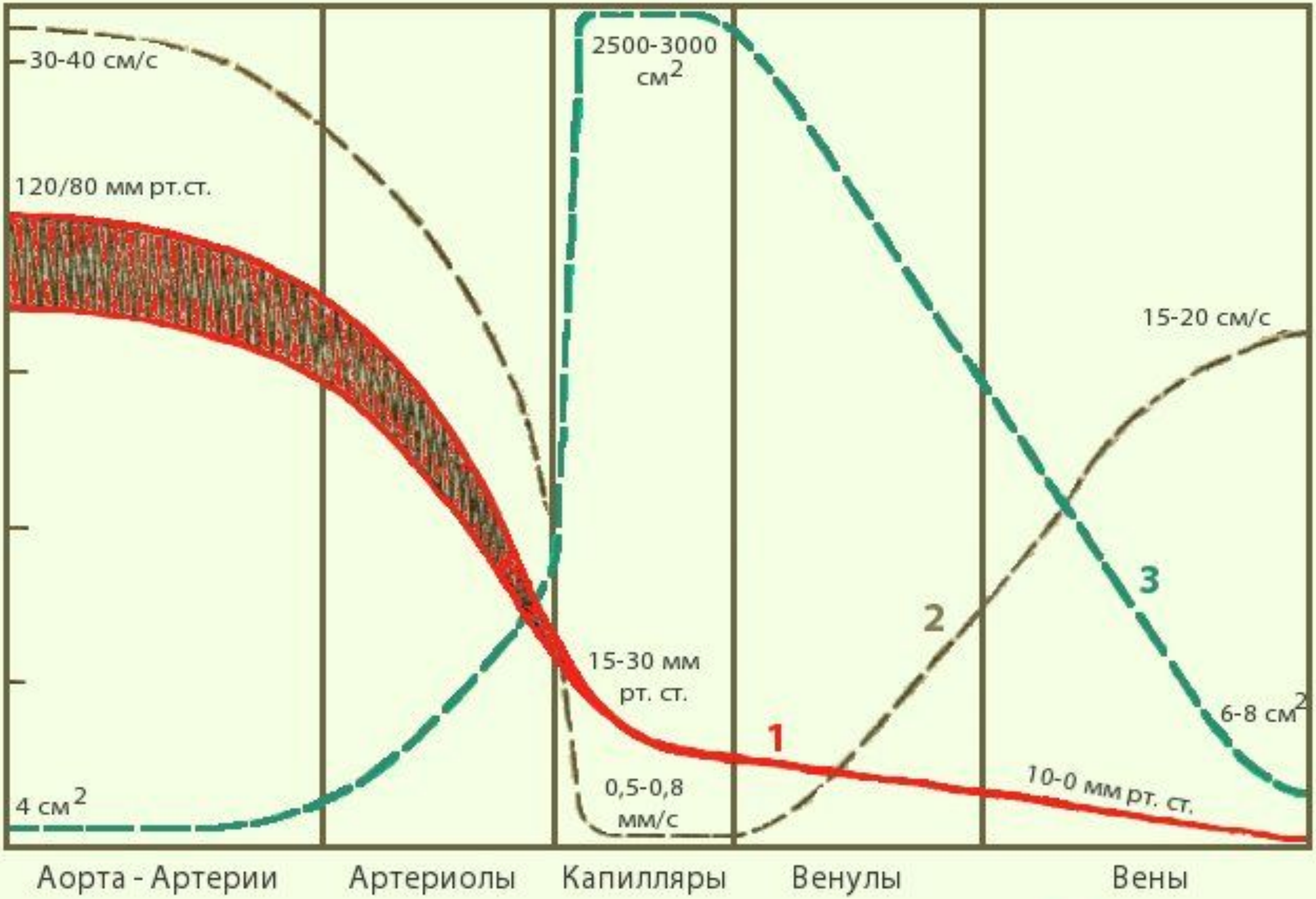
b Total cross-sectional area of vessels

A. Characteristics of the vessel segments



	Aorta	Greater arteries	Arterial branches	Arterioles	Capillaries	Venules	Venous branches	Greater veins	Venae cavae
Number	1	Increasing		$0.16 \cdot 10^9$	$5 \cdot 10^9$	$0.5 \cdot 10^9$	Decreasing		2
1 Fraction of TPR		19%		47%	27%		7%		
2 Mean blood pressure $\bar{P}$ (mmHg)		100	40		25	20			2–4
3 Mean flow velocity $\bar{\dot{V}}_A$ ($cm \cdot s^{-1}$)		18	5	1.5	0.02–0.1	1,0			6


Cross-sectional area
Velocity
Aorta
Arteries
Arterioles
Capillaries
Venules
Veins
Venae cavae



Соотношение между разными показателями кровообращения

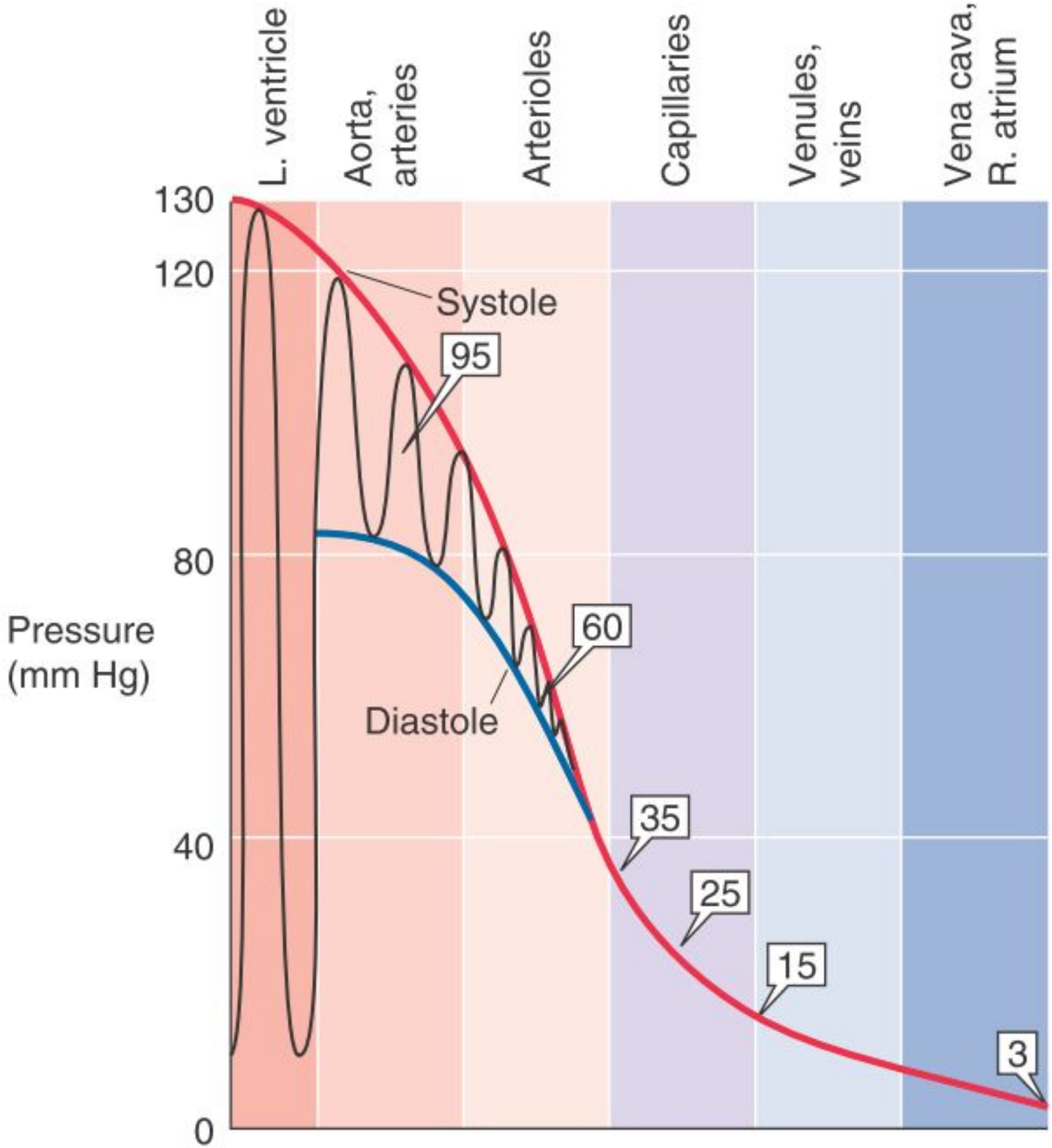
1 - кровяное давление; 2 - скорость движения крови; 3 - площадь поперечного сечения сосудистого русла. Вертикальные линии условно разделяют разные отделы сосудистой системы.

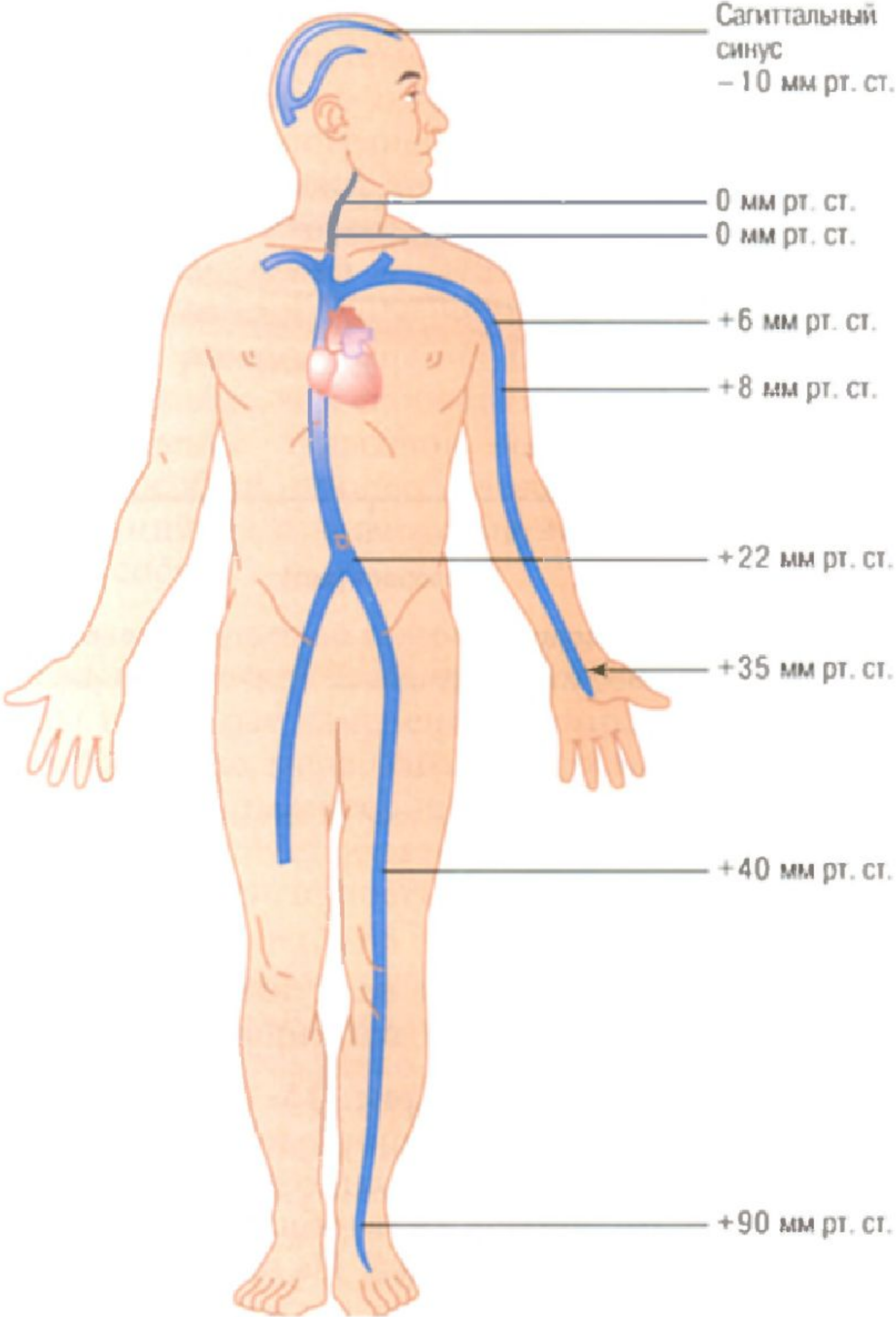
Таблица 20.4. Средние значения линейной скорости кровотока и давления в системном кровообращении у человека

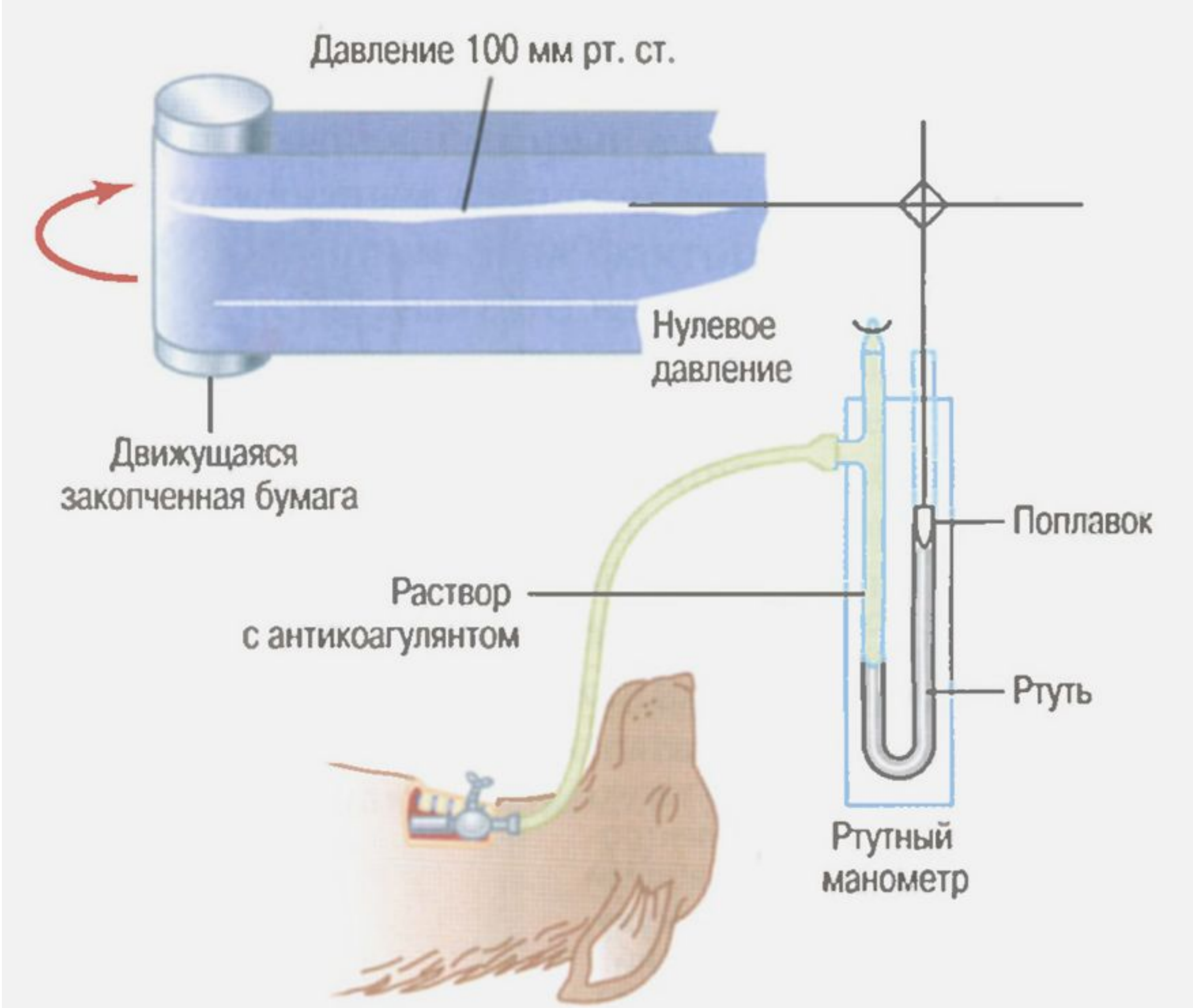
	Диаметр, мм	Средняя скорость, см/с	Среднее давление, мм рт. ст.
Аорта	20–25	20	100
Мелкие артерии		10–15	95
Мельчайшие артерии		2	70–80
Артериолы	0,06–0,02	0,2–0,3	35–70
Капилляры			
артериальный конец	0,006	0,03	30–35
средний участок			20–25
венозный конец			15–20
Мельчайшие вены		0,5–1,0	10–15
Мелкие и средние вены		1–5	10 или меньше
Крупные вены	5–15	5–15	
Полые вены	30–35	10–16	

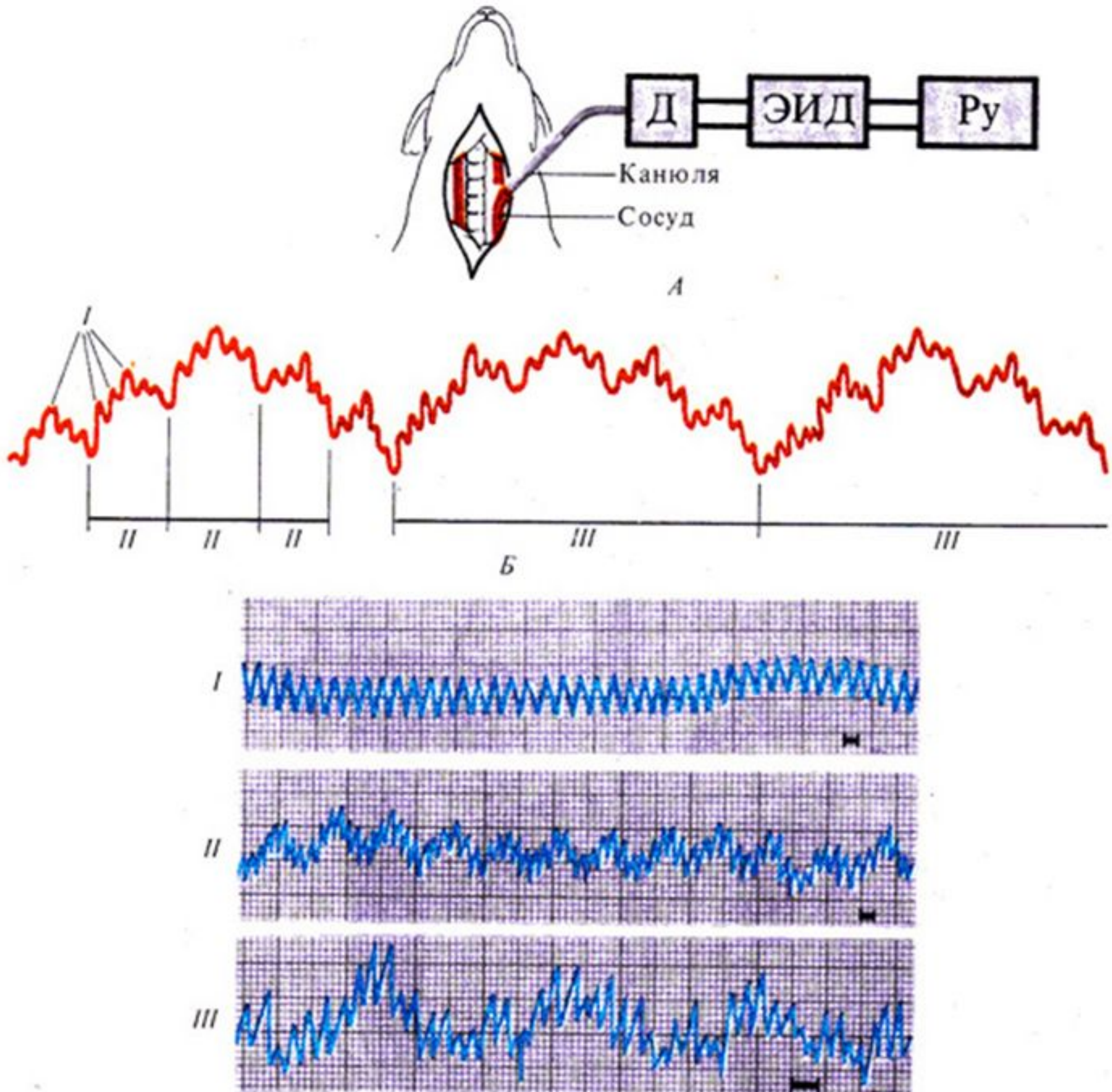
$$Mean\ Arterial\ Pressure = Diastolic\ Pressure + \left(\frac{1}{3} \times Pulse\ Pressure\right)$$

$$Pulse\ Pressure = Systolic\ Pressure - Diastolic\ Pressure$$

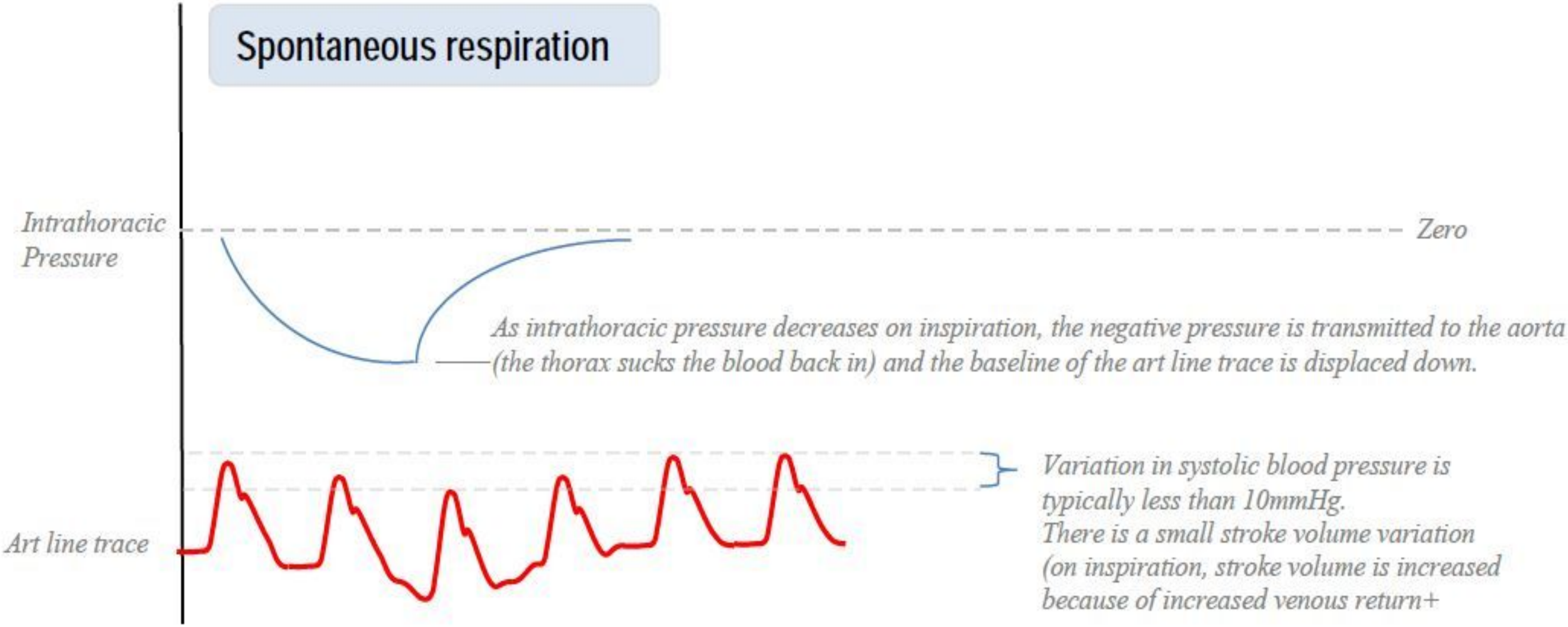

L. ventricle
Aorta, arteries
Arterioles
Capillaries
Venules, veins
Vena cava, R. atrium
130
120
80
40
0
Pressure (mm Hg)
Systole
95
60
Diastole
35
25
15
3


Сагиттальный синус −10 мм рт. ст.
0 мм рт. ст.
0 мм рт. ст.
+6 мм рт. ст.
+8 мм рт. ст.
+22 мм рт. ст.
+35 мм рт. ст.
+40 мм рт. ст.
+90 мм рт. ст.

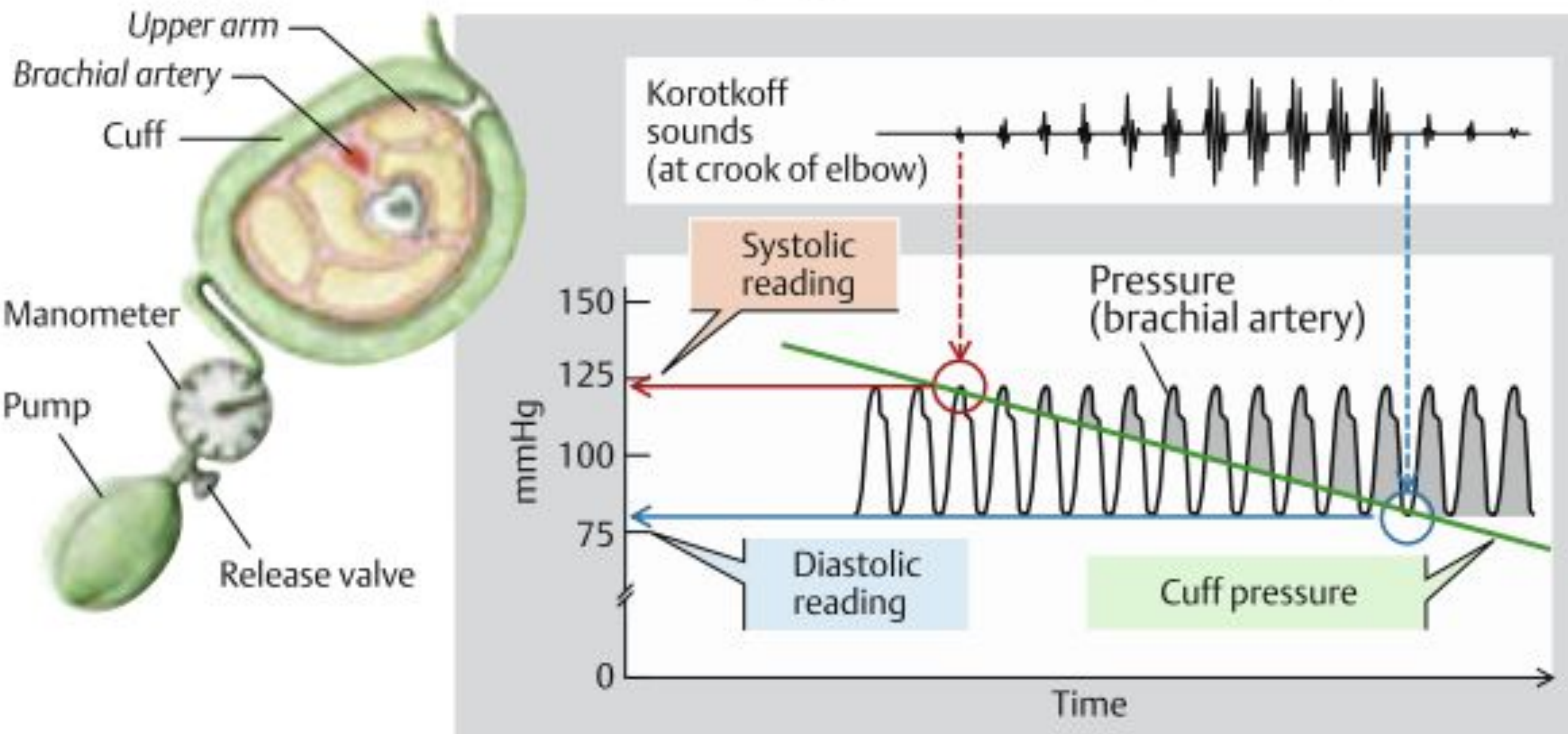

Давление 100 мм рт. ст.
Нулевое давление
Движущаяся закопченная бумага
Поплавок
Раствор с антикоагулянтом
Ртуть
Ртутный манометр


Д
ЭИД
Ру
Канюля
Сосуд
А
I
II
II
II
III
III
Б
I
II
III
Время, 2 с

Spontaneous respiration



B. Blood-pressure measurement with sphygmomanometer (Riva–Rocci)



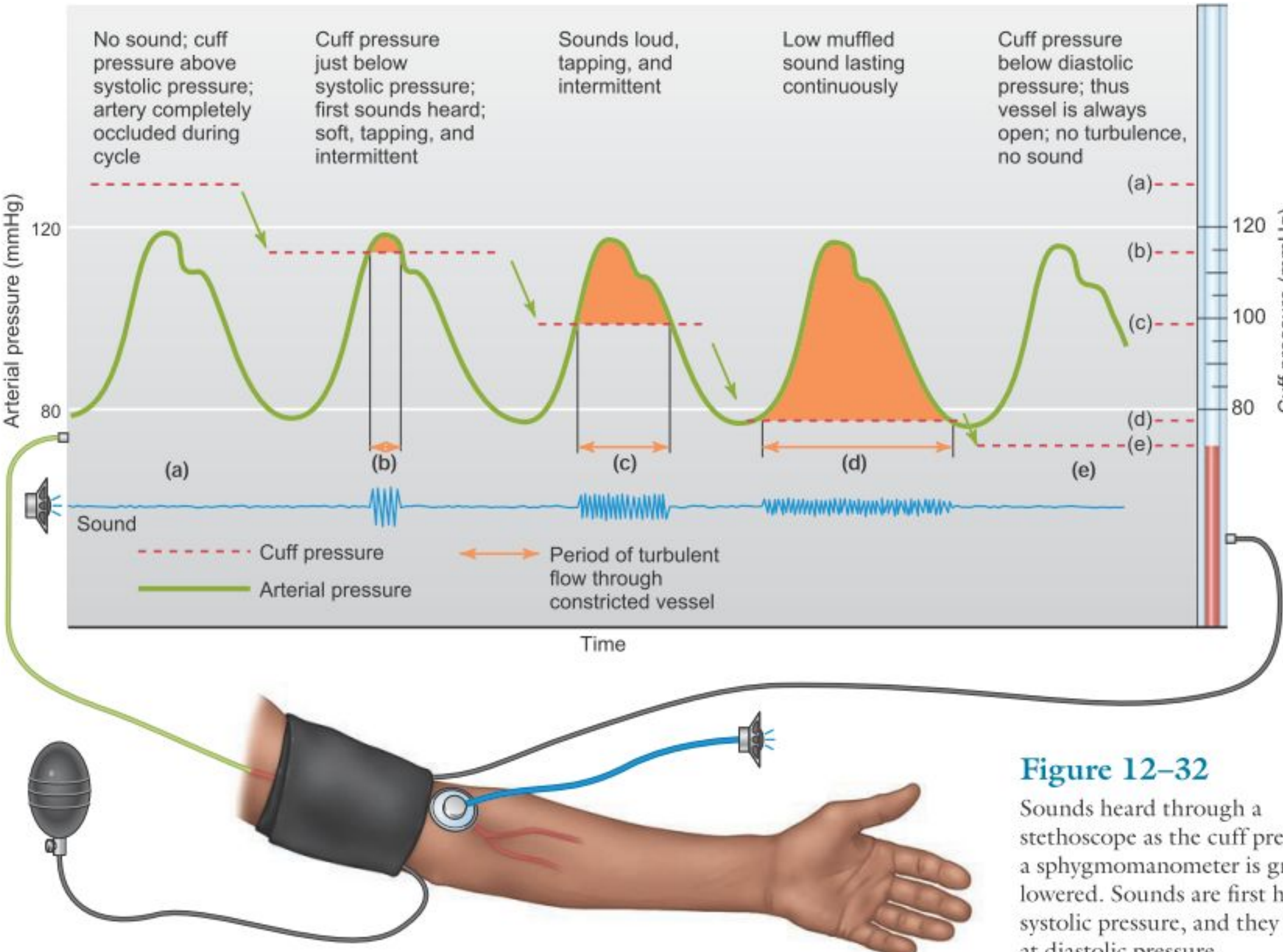
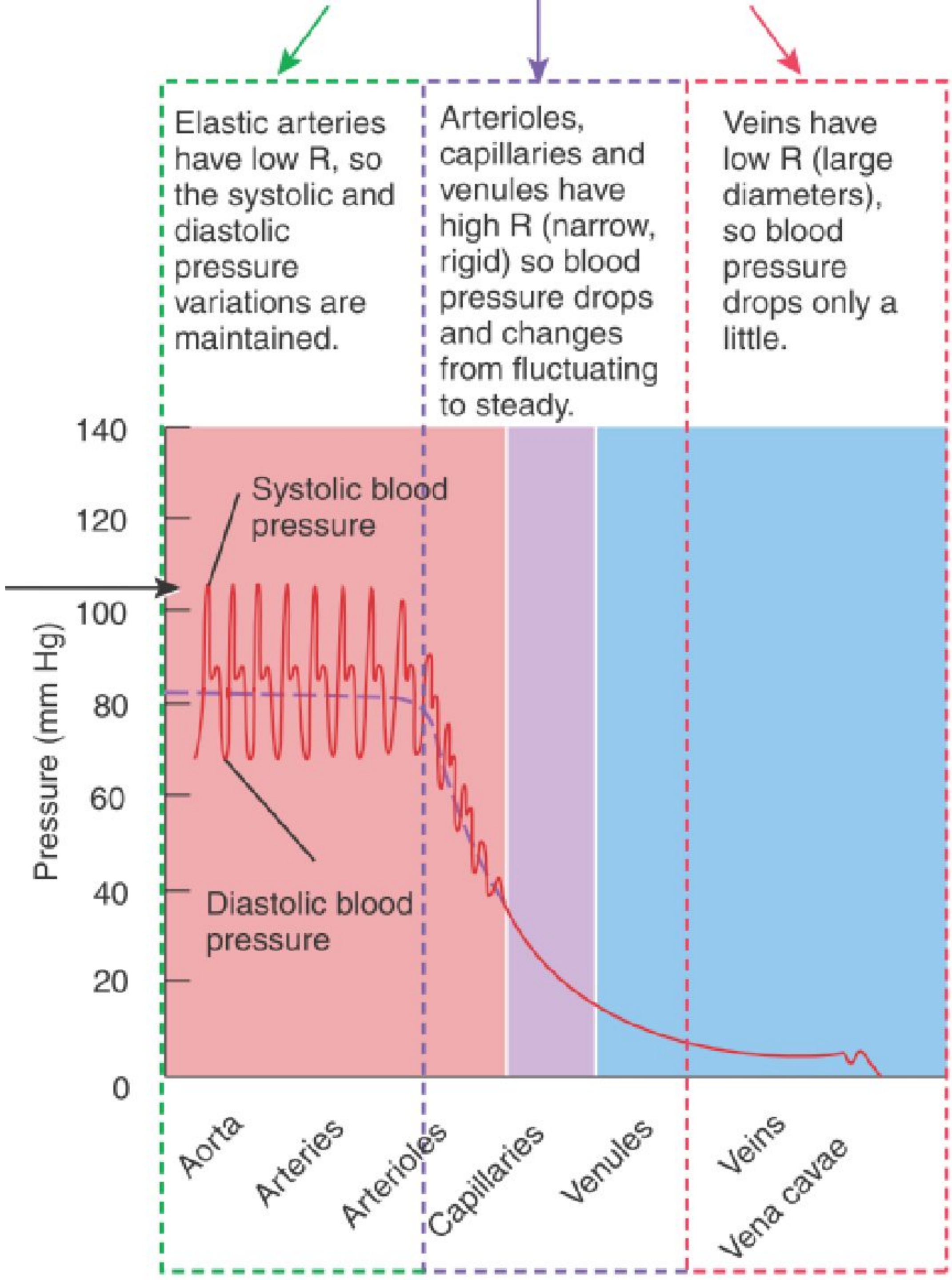
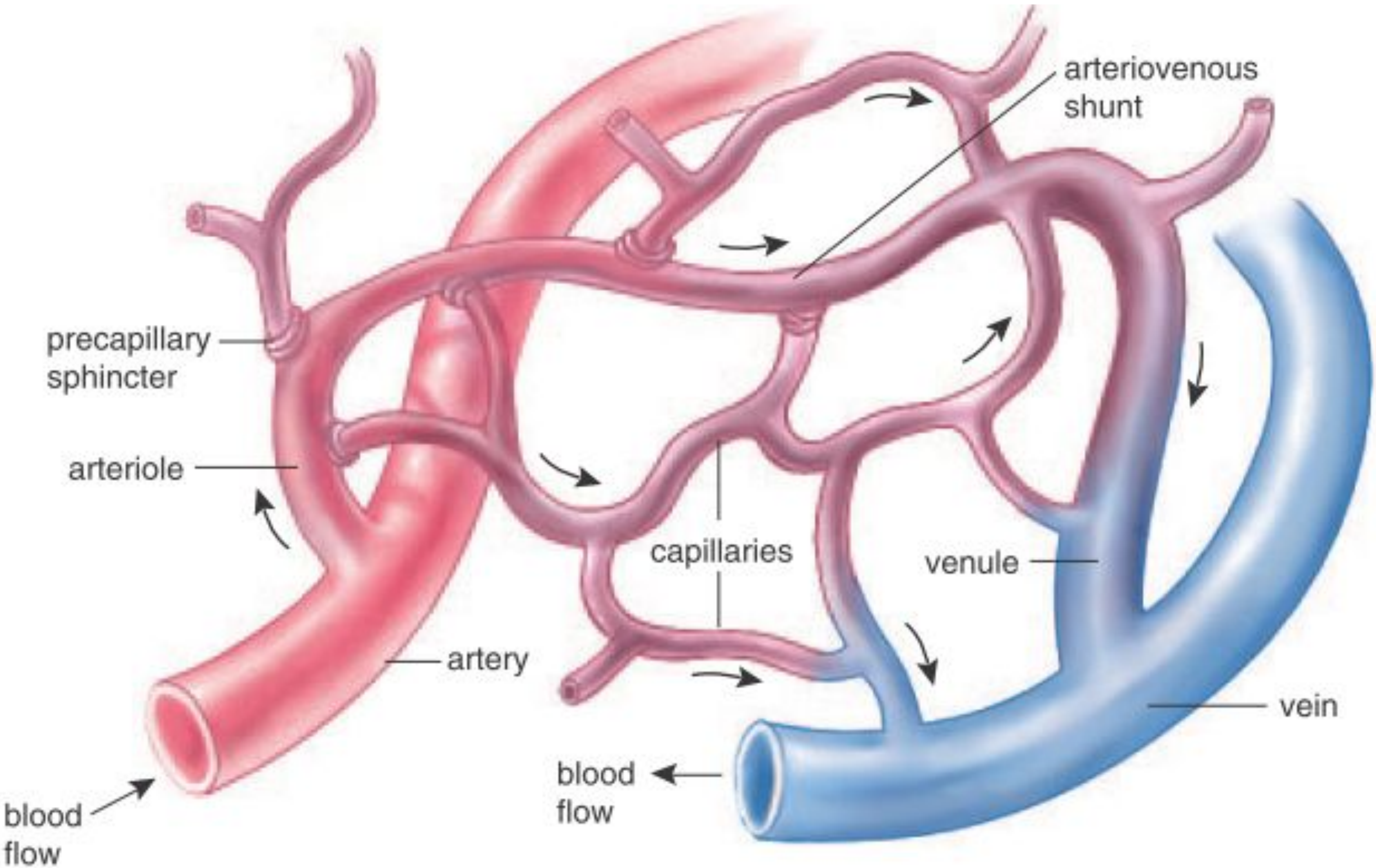
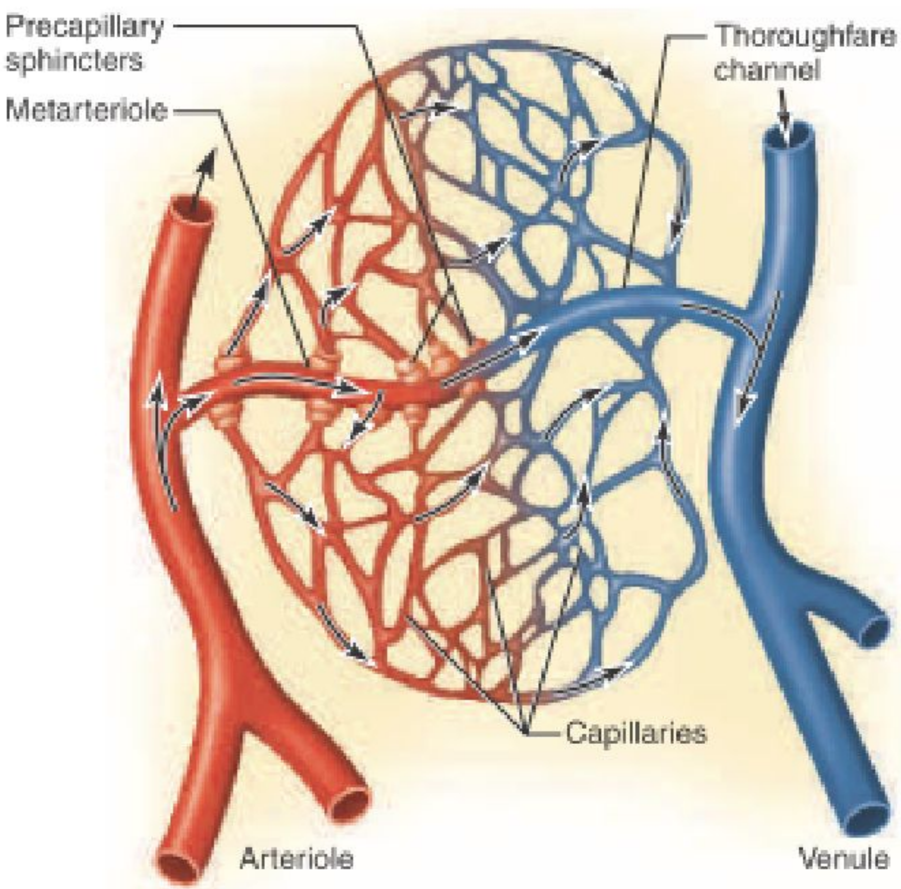


Figure 12–32

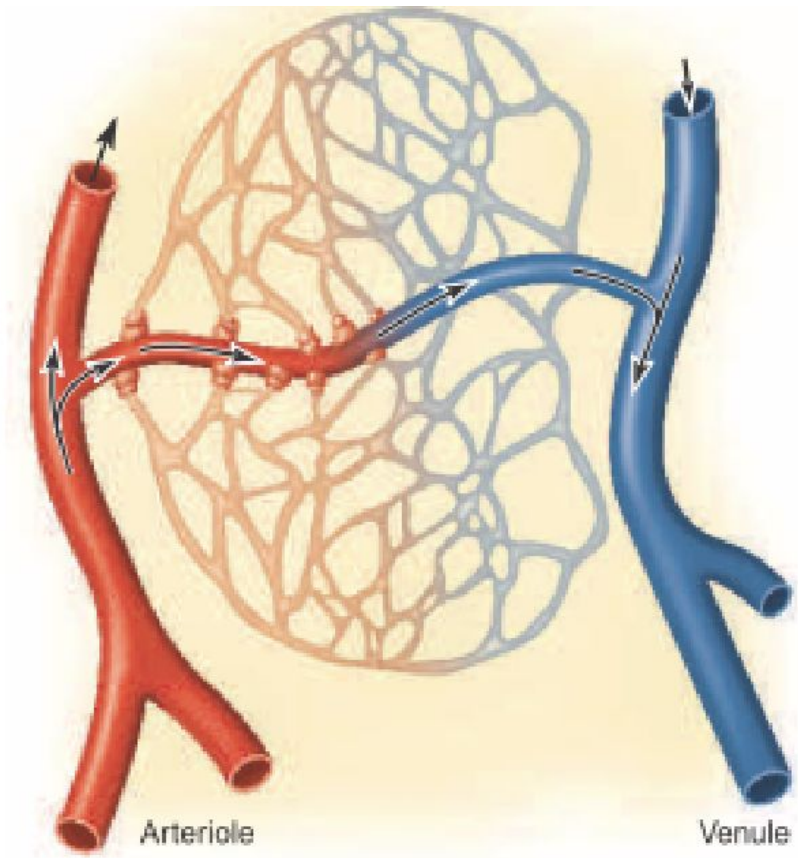
Sounds heard through a stethoscope as the cuff pressure of a sphygmomanometer is gradually lowered. Sounds are first heard at systolic pressure, and they disappear at diastolic pressure.


Elastic arteries have low R, so the systolic and diastolic pressure variations are maintained.
Arterioles, capillaries and venules have high R (narrow, rigid) so blood pressure drops and changes from fluctuating to steady.
Veins have low R (large diameters), so blood pressure drops only a little.
140
120
100
80
60
40
20
0
Pressure (mm Hg)
Systolic blood pressure
Diastolic blood pressure
Aorta
Arteries
Arterioles
Capillaries
Venules
Veins
Vena cavae

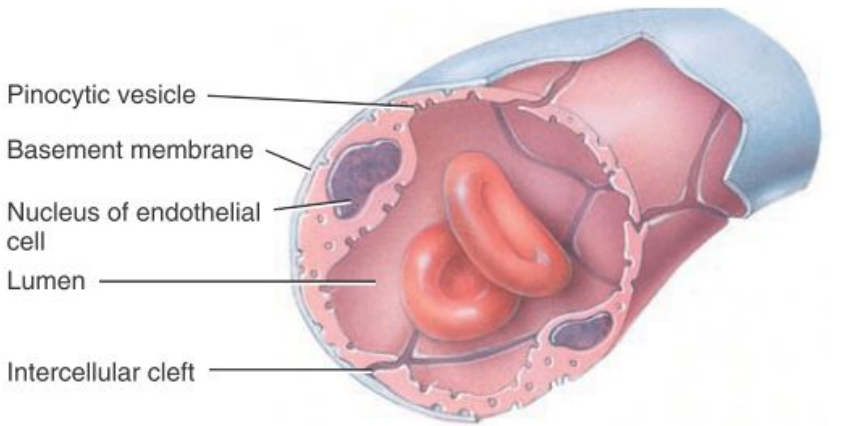

arteriovenous
shunt
precapillary
sphincter
arteriole
capillaries
venule
artery
vein
blood
flow
blood
flow



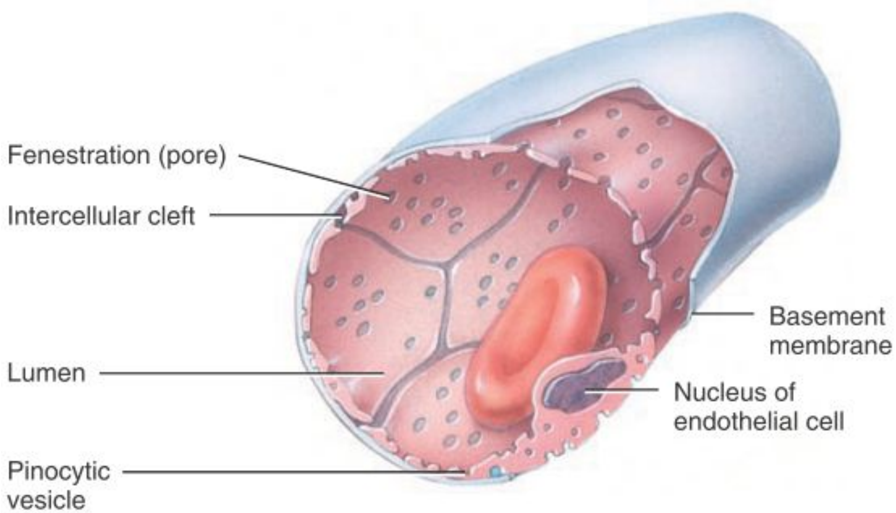
(a) Sphincters open



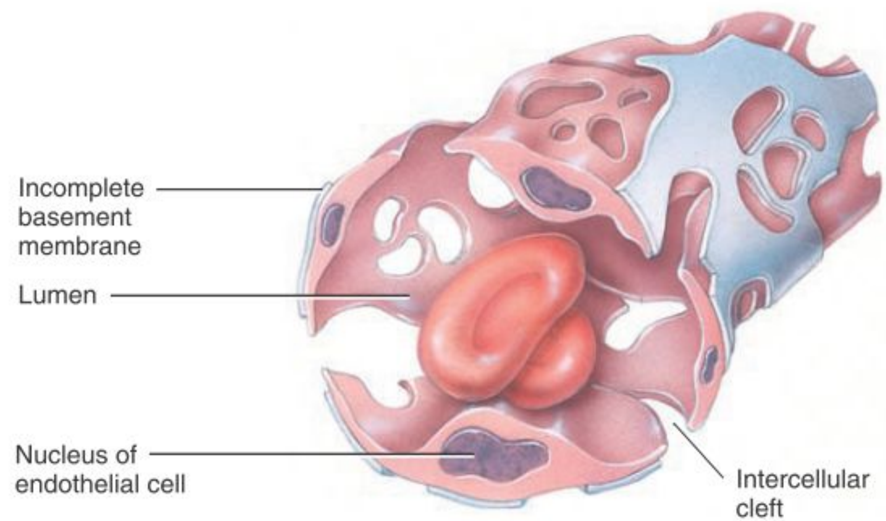
(b) Sphincters closed



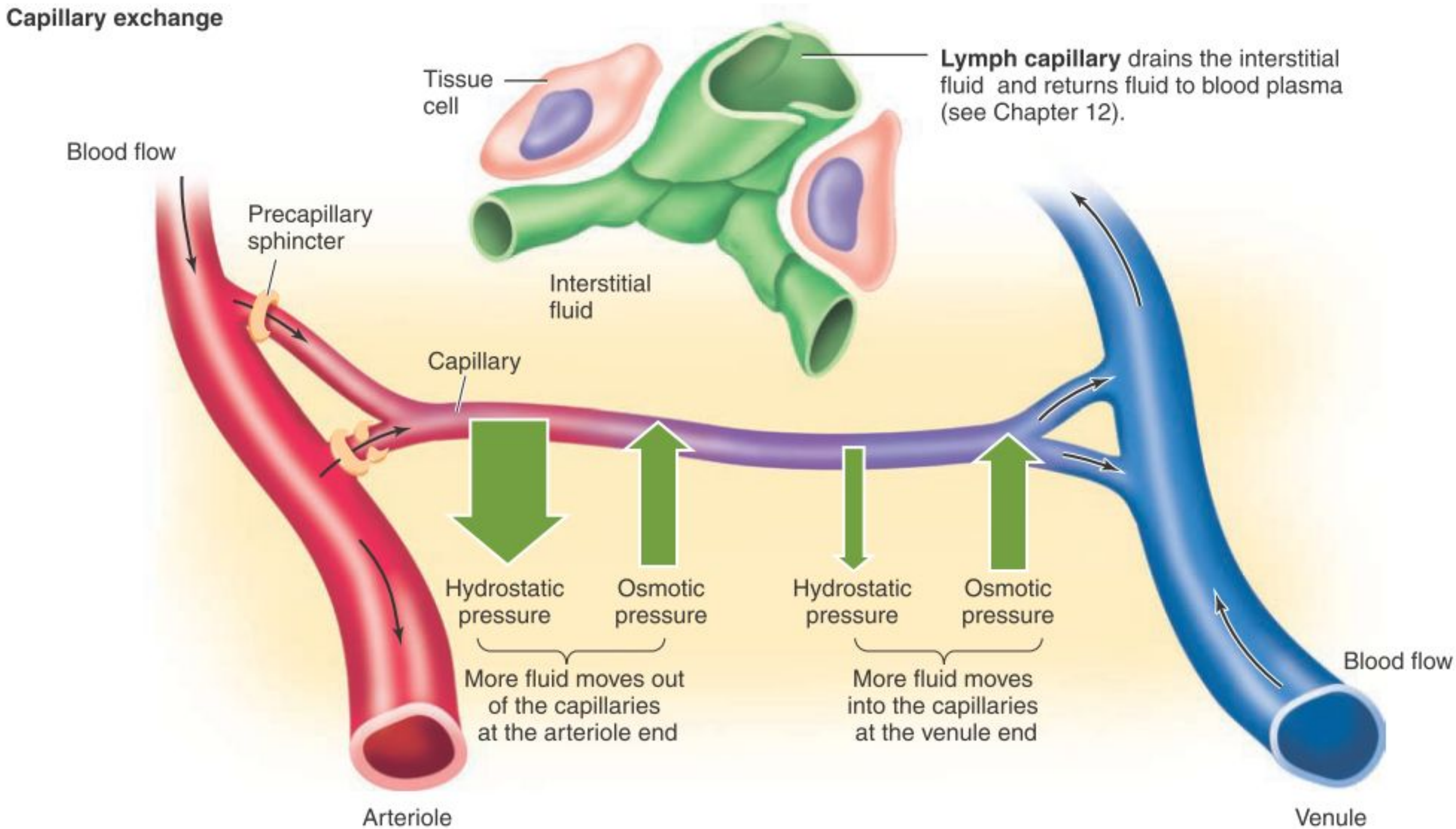
(a) Continuous capillary formed by endothelial cells

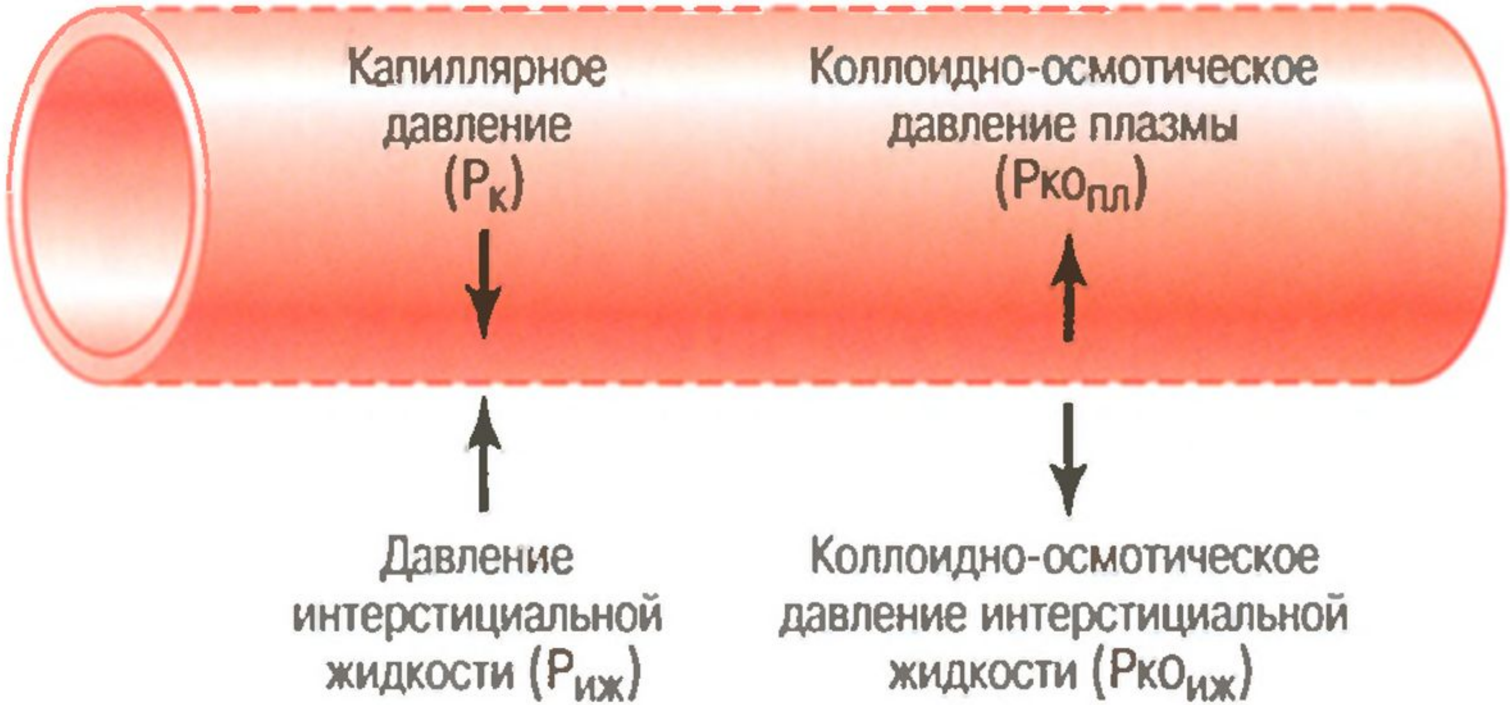


(b) Fenestrated capillary



(c) Sinusoid

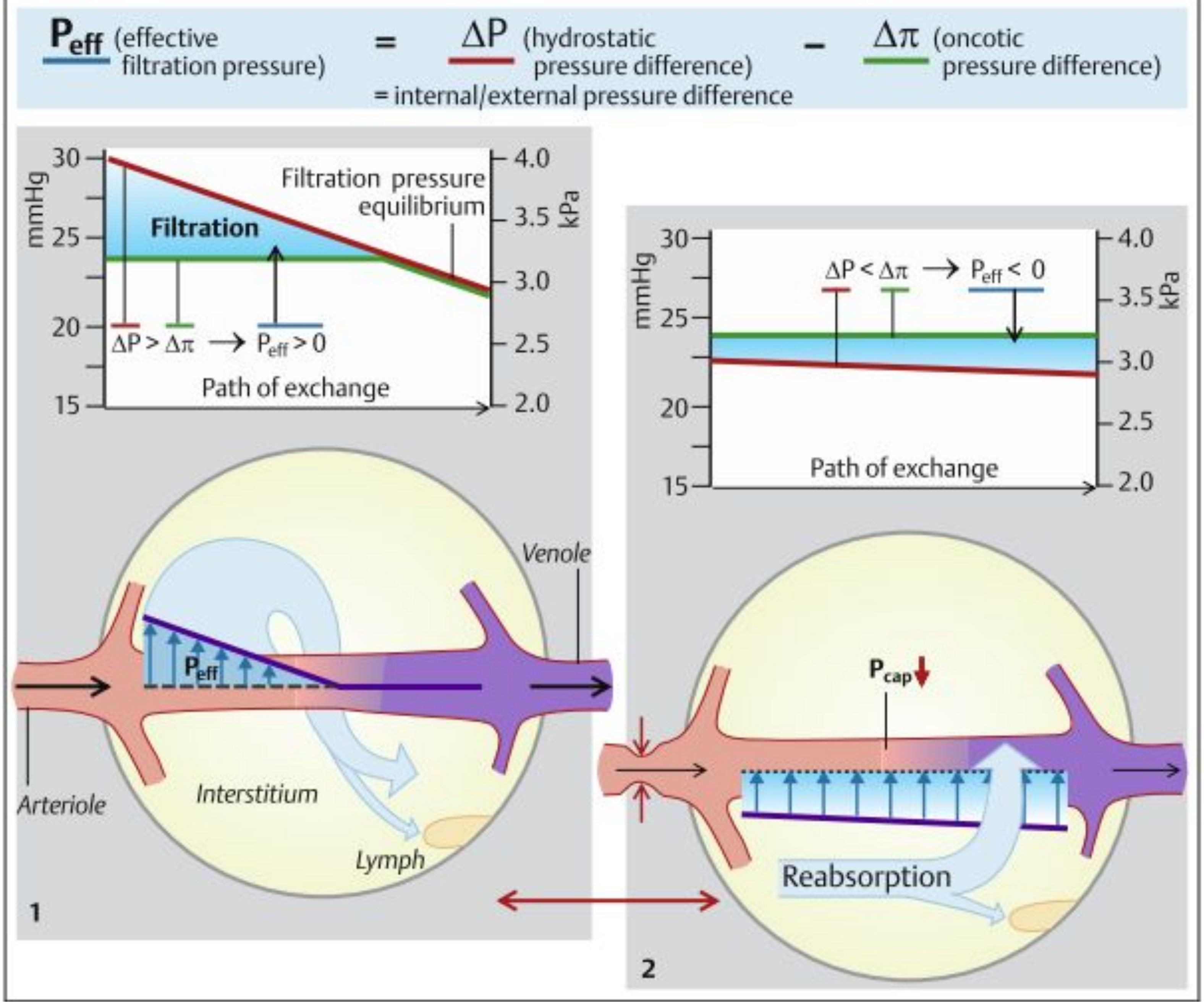

Capillary exchange
Tissue cell
Lymph capillary drains the interstitial fluid and returns fluid to blood plasma (see Chapter 12).
Blood flow
Precapillary sphincter
Interstitial fluid
Capillary
Hydrostatic pressure
Osmotic pressure
More fluid moves out of the capillaries at the arteriole end
Hydrostatic pressure
Osmotic pressure
More fluid moves into the capillaries at the venule end
Blood flow
Arteriole
Venule

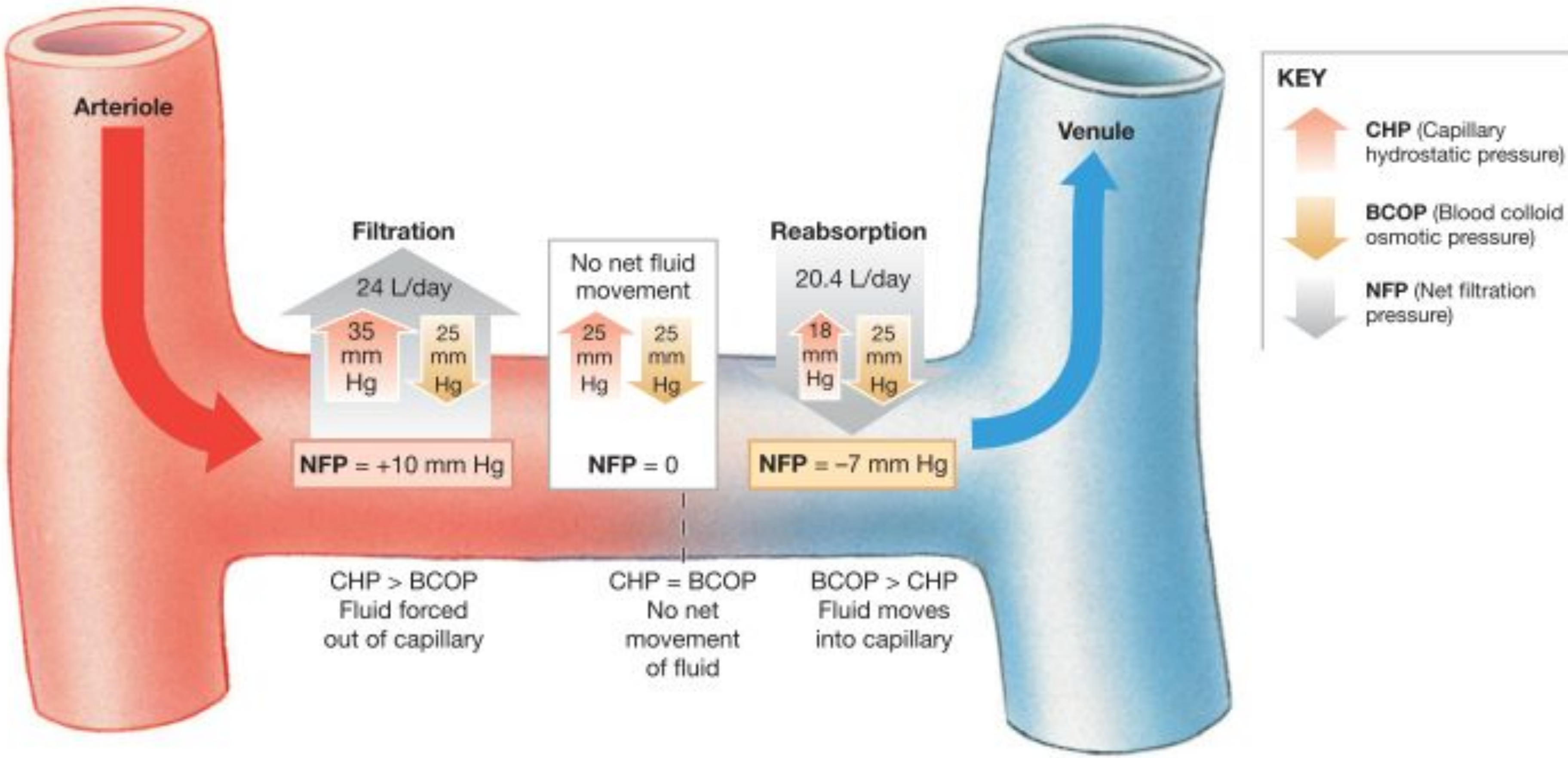


Артериальный конец: Ргк + Рот – Ргт – Рок = 32,5 +5 – 3 – 25 = +9.5 (мм рт. ст.)

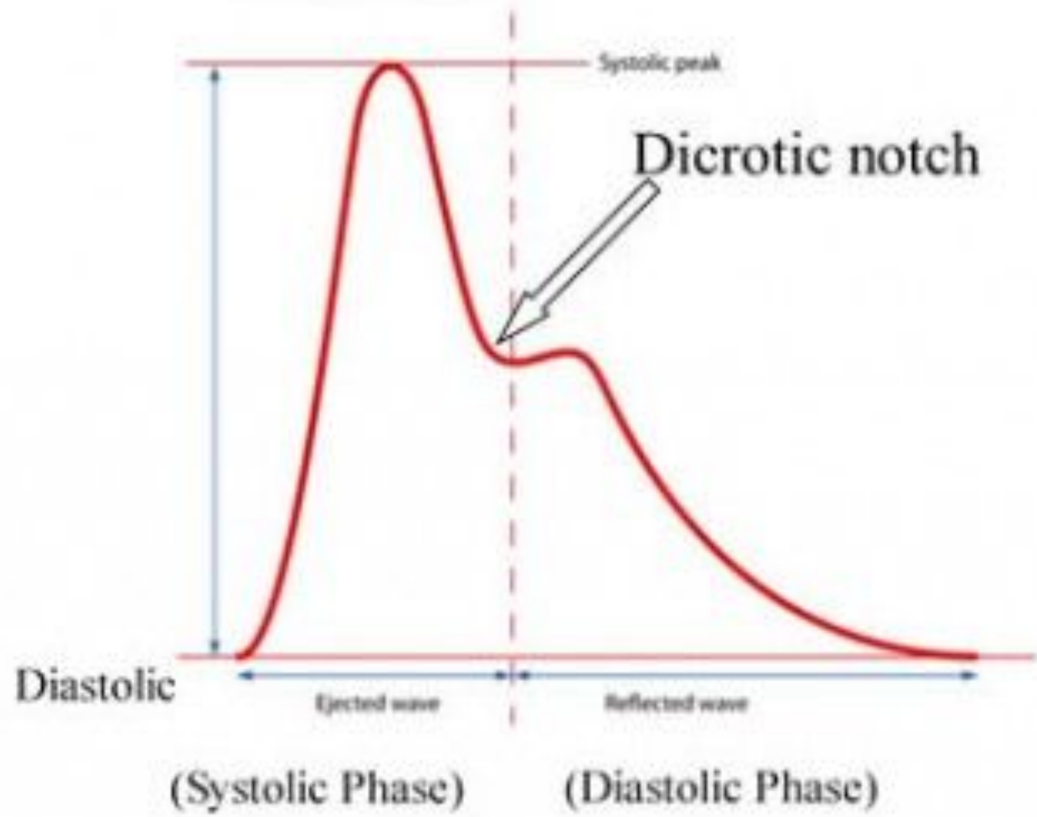
Венозный конец: Ргк + Рот – Ргт – Рок = 15 + 5 – 3 – 25 = -8 (мм рт. ст.)

A. Exchange of fluids via capillaries

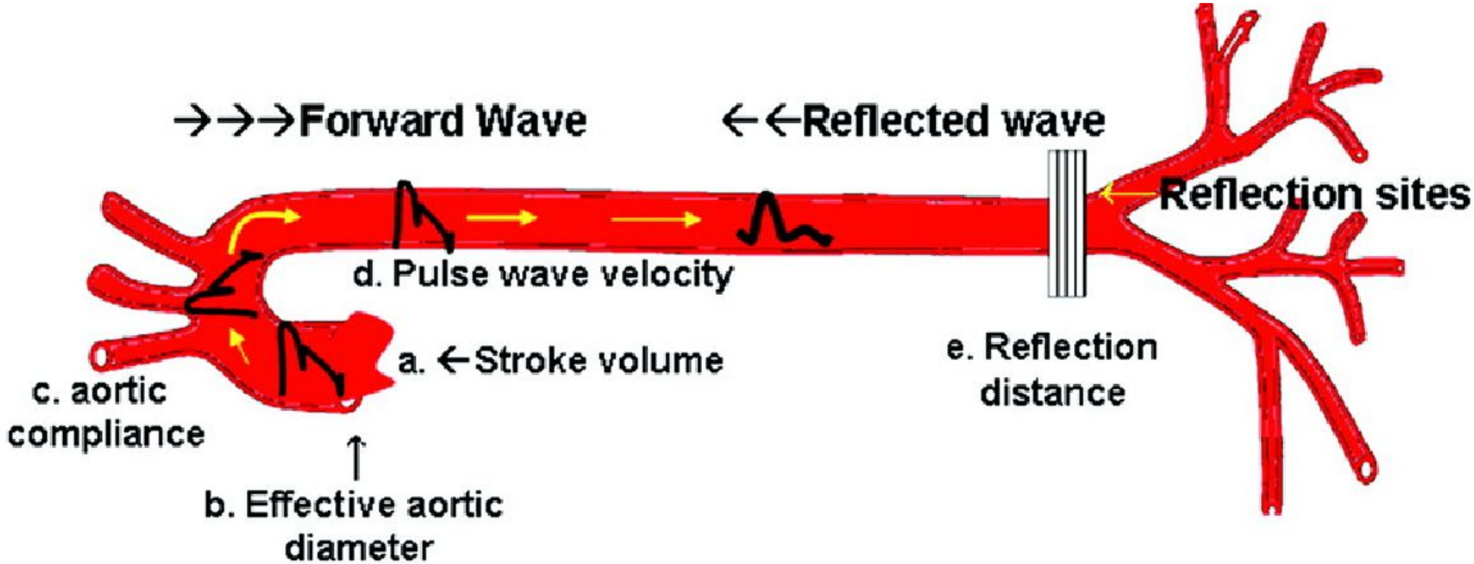




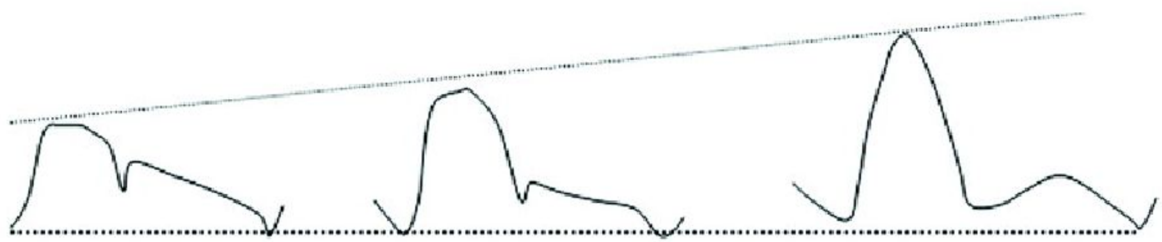
Arteriole
Filtration
24 L/day
35 mm Hg
25 mm Hg
NFP = +10 mm Hg
No net fluid movement
25 mm Hg
25 mm Hg
NFP = 0
Reabsorption
20.4 L/day
18 mm Hg
25 mm Hg
NFP = –7 mm Hg
Venule
CHP > BCOP
Fluid forced out of capillary
CHP = BCOP
No net movement of fluid
BCOP > CHP
Fluid moves into capillary
KEY
CHP (Capillary hydrostatic pressure)
BCOP (Blood colloid osmotic pressure)
NFP (Net filtration pressure)


Systolic peak
Dicrotic notch
Diastolic
Ejected wave
Reflected wave
(Systolic Phase)
(Diastolic Phase)

I. Correlates of Pulse Pressure



II. Peripheral Amplification of Pulse Wave



- **А-волна** связана с систолой предсердий
  С-волна отражает выпячивание атриовентрикулярного клапана в правое предсердие при изоволюметрическом сокращении правого желудочка
  X связана со смещением атриовентрикулярной перегородки в сторону верхушки сердца при систоле желудочков
  V-волна связана с возвращением атриовентрикулярной перегородки первоначально при закрытых атриовентрикулярных клапанах, что приводит к повышению венозного давления, затем
  Y свя
  клапа