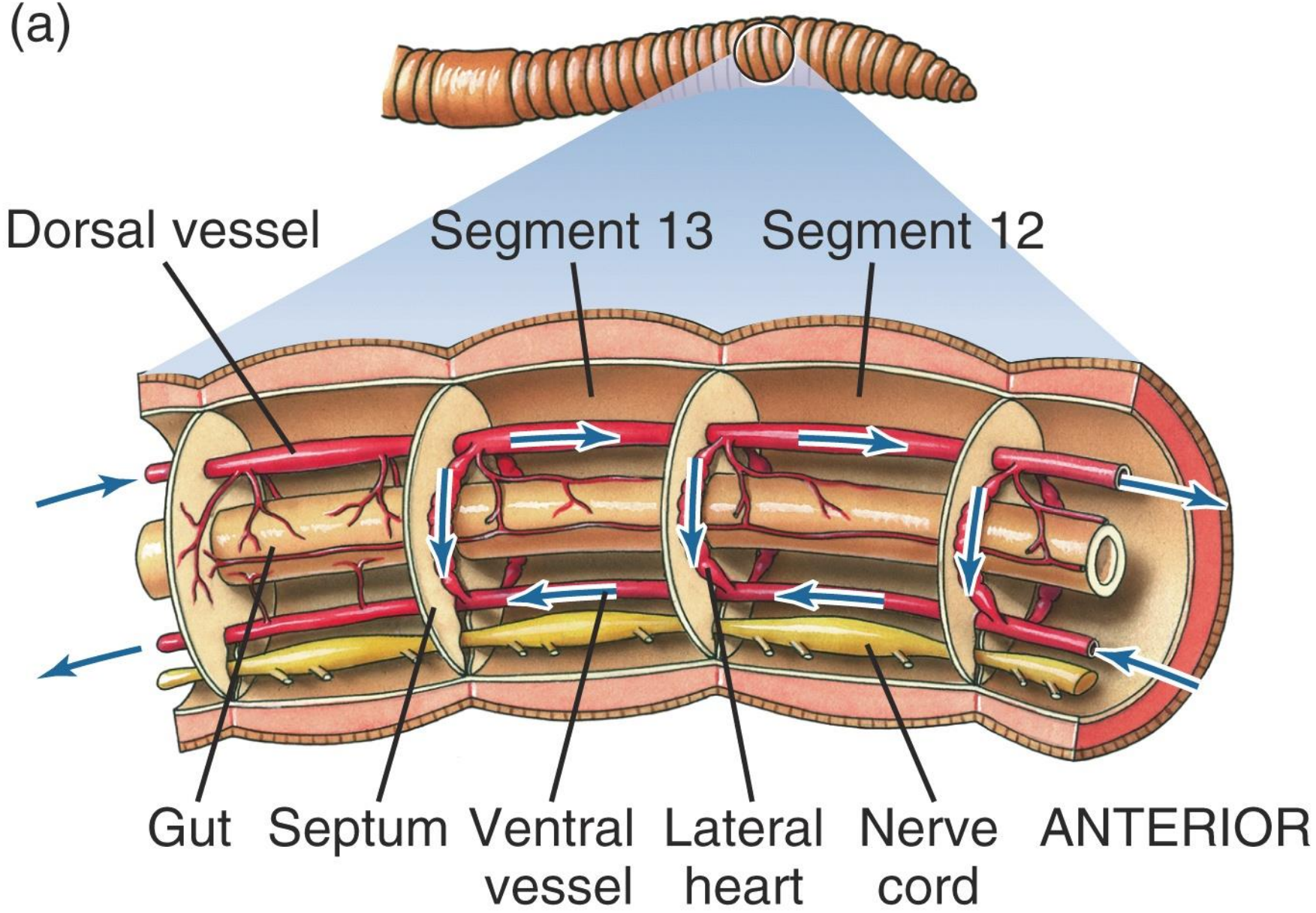
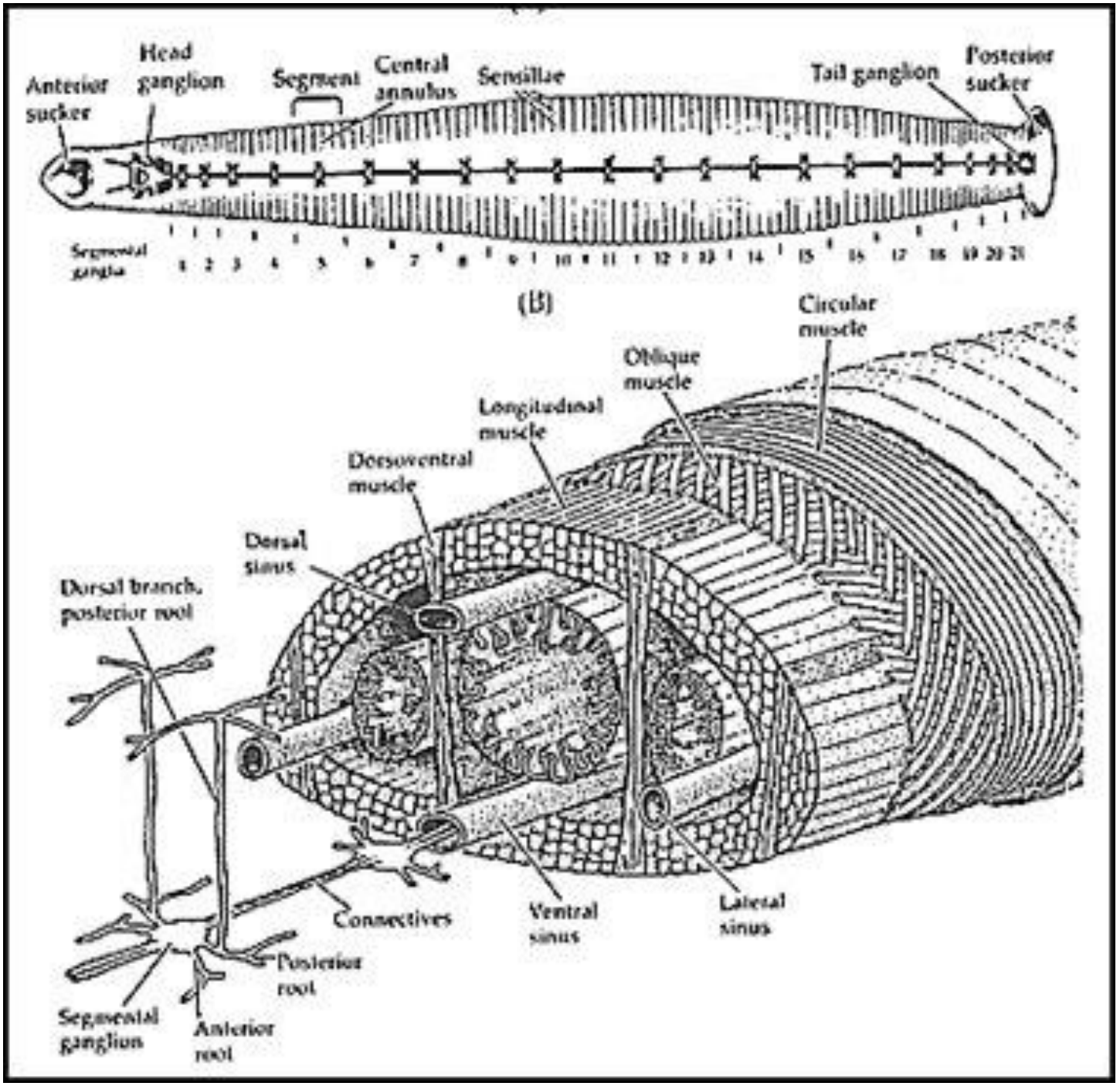
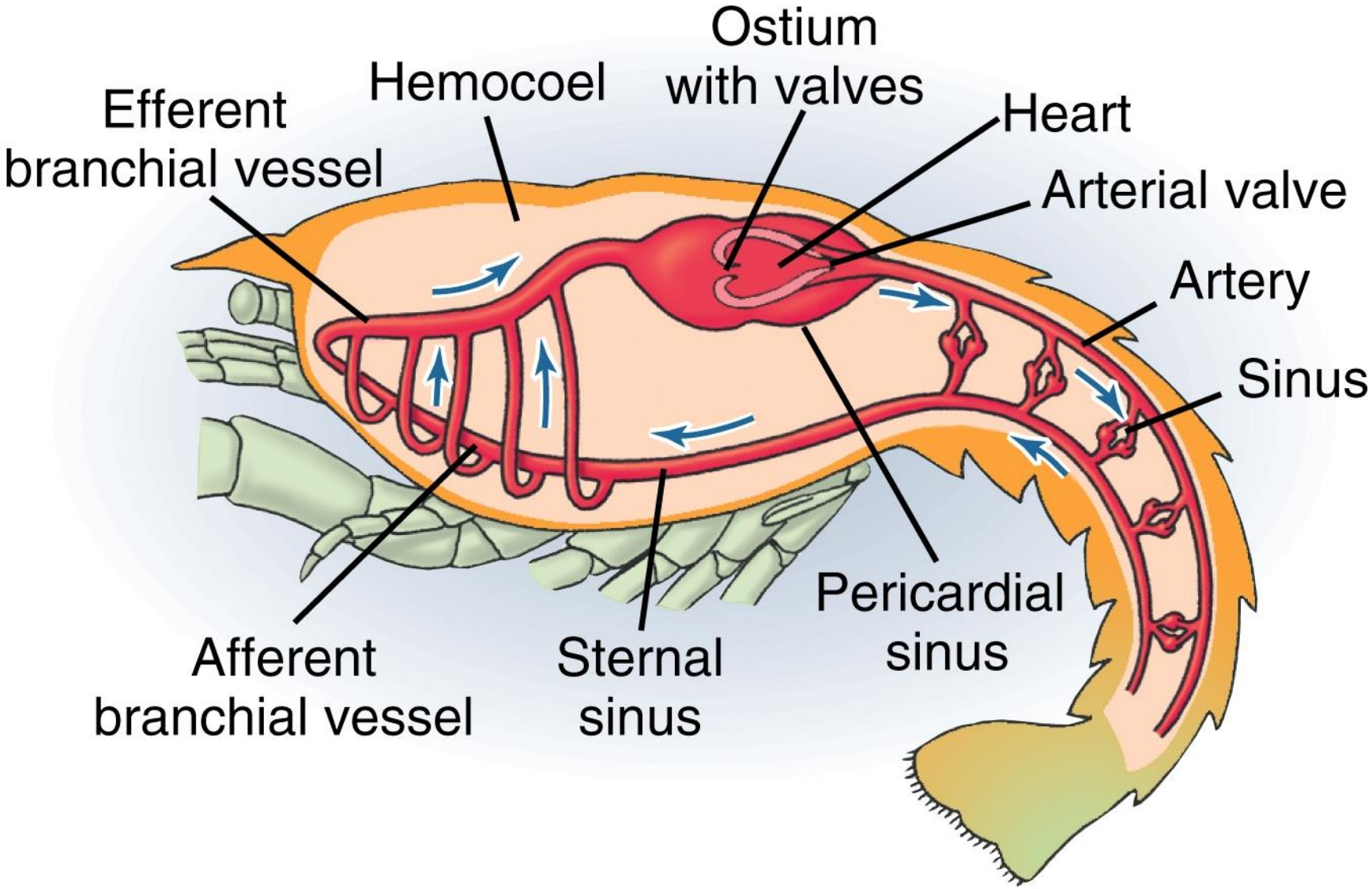
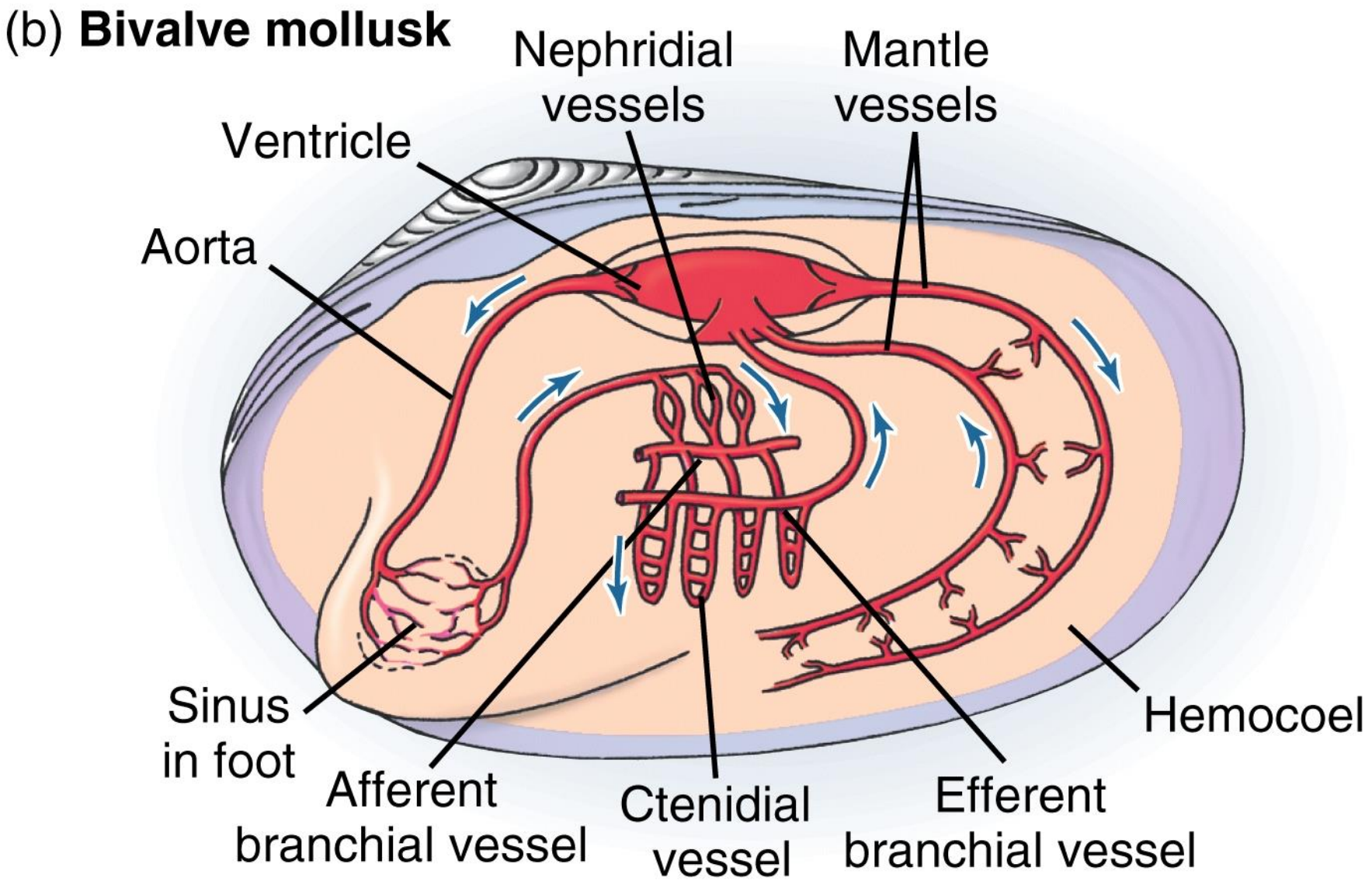

(a)
Dorsal vessel
Segment 13
Segment 12
Gut
Septum
Ventral vessel
Lateral heart
Nerve cord
ANTERIOR

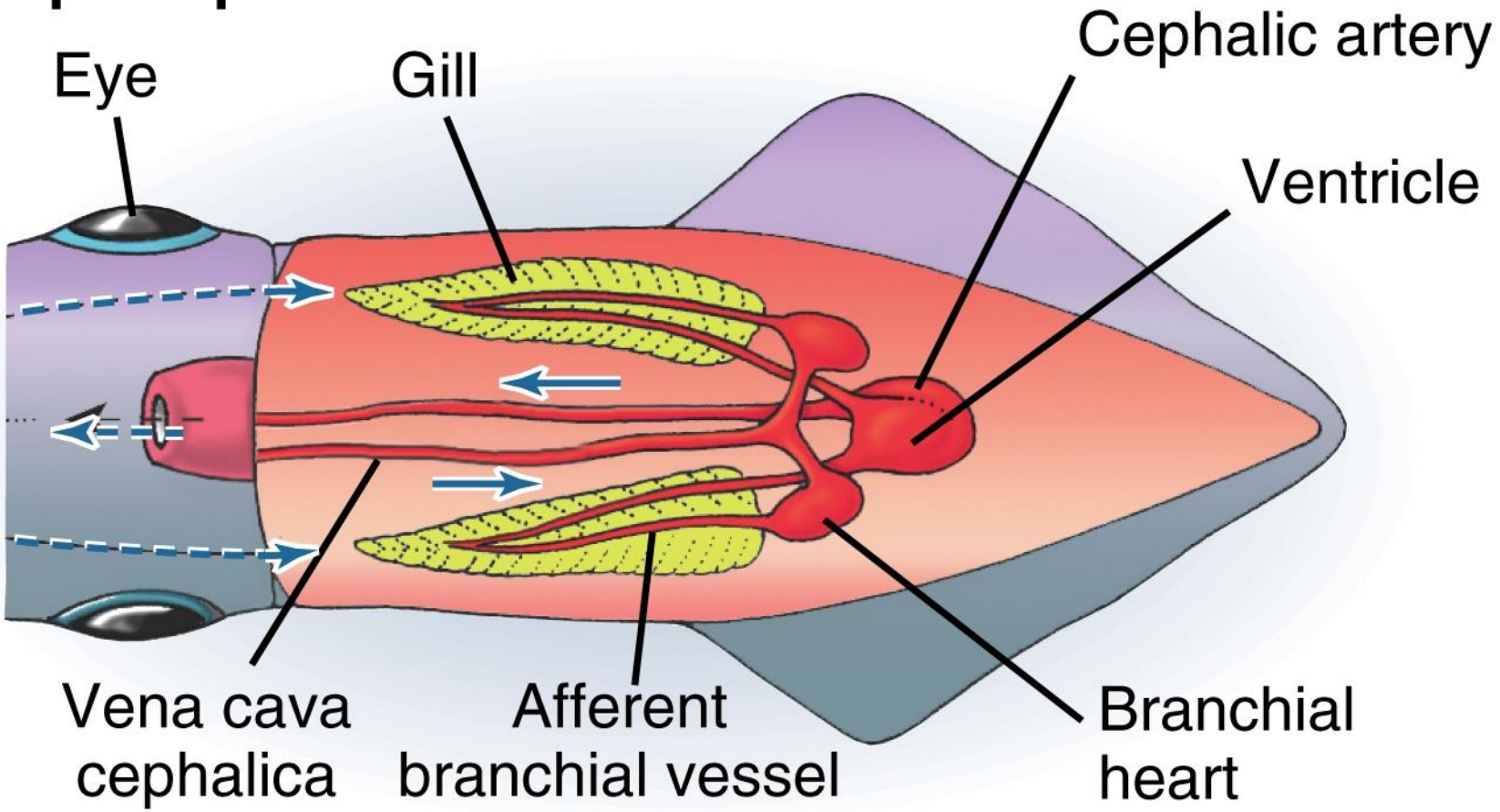

Anterior sucker
Head ganglion
Segment
Central annulus
Setal line
Tail ganglion
Posterior sucker
Segmental ganglia
(B)
Circular muscle
Oblique muscle
Longitudinal muscle
Dorsoventral muscle
Dorsal sinus
Dorsal branch, posterior root
Connectives
Ventral sinus
Lateral sinus
Posterior root
Segmental ganglion
Anterior root

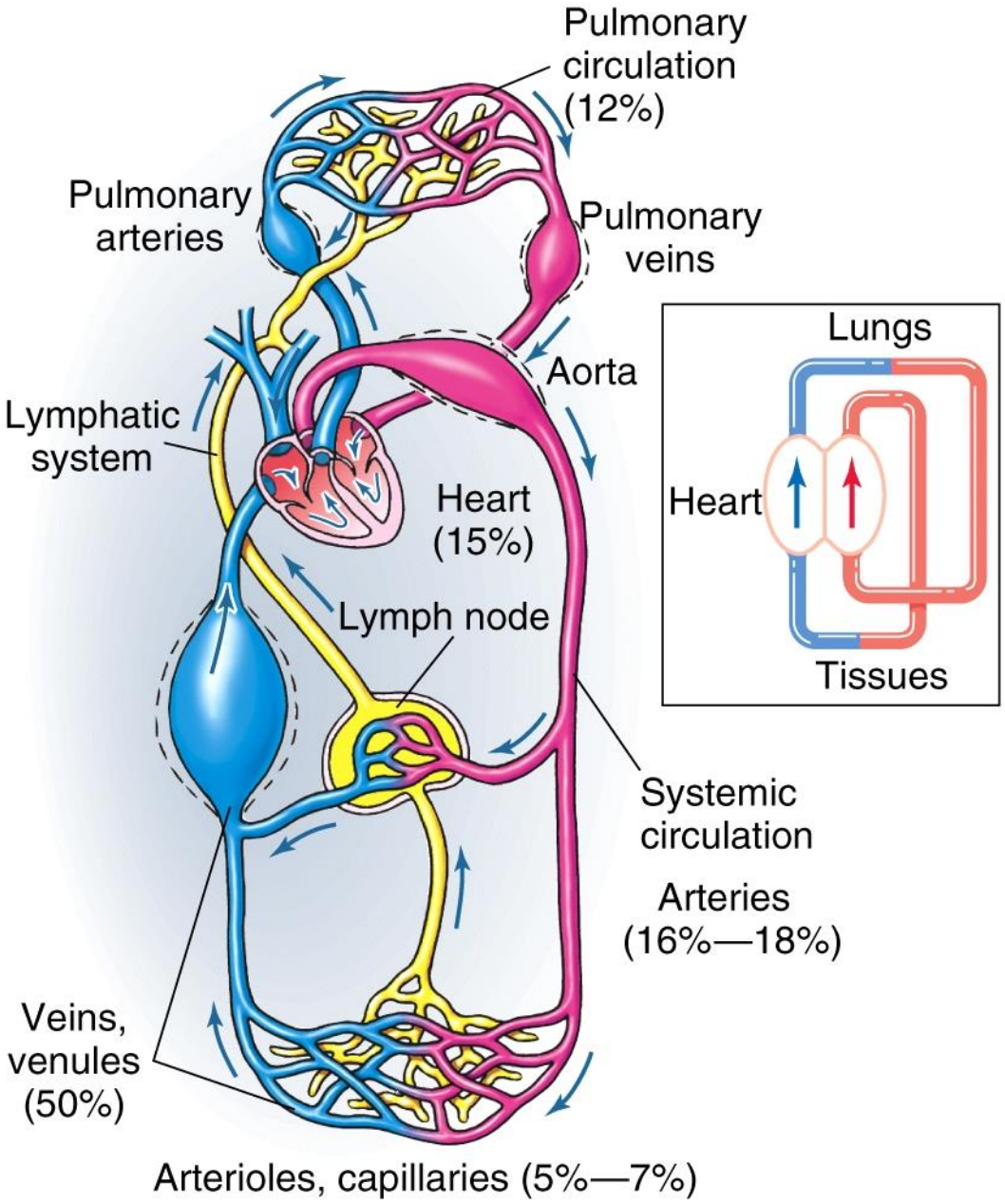
(a) **Crayfish**

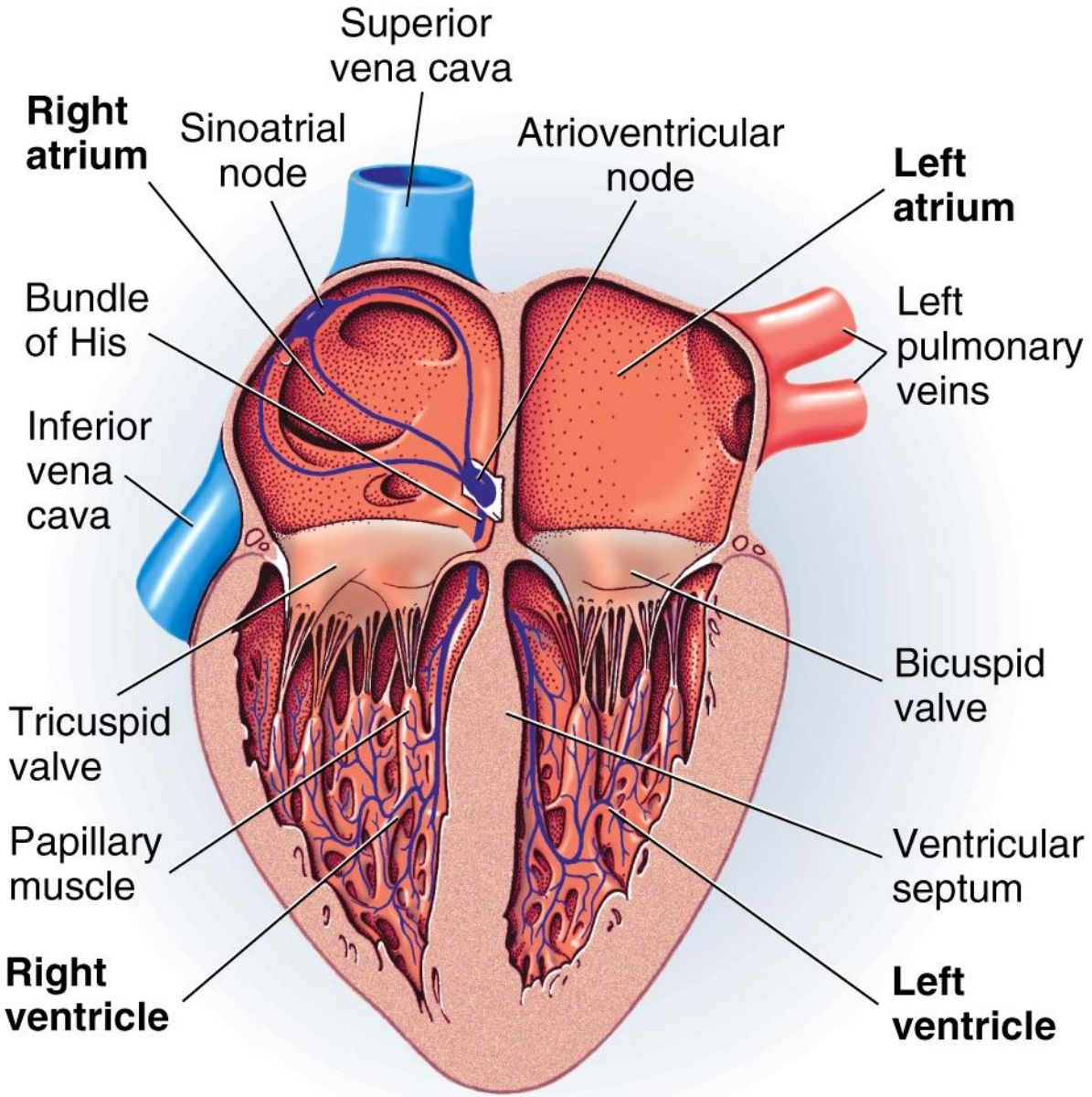

Efferent branchial vessel
Hemocoel
Ostium with valves
Heart
Arterial valve
Artery
Sinus
Pericardial sinus
Sternal sinus
Afferent branchial vessel

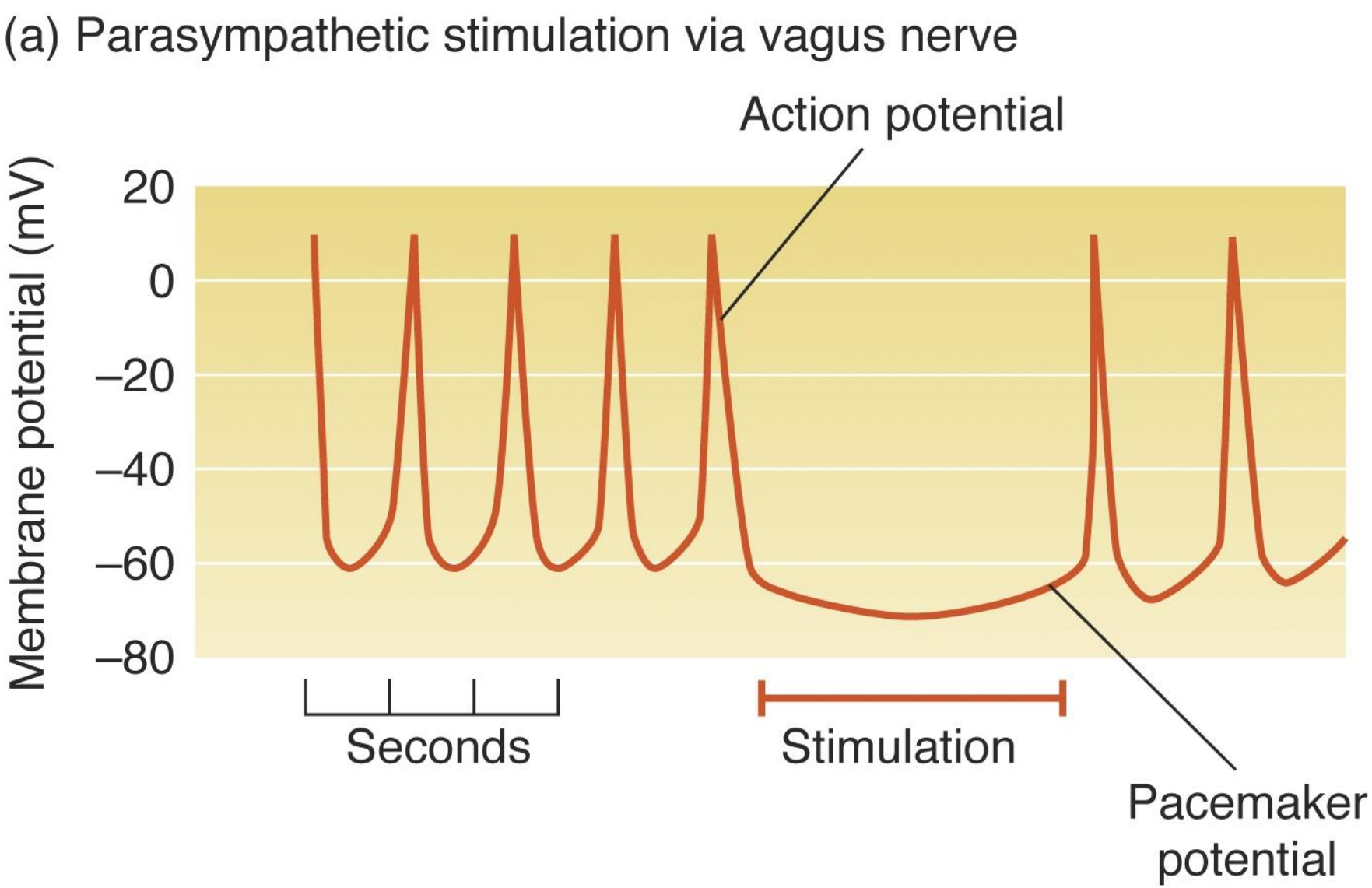

(b) Bivalve mollusk
Nephridial vessels
Mantle vessels
Ventricle
Aorta
Sinus in foot
Afferent branchial vessel
Ctenidial vessel
Efferent branchial vessel
Hemocoel

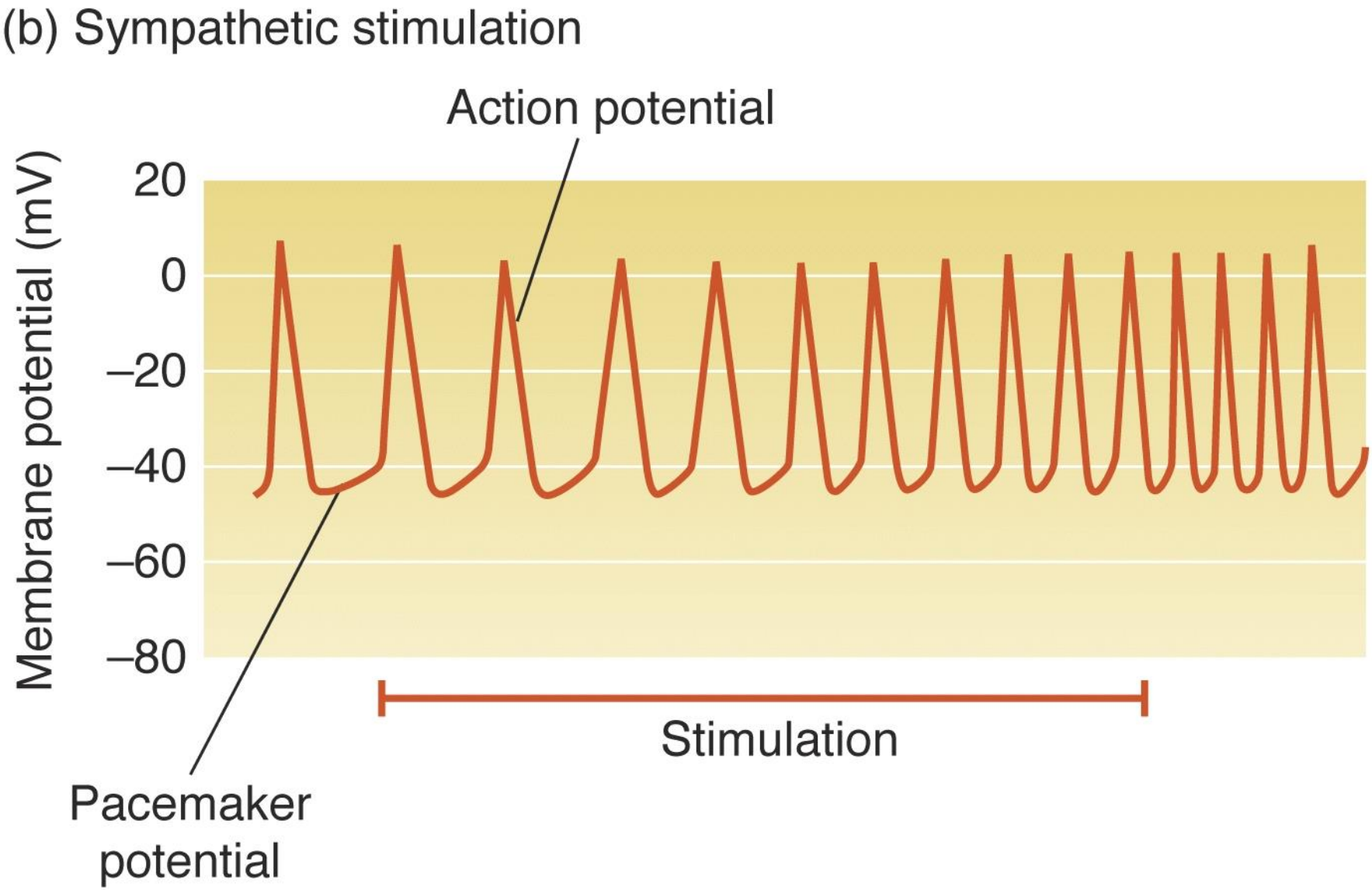
(c) **Cephalopod**

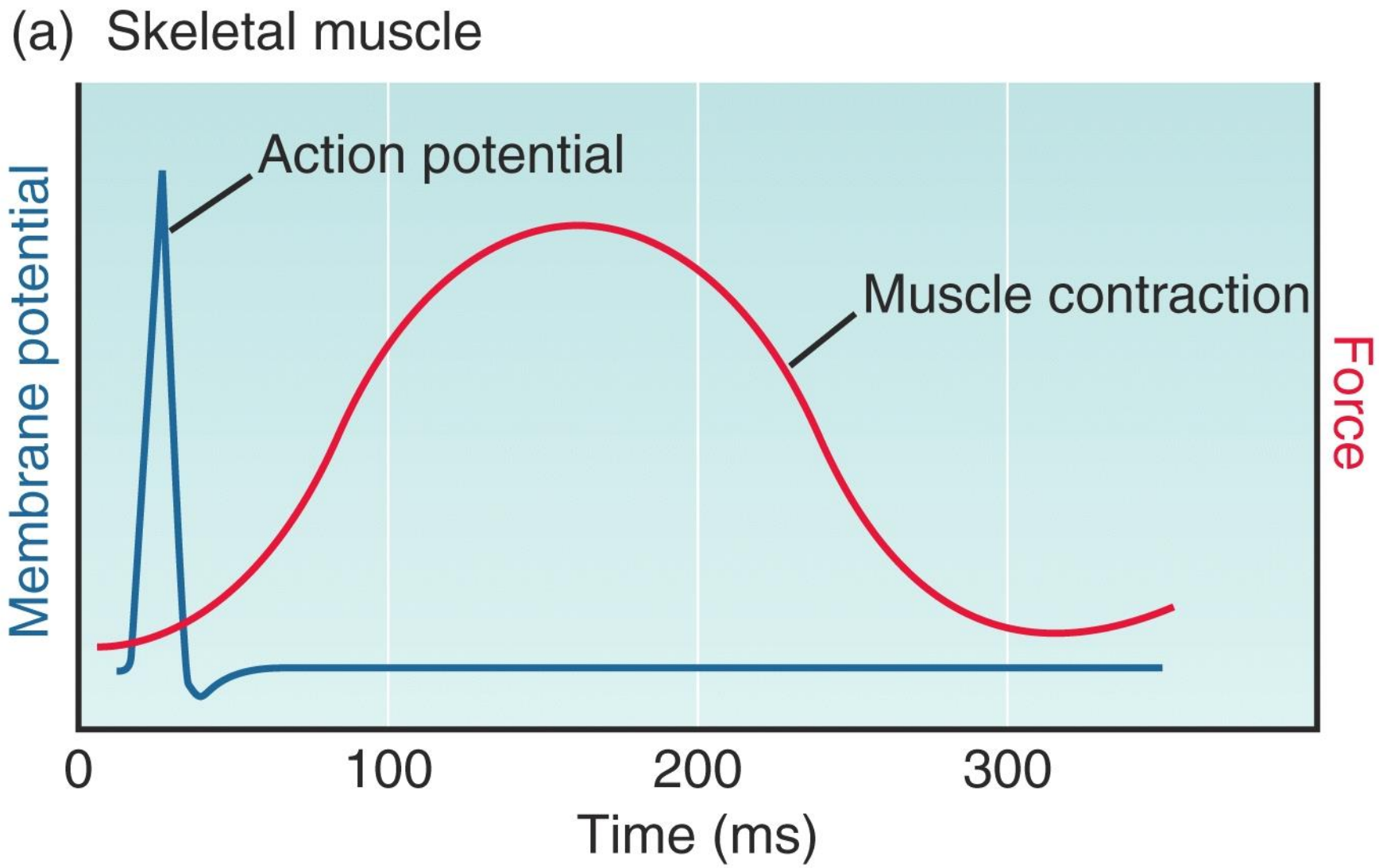


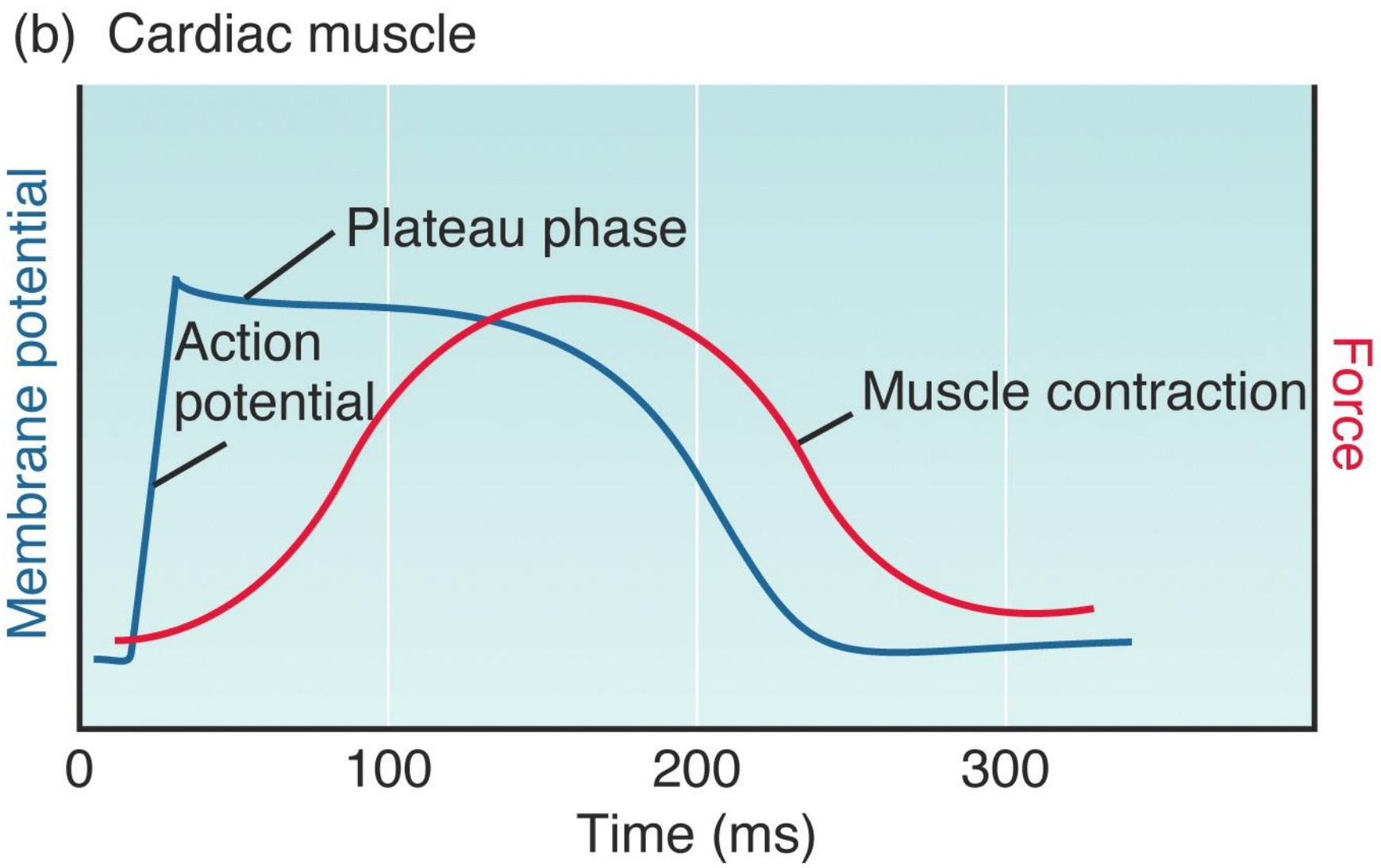

Pulmonary circulation (12%)
Pulmonary arteries
Pulmonary veins
Aorta
Lymphatic system
Heart (15%)
Lymph node
Systemic circulation
Arteries (16%—18%)
Veins, venules (50%)
Arterioles, capillaries (5%—7%)
Lungs
Heart
Tissues


Superior vena cava
Right atrium
Sinoatrial node
Atrioventricular node
Left atrium
Bundle of His
Left pulmonary veins
Inferior vena cava
Bicuspid valve
Tricuspid valve
Papillary muscle
Ventricular septum
Right ventricle
Left ventricle

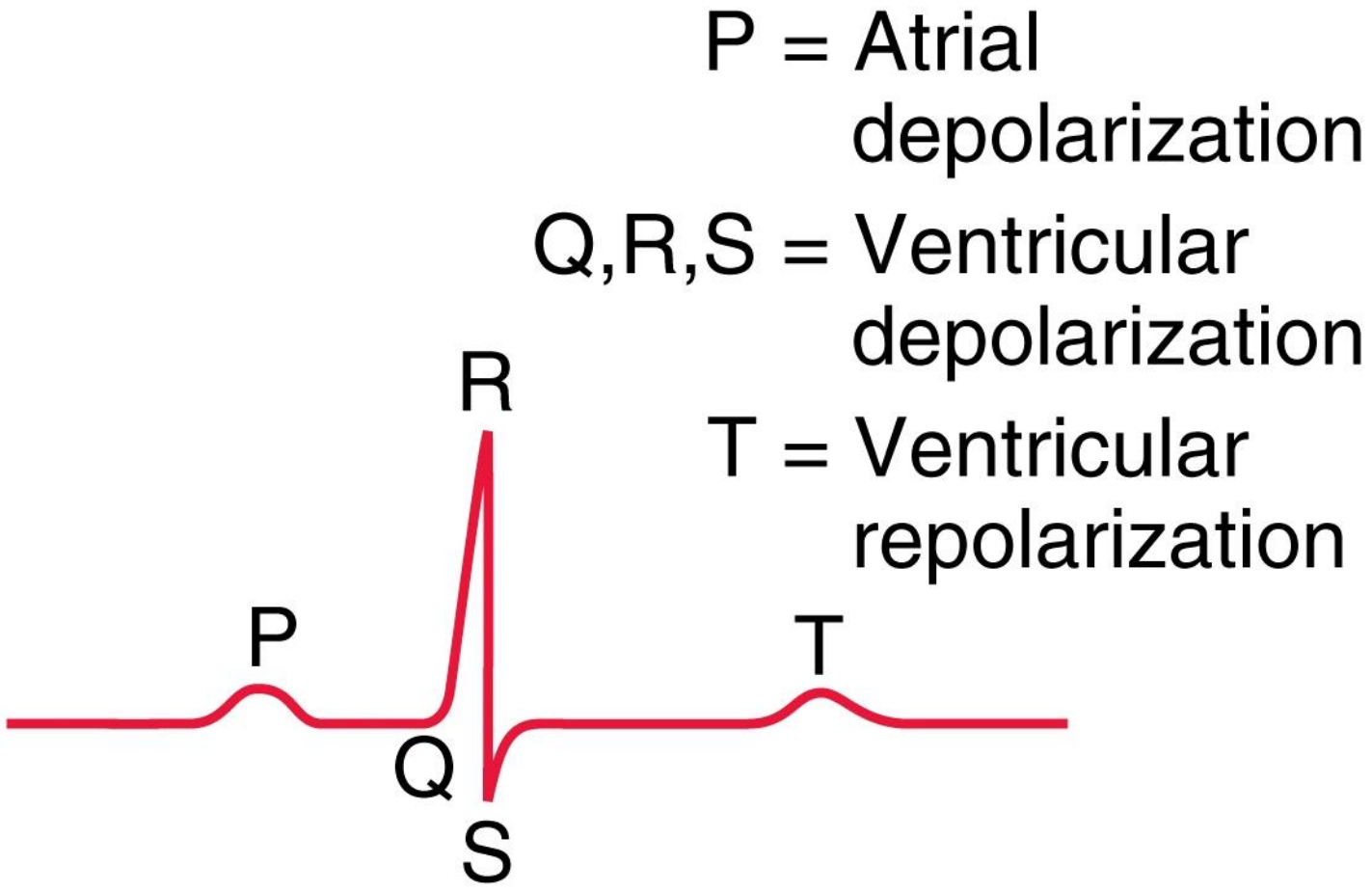

(a) Parasympathetic stimulation via vagus nerve
Action potential
Membrane potential (mV)
20
0
–20
–40
–60
–80
Seconds
Stimulation
Pacemaker potential


(b) Sympathetic stimulation
Action potential
Membrane potential (mV)
20
0
–20
–40
–60
–80
Stimulation
Pacemaker potential


(a) Skeletal muscle
Action potential
Muscle contraction
Membrane potential
Force
0
100
200
300
Time (ms)


(b) Cardiac muscle
Membrane potential
Plateau phase
Action potential
Muscle contraction
Force
0
100
200
300
Time (ms)

(a) Electrocardiogram



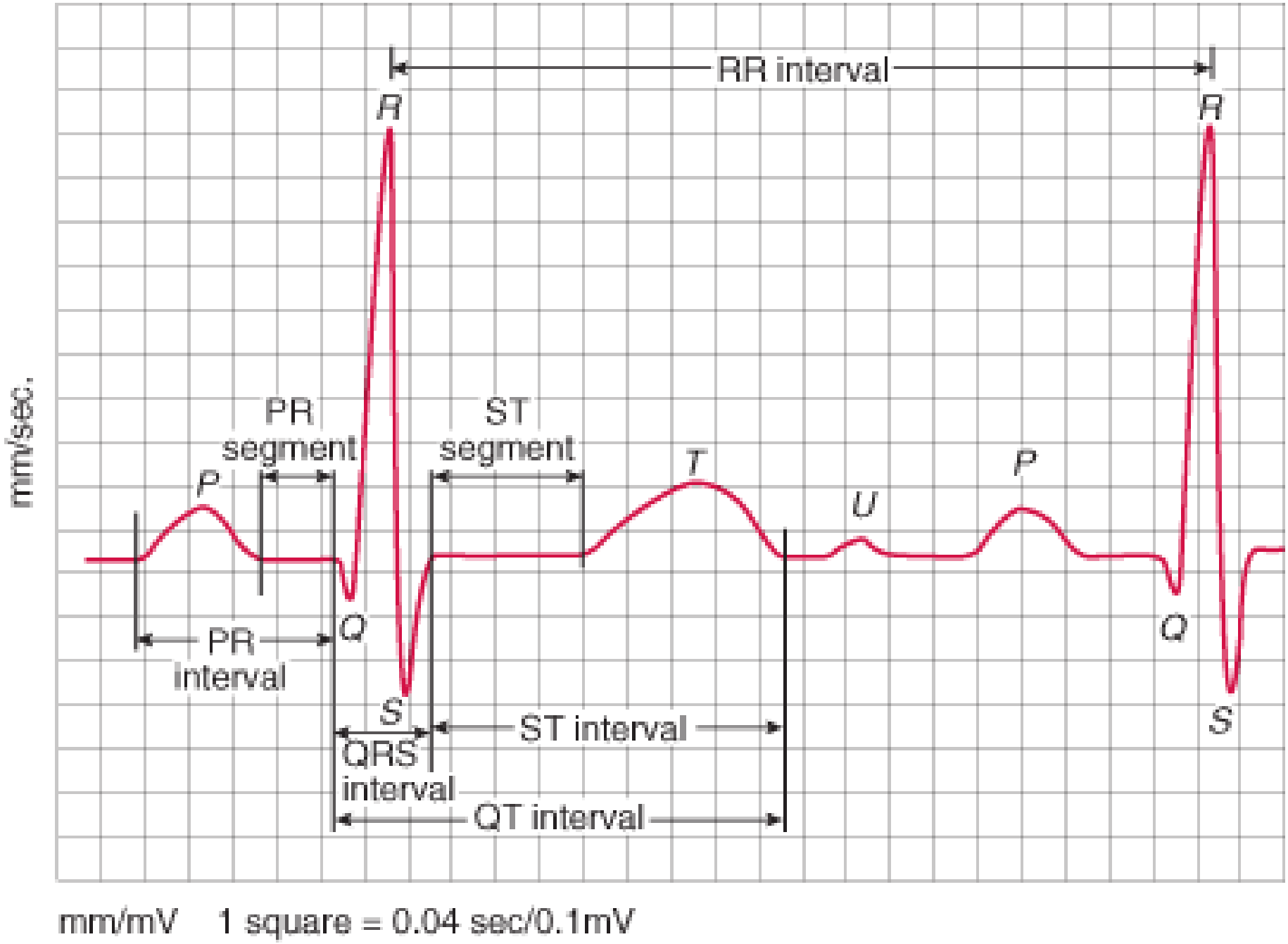
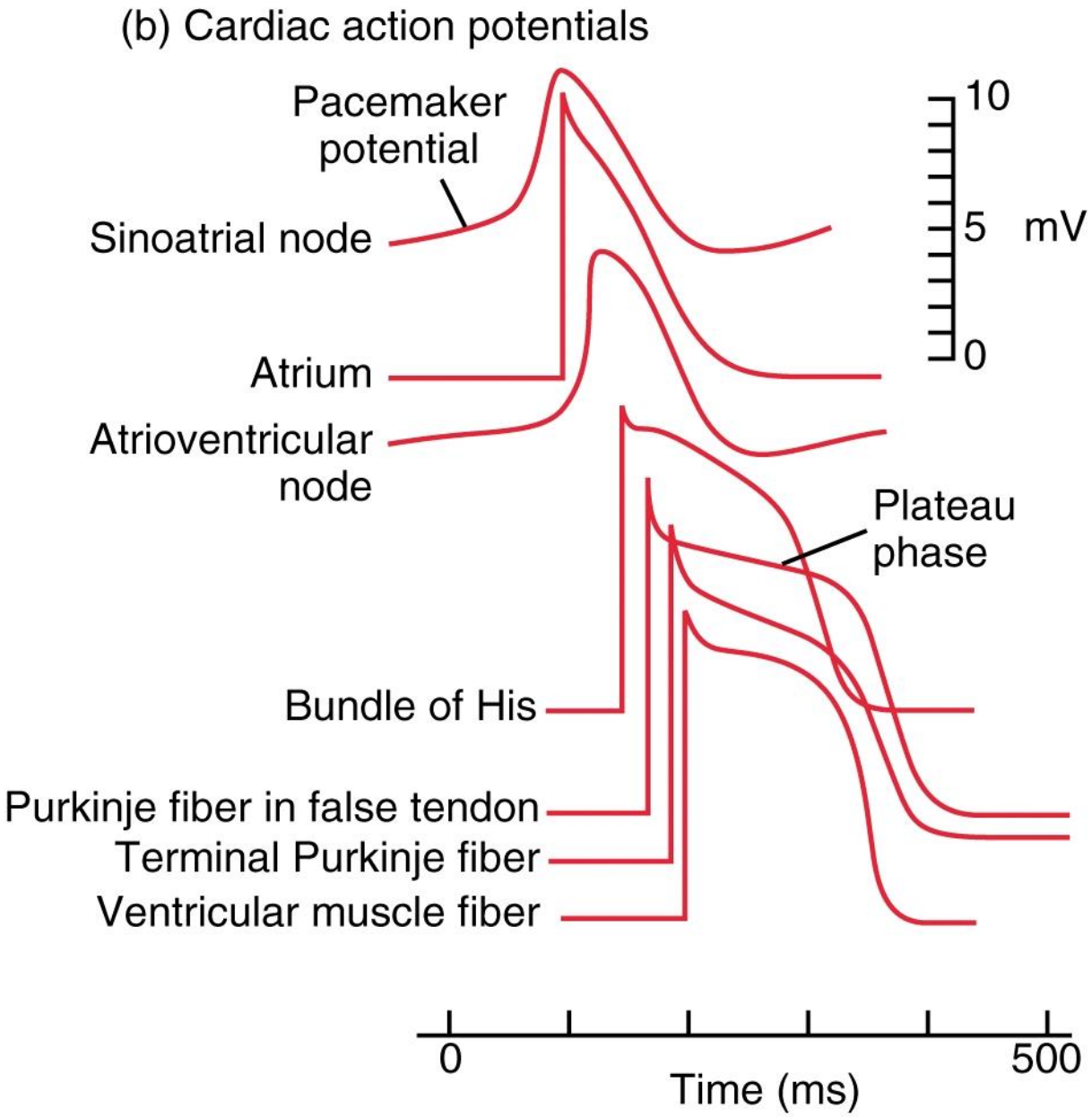
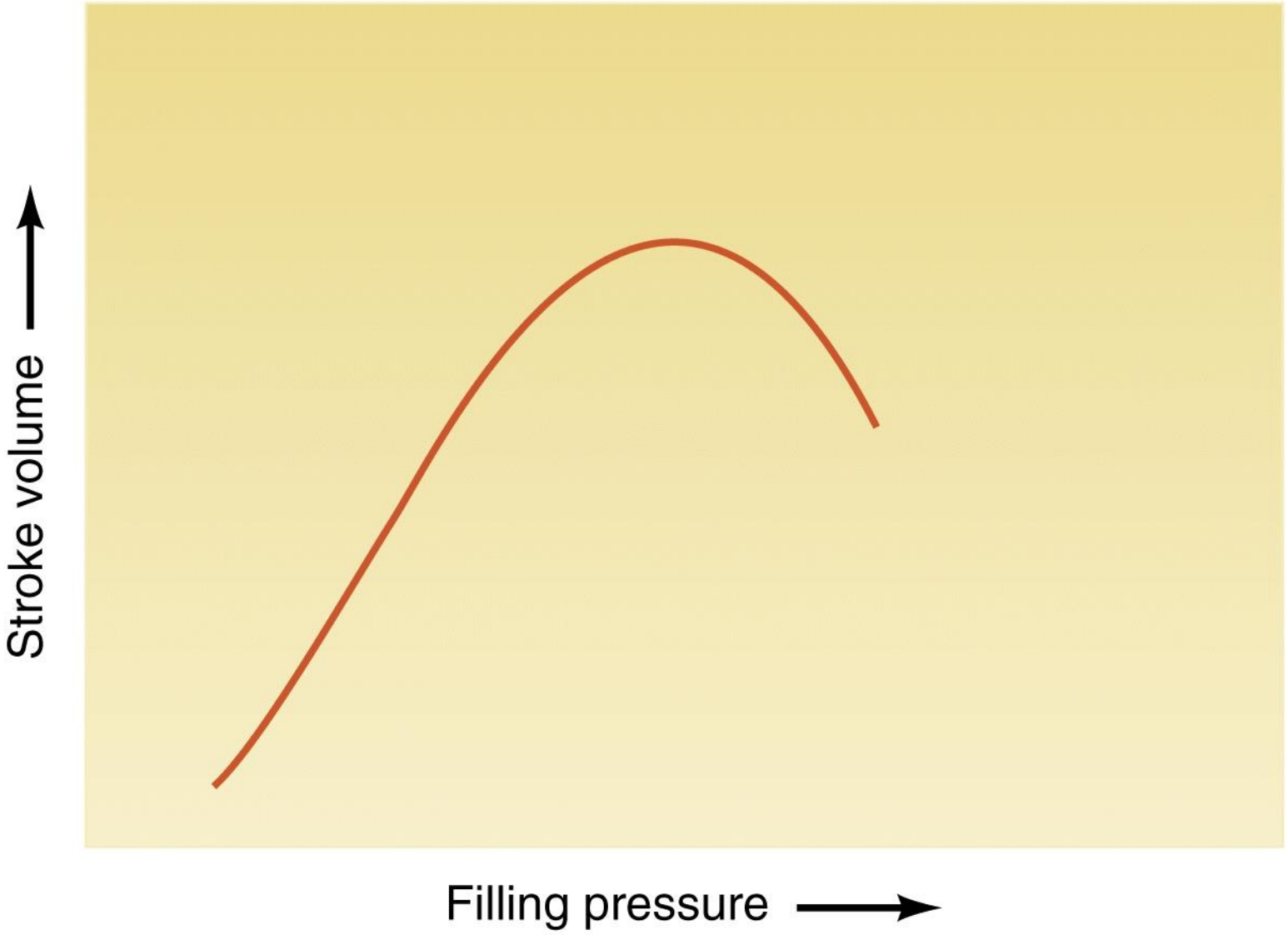

RR interval
R
R
PR
segment
ST
segment
P
T
P
U
PR
interval
Q
Q
S
S
ST interval
QRS
interval
QT interval
mm/sec.
mm/mV 1 square = 0.04 sec/0.1mV

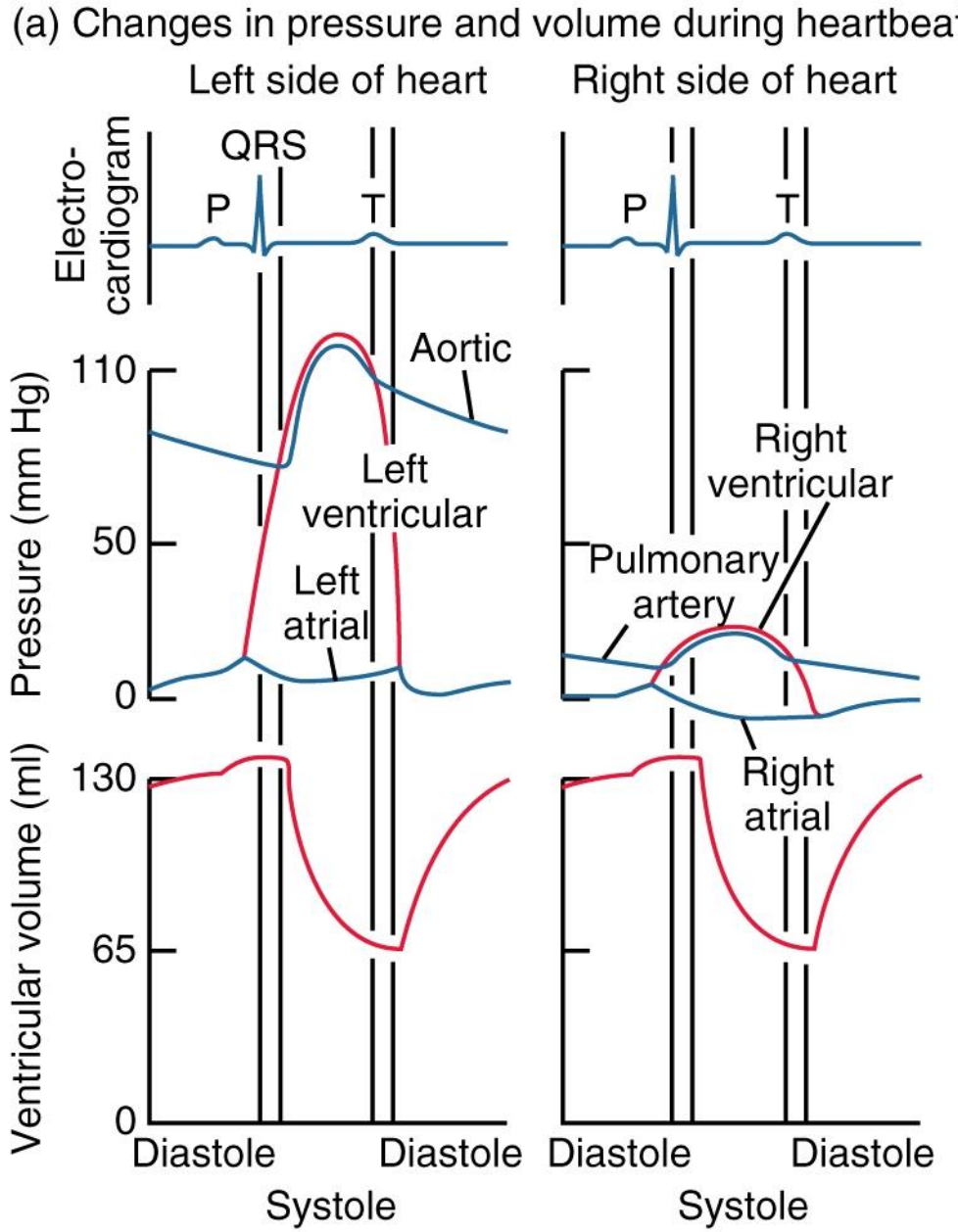
Table 5.1 Components of the ECG & Typical Lead II Values*

ECG COMPONENT		*Measurement area…*	*Represent…*	**Duration** *(seconds)*	***Amplitude*** *(millivolts)*
Waves	**P**	begin and end on isoelectric line (baseline); normally upright in standard limb leads	depolarization of the right and left atria.	0.07 – 0.18	< 0.25
	QRS complex	begin and end on isoelectric line (baseline) from start of Q wave to end of S wave	depolarization of the right and left ventricles. Atrial repolarization is also part of this segment, but the electrical signal for atrial repolarization is masked by the larger QRS complex (see Fig 5.2)	0.06 – 0.12	0.10 – 1.50
	T	begin and end on isoelectric line (baseline)	repolarization of the right and left ventricles.	0.10 – 0.25	< 0.5
Intervals	**P-R**	from start of P wave to start of QRS complex	time from the onset of atrial depolarization to the onset of ventricular depolarization.	0.12-0.20	
	Q-T	from start of QRS complex to end of T wave	time from onset of ventricular depolarization to the end of ventricular repolarization. It represents the refractory period of the ventricles.	0.32-0.36	
	R-R	from peak of R wave to peak of succeeding R wave	time between two successive ventricular depolarizations.	0.80	
Segments	**P-R**	from end of P wave to start of QRS complex	time of impulse conduction from the AV node to the ventricular myocardium.	0.02 – 0.10	
	S-T	between end of S wave and start of T wave	period of time representing the early part of ventricular repolarization during which ventricles are more or less uniformly excited.	< 0.20	
	T-P	from end of T wave to start of successive P wave	time from the end of ventricular repolarization to the onset of atrial depolarization.	0.0 – 0.40	

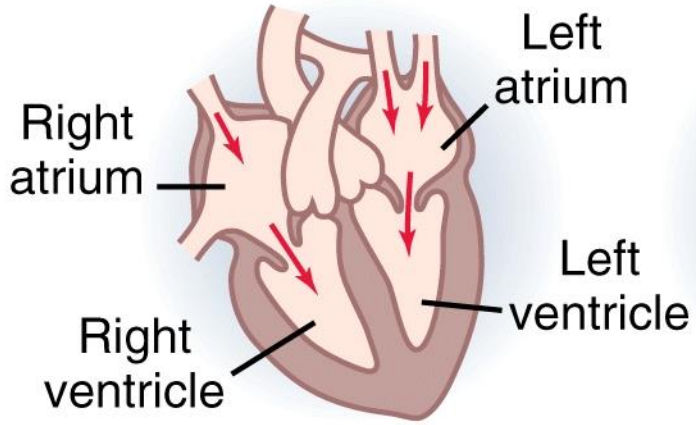

(b) Cardiac action potentials
Pacemaker potential
Sinoatrial node
Atrium
Atrioventricular node
Plateau phase
Bundle of His
Purkinje fiber in false tendon
Terminal Purkinje fiber
Ventricular muscle fiber
10
5
mV
0
0
500
Time (ms)

(a) Frank-Starling mechanism in frog heart

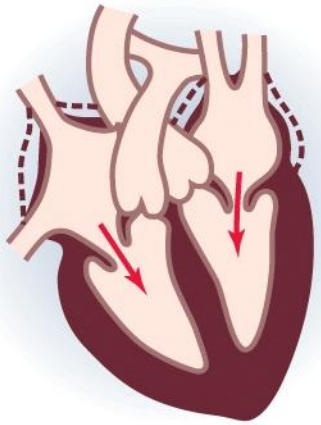



(a) Changes in pressure and volume during heartbeat
Left side of heart
Right side of heart
Electro-cardiogram
QRS
P
T
P
T
Aortic
110
50
0
Pressure (mm Hg)
Left ventricular
Left atrial
Right ventricular
Pulmonary artery
Right atrial
130
65
0
Ventricular volume (ml)
Diastole
Diastole
Systole
Diastole
Diastole
Systole

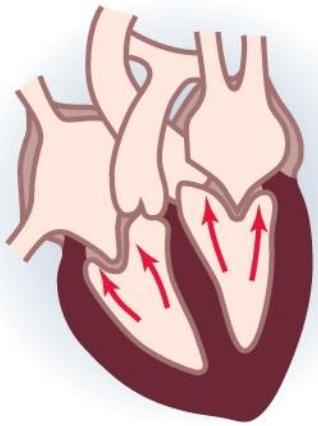
(b) Sequence of events in heartbeat



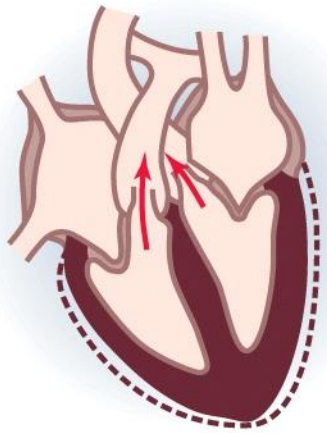
(1) **Mid-diastole**



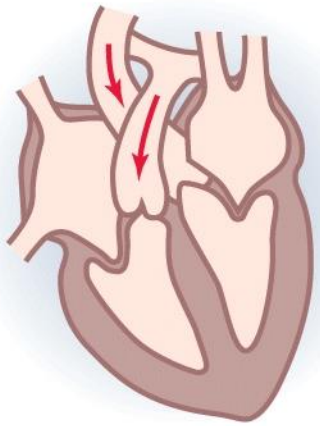
(2) **Atrial contraction**



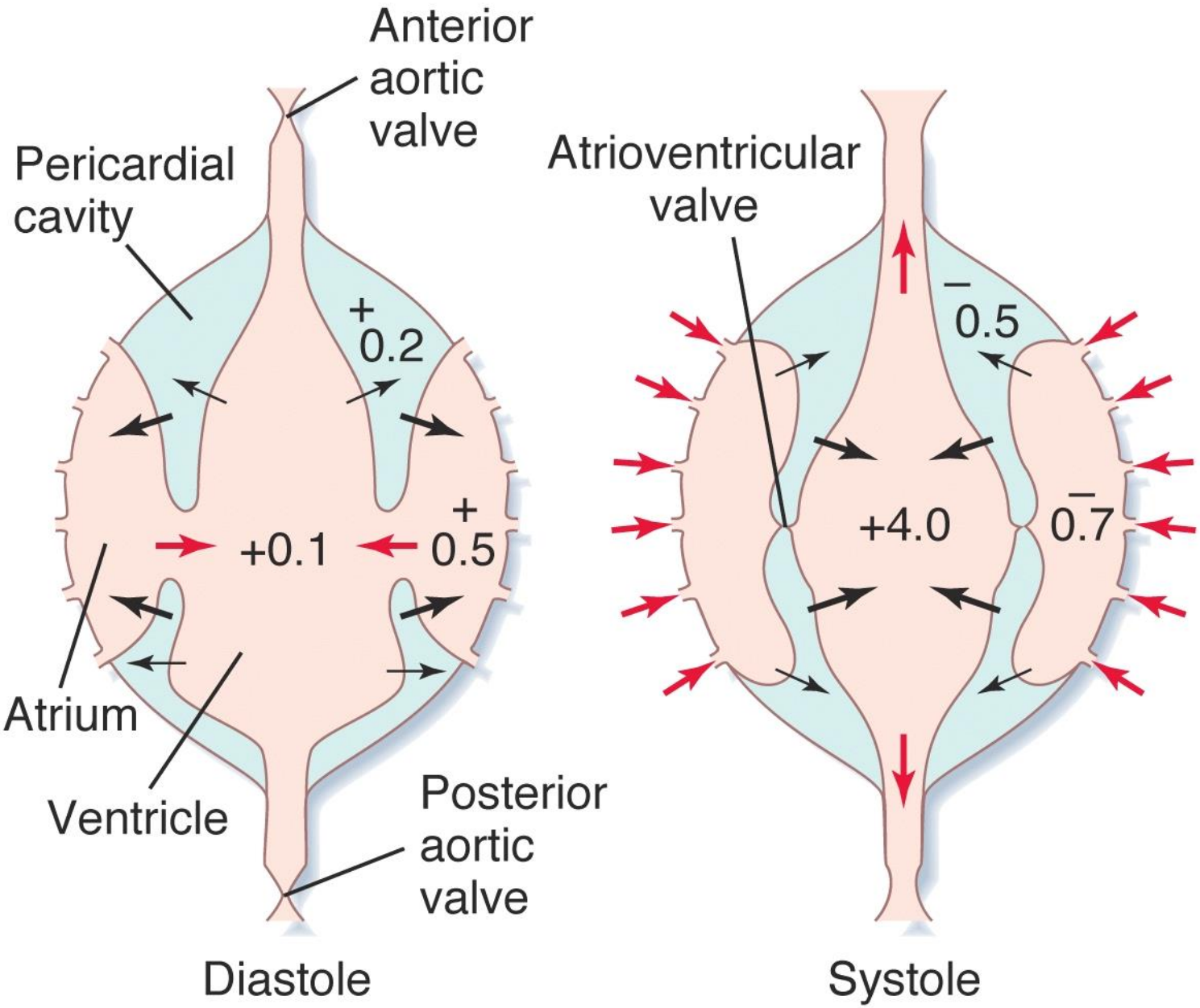
(3) **Isometric ventricular contraction**

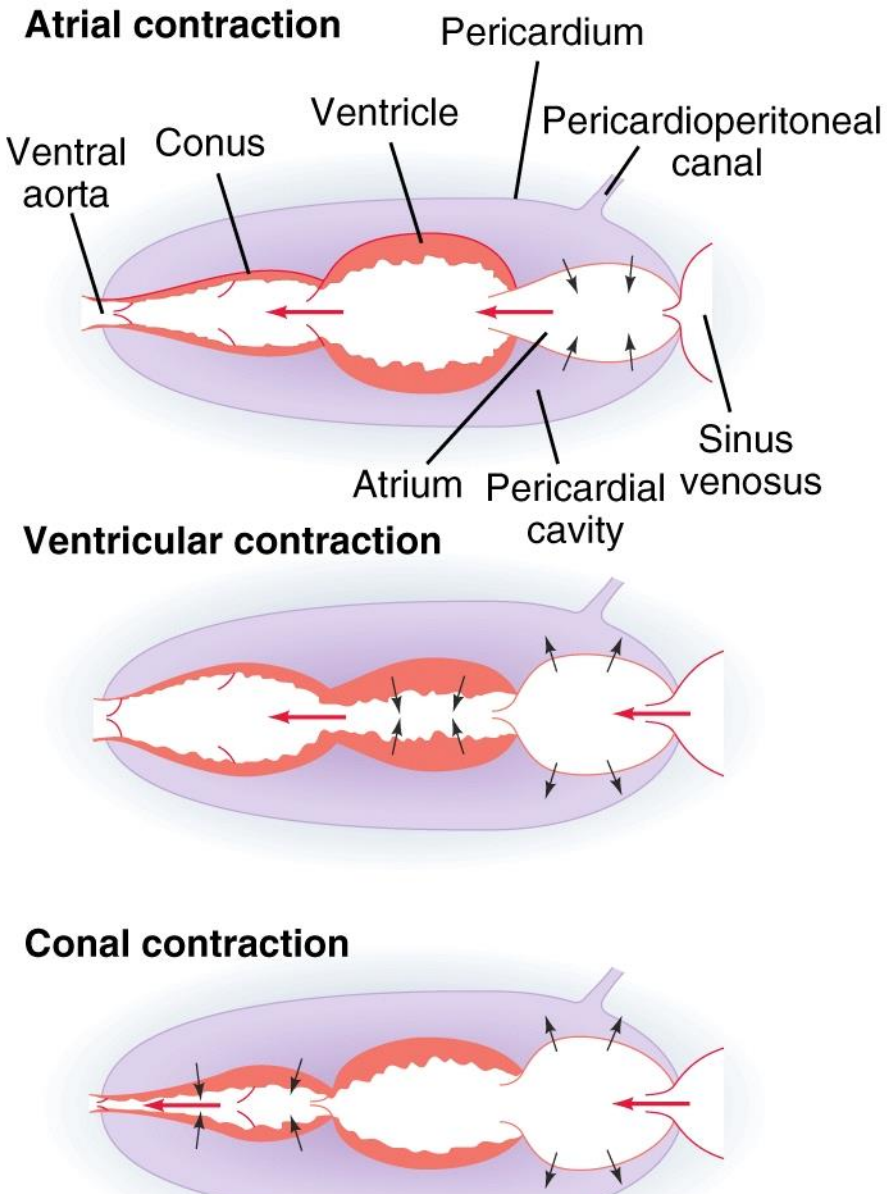


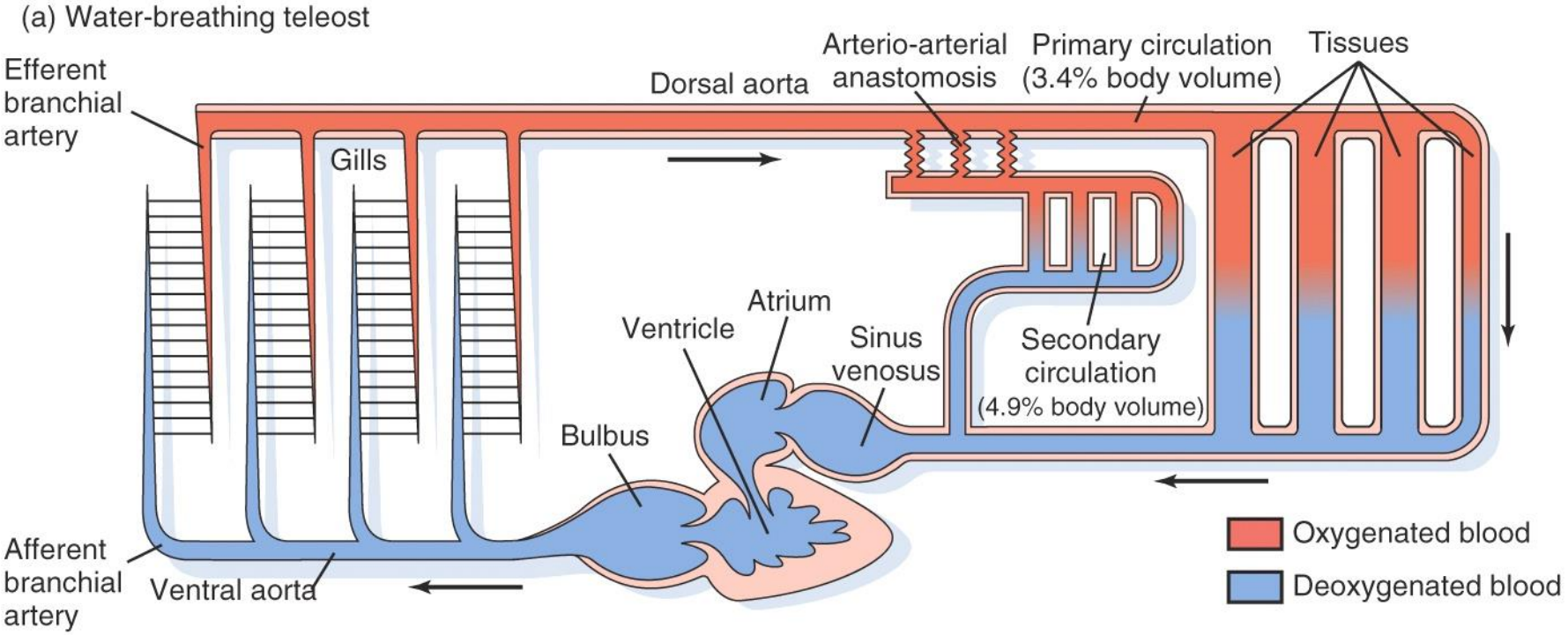
(4) **Ventricular ejection**

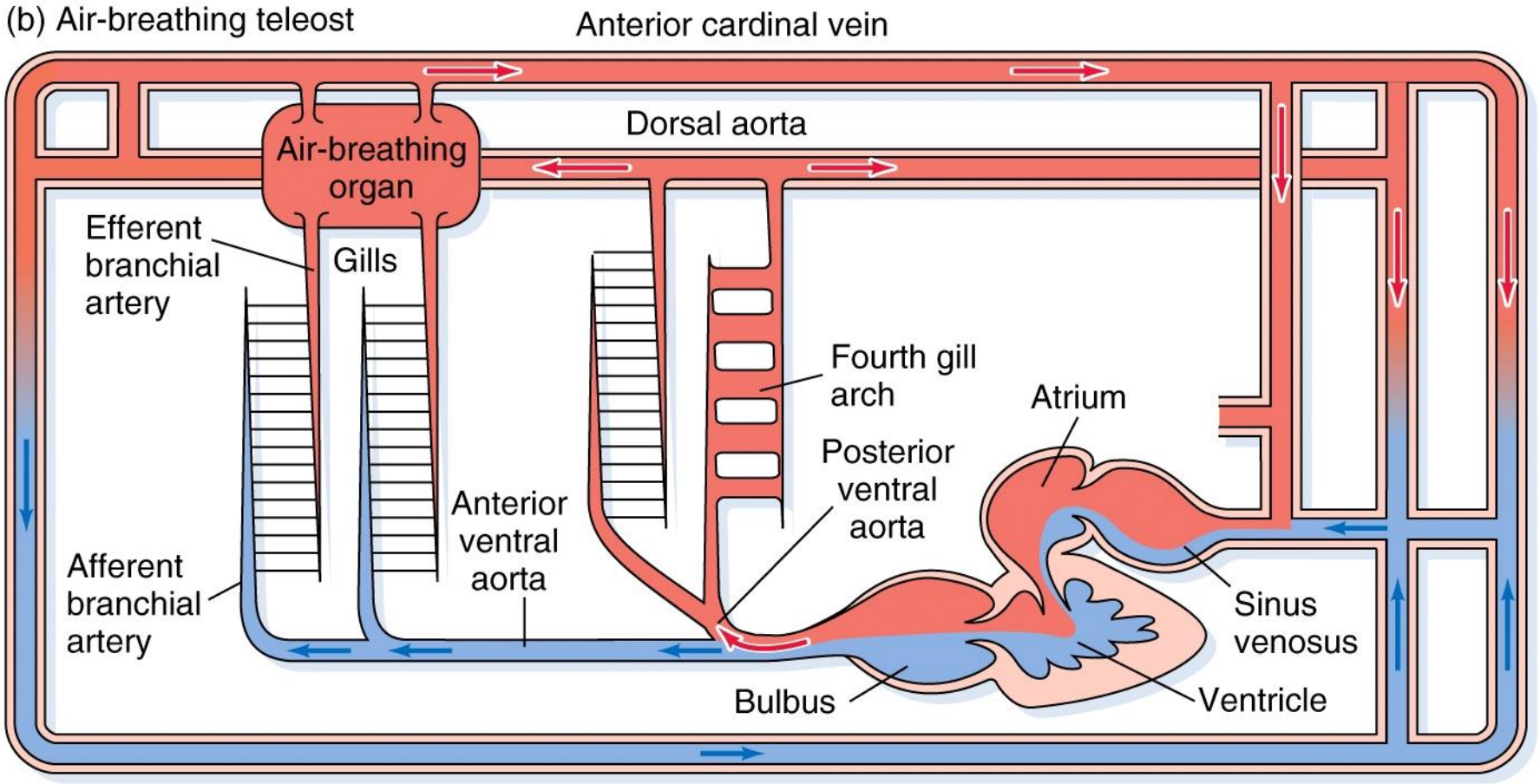


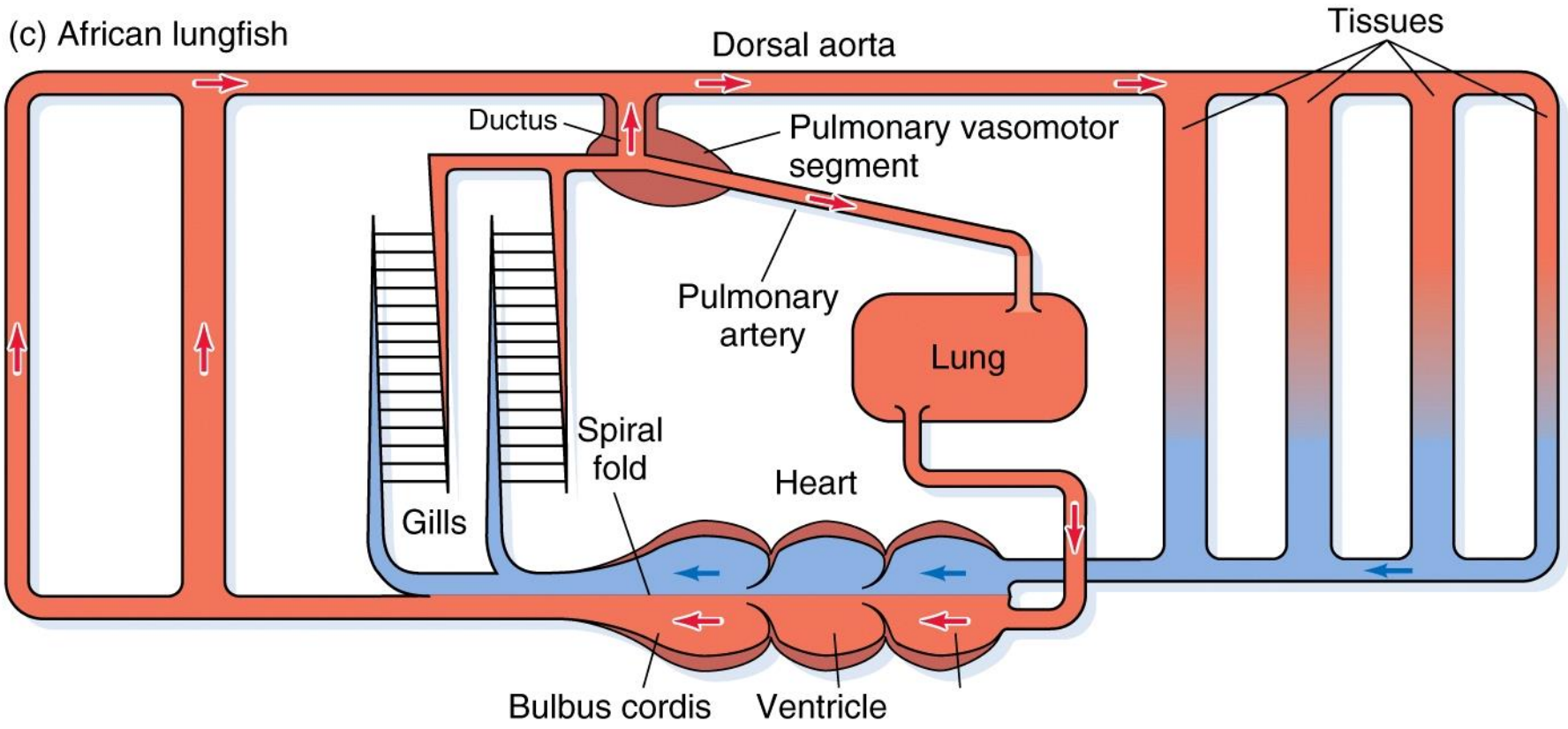
(5) **Isometric ventricular relaxation**

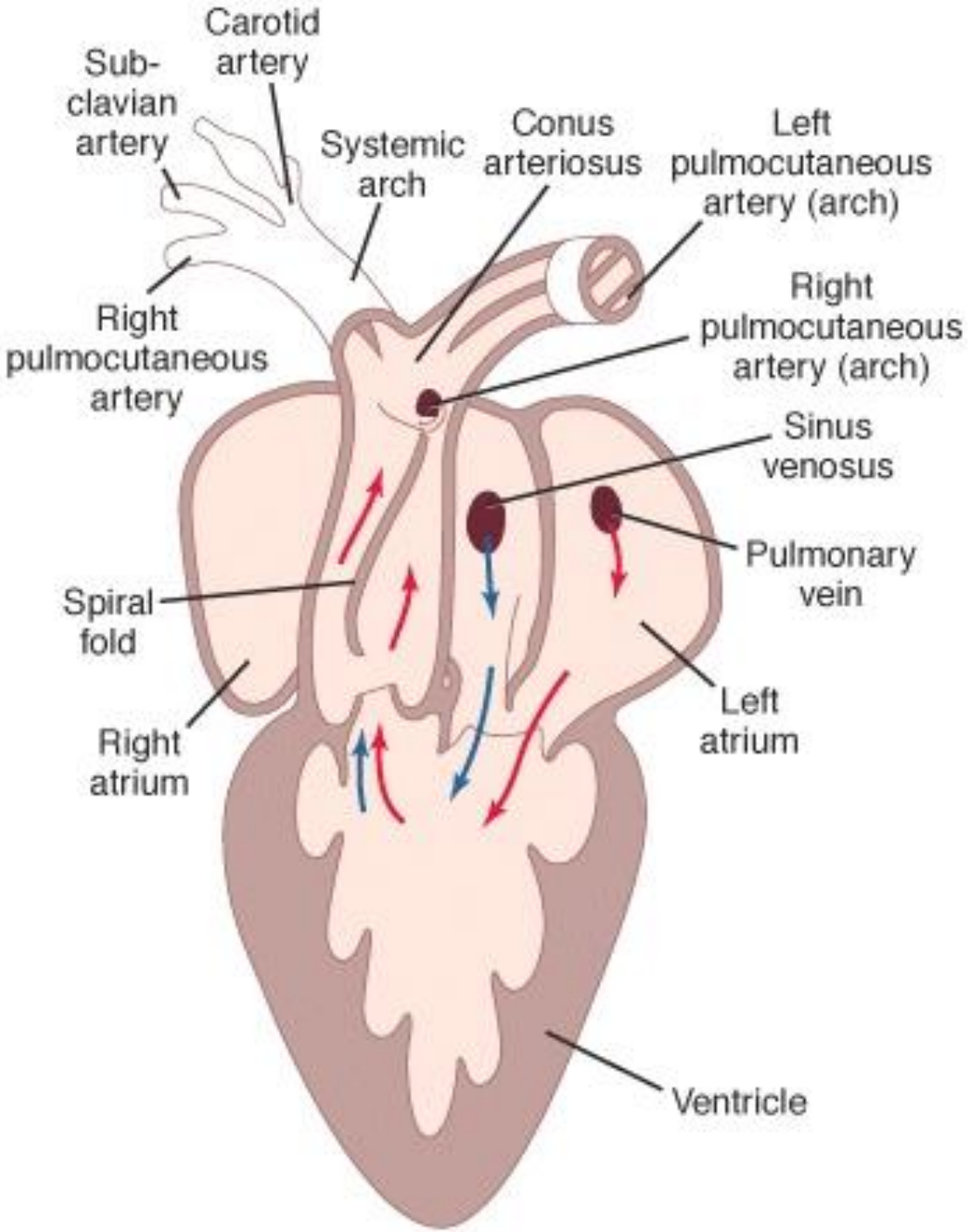

Anterior aortic valve
Pericardial cavity
Atrioventricular valve
+ 0.2
− 0.5
+0.1
+ 0.5
+4.0
− 0.7
Atrium
Ventricle
Posterior aortic valve
Diastole
Systole


Atrial contraction
Pericardium
Ventricle
Pericardioperitoneal canal
Ventral aorta
Conus
Sinus venosus
Atrium
Pericardial cavity
Ventricular contraction
Conal contraction

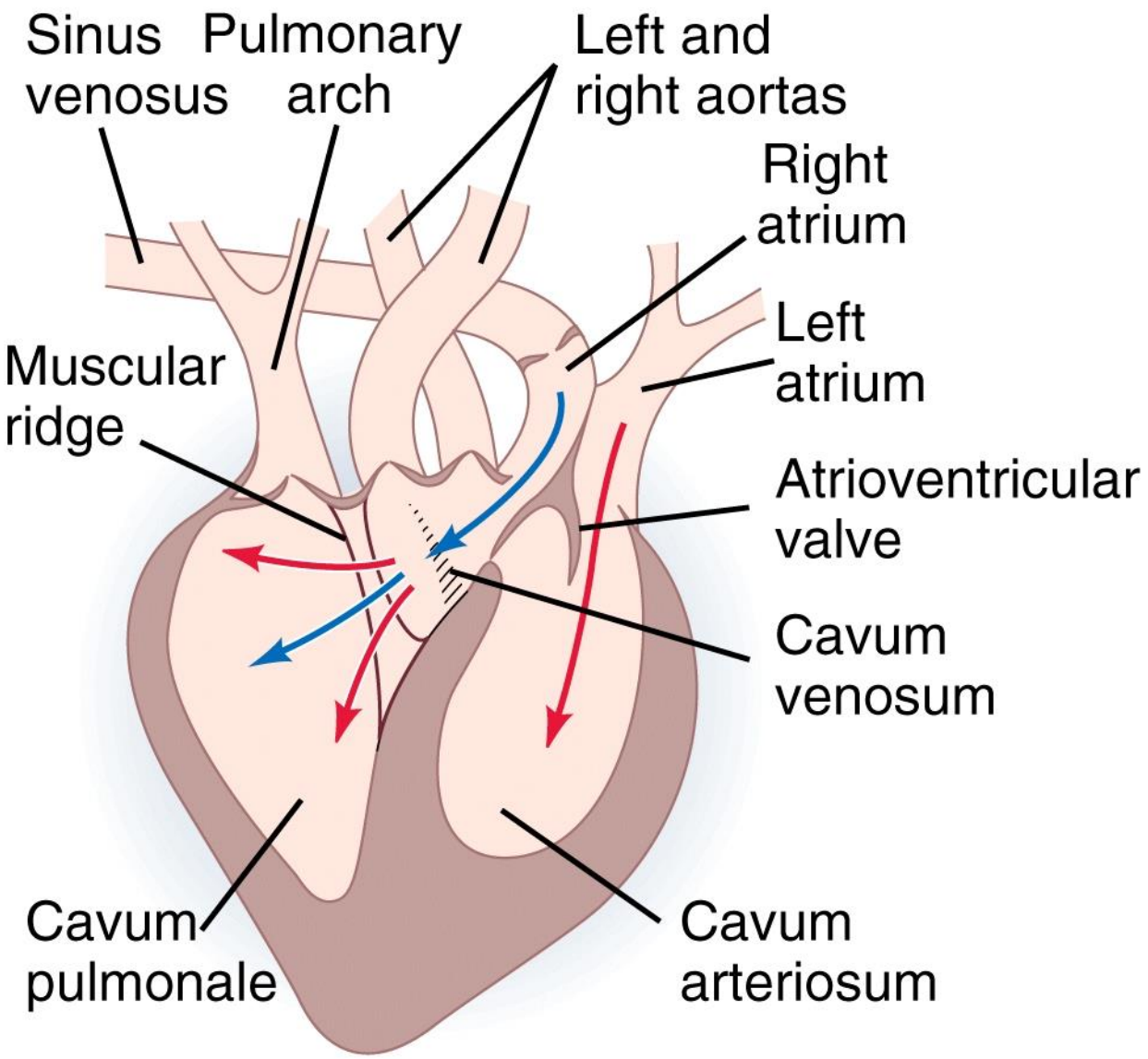

(a) Water-breathing teleost
Efferent branchial artery
Gills
Dorsal aorta
Arterio-arterial anastomosis
Primary circulation (3.4% body volume)
Tissues
Atrium
Ventricle
Sinus venosus
Secondary circulation (4.9% body volume)
Bulbus
Afferent branchial artery
Ventral aorta
Oxygenated blood
Deoxygenated blood


(b) Air-breathing teleost
Anterior cardinal vein
Dorsal aorta
Air-breathing organ
Efferent branchial artery
Gills
Fourth gill arch
Atrium
Posterior ventral aorta
Anterior ventral aorta
Afferent branchial artery
Sinus venosus
Bulbus
Ventricle

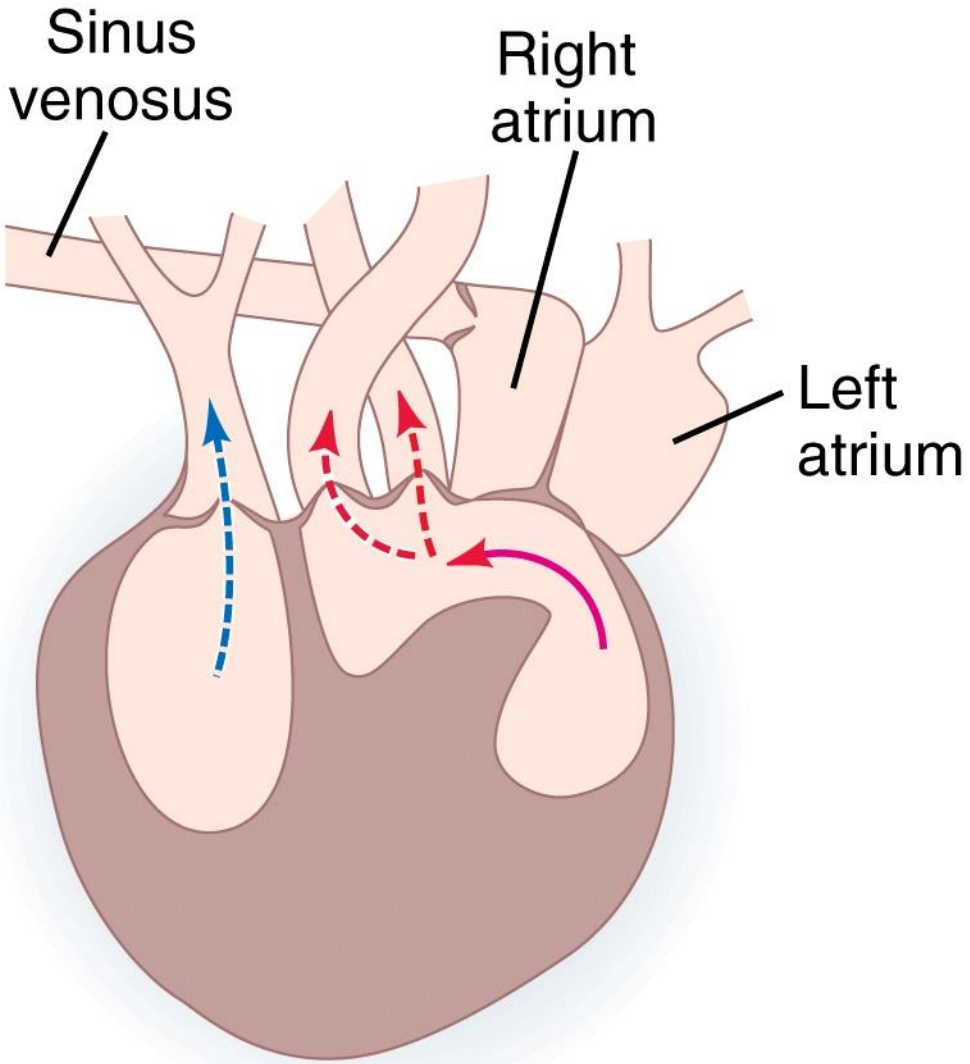

(c) African lungfish
Dorsal aorta
Tissues
Ductus
Pulmonary vasomotor segment
Pulmonary artery
Lung
Spiral fold
Heart
Gills
Bulbus cordis
Ventricle


Carotid artery
Sub-clavian artery
Systemic arch
Conus arteriosus
Left pulmocutaneous artery (arch)
Right pulmocutaneous artery
Right pulmocutaneous artery (arch)
Sinus venosus
Pulmonary vein
Spiral fold
Right atrium
Left atrium
Ventricle

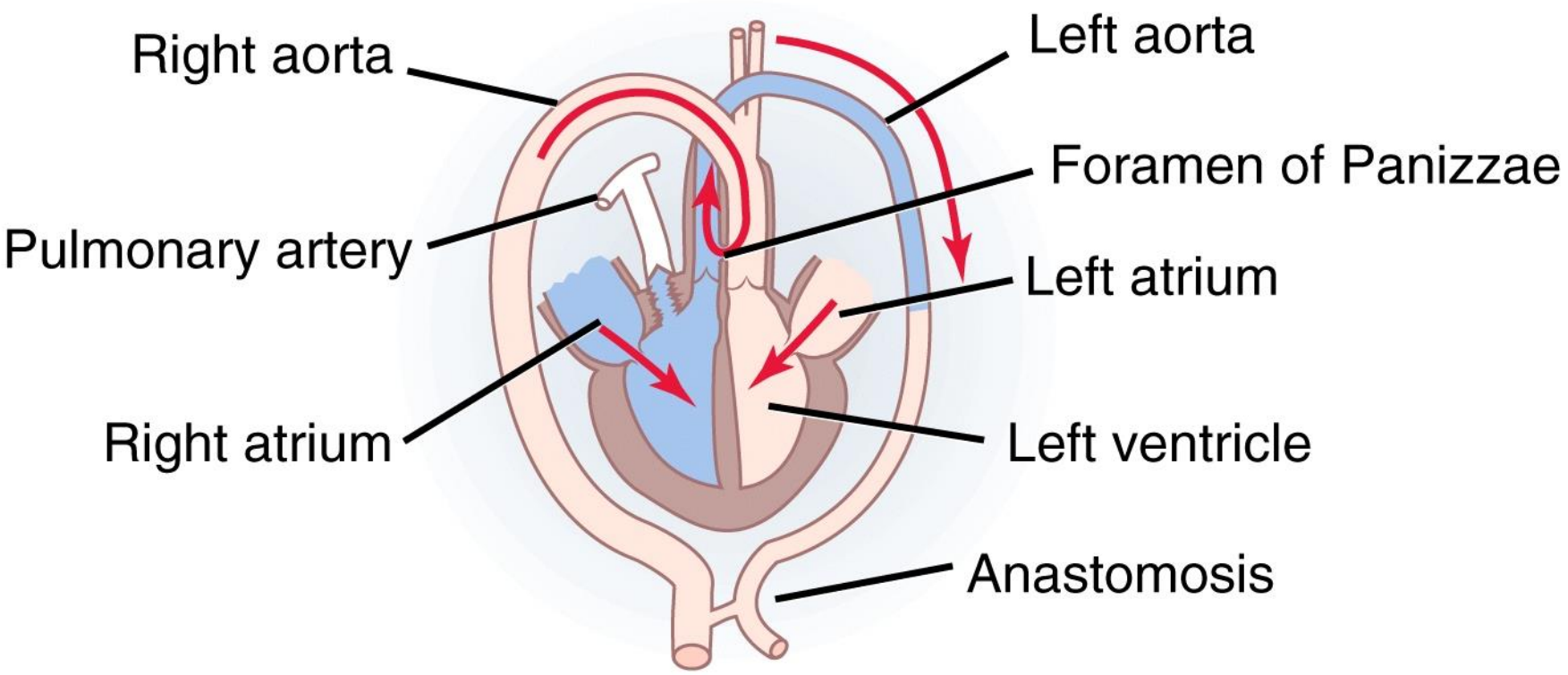
(a) Diastole


Sinus venosus
Pulmonary arch
Left and right aortas
Right atrium
Left atrium
Muscular ridge
Atrioventricular valve
Cavum venosum
Cavum pulmonale
Cavum arteriosum

(b) Systole



(a) Diastole


Right aorta
Left aorta
Foramen of Panizzae
Pulmonary artery
Left atrium
Right atrium
Left ventricle
Anastomosis

4. THE AORTIC ARCHES

The first pair of aortic arches is formed by the curving of the ventral aorta into the primitive dorsal aorta. This arch is hidden in the mandibular arch and participates in formation of the *maxillary artery,* and contribute to the *external carotid artery*

II. **The second pair of aortic arches** make their appearance in the middle of week 4. They cross the second branchial arches and give rise to the *stapedial* and *hyoid arteries.* (It should be noted that arches I and II regress rapidly and are not seen after day 31)

III. **The third pair of aortic arches** make their appearance at the end of week 4. They give rise to the *common carotids* and *proximal portions of the internal carotid arteries.* The latter are the short cephalic prolongations of the primitive dorsal aortas and are associated with development and supply of the brain

A. THE INTERNAL CAROTID ARTERIES are secondarily attached to the cranial portions of the dorsal aortas, which form the remainder of the carotid artery

B. THE ORIGIN OF THE EXTERNAL CAROTID ARTERIES is controversial, but in later stages of development, they are found to sprout from aortic arch III. (Arch I, however, has been implicated in its developmental contribution)

IV. **The fourth pair of aortic arches** make their appearance shortly after the third arches, at the end of week 4. Their development is different for the right and left sides

A. ON THE RIGHT SIDE arch IV forms the proximal portion of the *right subclavian artery* and is continuous with the seventh segmental artery
   1. The caudal portion of the right primitive dorsal aorta disappears
   2. The distal portion of the subclavian artery forms from the right dorsal aorta and the right seventh intersegmental artery

B. ON THE LEFT SIDE arch IV persists as the *arch of the aorta,* which grows significantly and is continuous with the primitive left dorsal aorta.
   1. The *left subclavian artery* (or seventh segmental) arises directly from the aorta

C. THE SHORT PORTION of the right primitive ventral aorta, which persists between arches IV and VI, forms the *brachiocephalic arterial trunk* and the *first portion of the aortic arch*

V. **The fifth pair of aortic arches:** in 50% of embryos, these arches are rudimentary vessels that degenerate with no derivatives. In fact, they may never even develop

VI. **The sixth pair of aortic arches** make their appearance in the middle of week 5 and give rise to the *right* and *left pulmonary arteries.* After pulmonary vascularization is established, the communication with the corresponding primitive dorsal aorta regresses

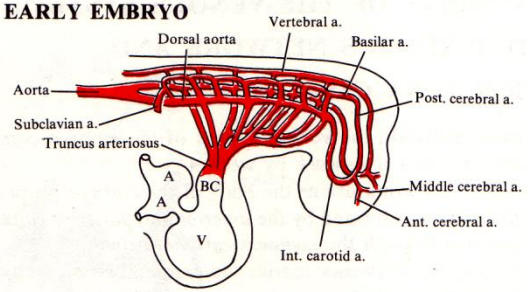
A. REGRESSION is total and complete on the right side. The proximal portion of the right arch forms the proximal part of right pulmonary artery; its distal portion degenerates

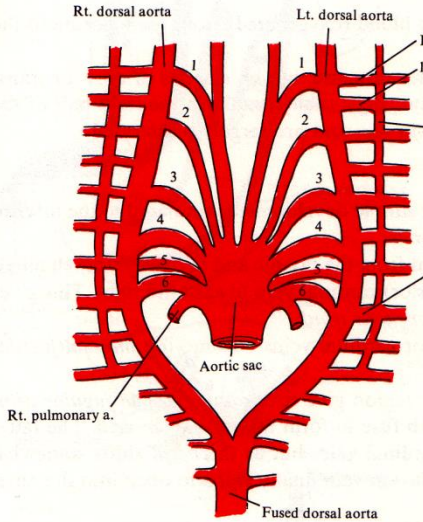
B. THE PROXIMAL PORTION OF THE LEFT ARCH persists as the proximal part of the left pulmonary artery
   1. The distal portion of the left arch, in which communication persists with the dorsal aorta until birth, forms the *ductus arteriosus* and diverts blood from the pulmonary artery to the aorta. Closure of the ductus arteriosus takes place in the neonatal period, and the functional duct becomes the anatomic *ligamentum arteriosum*

C. THE DISTAL PORTIONS OF THE PULMONARY ARTERIES are derived from buds of the sixth aortic arches that grow into the developing lungs. After partitioning of the truncus arteriosus, the pulmonary arteries arise from the pulmonary trunk

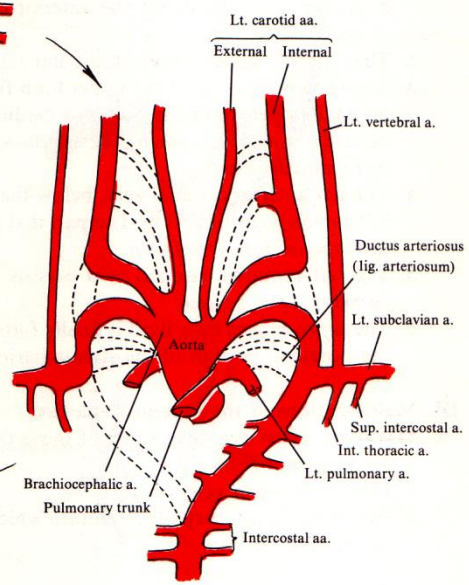
VII. **Summary of the aortic arches:** arch I regresses; arch II regresses; arch III forms the carotid system; arch IV forms the aortic arch (on the left) and the subclavian (on the right); arch V disappears; and arch VI forms the pulmonary arteries and the ductus arteriosus (on the left)

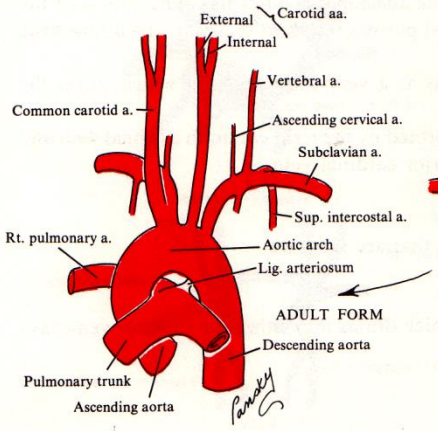
DEVELOPING ARTERIES IN HEAD REGION OF EARLY EMBRYO

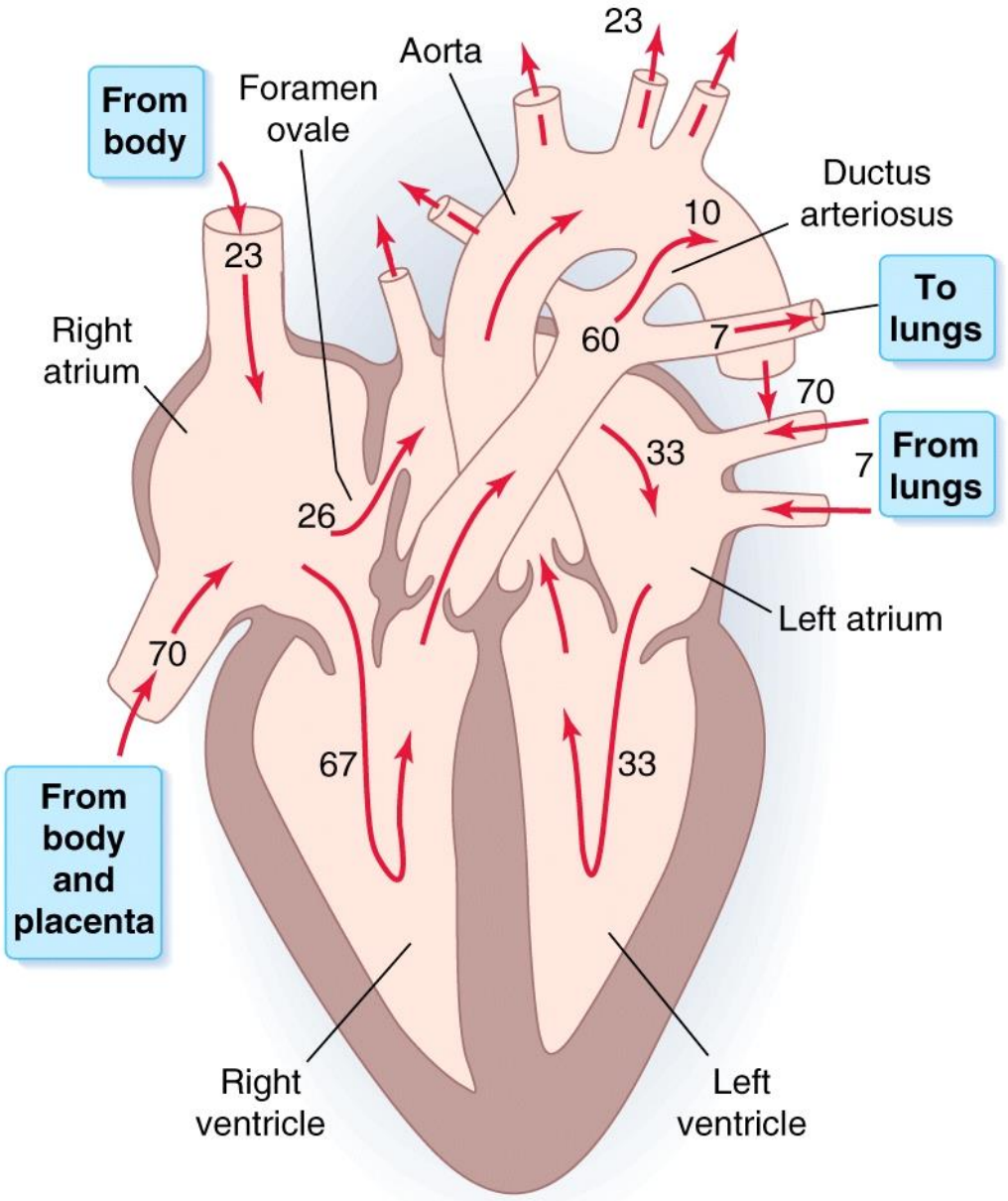


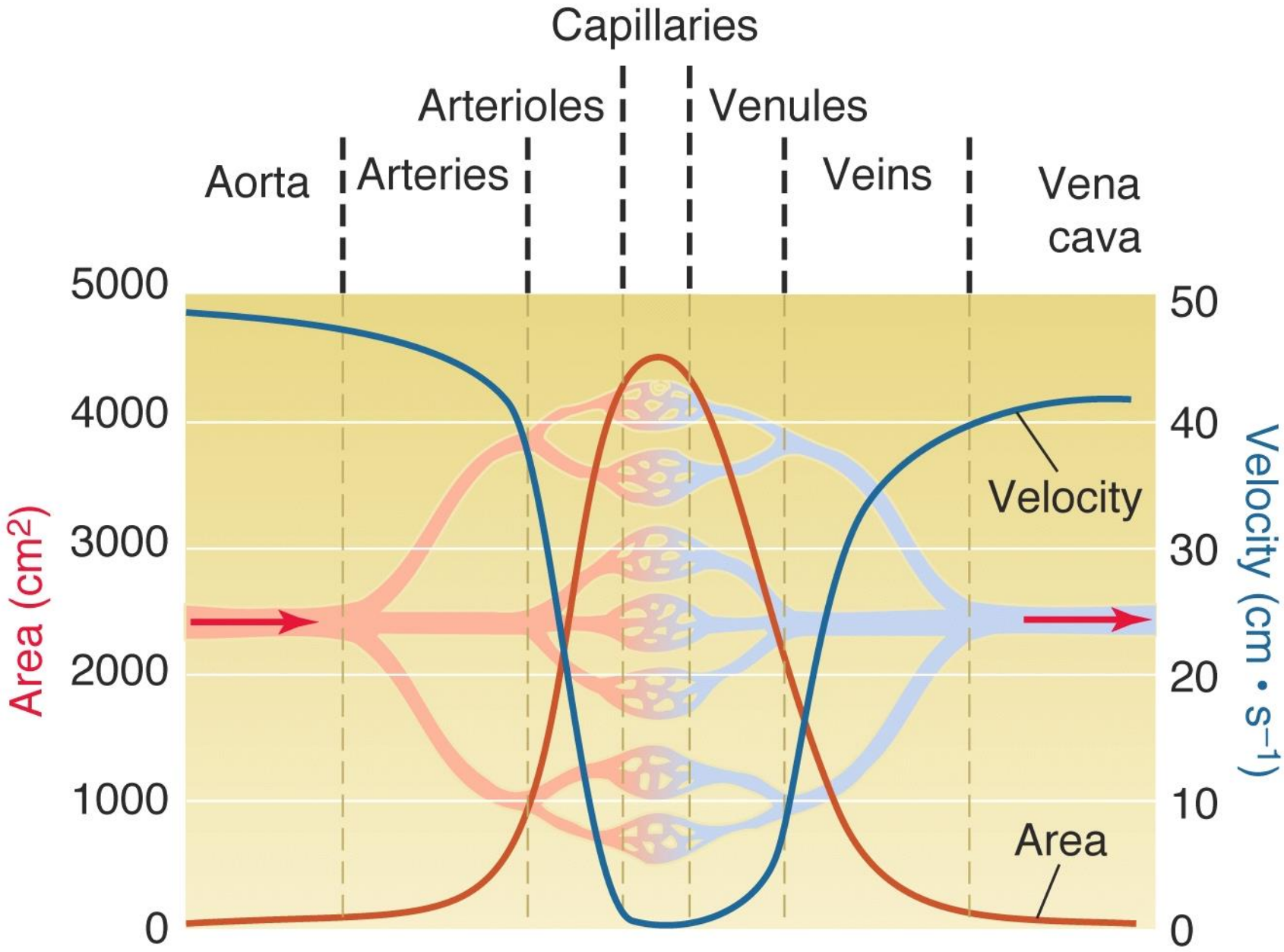


BRANCHIAL (PHARYNGEAL) ARCH ARTERIES

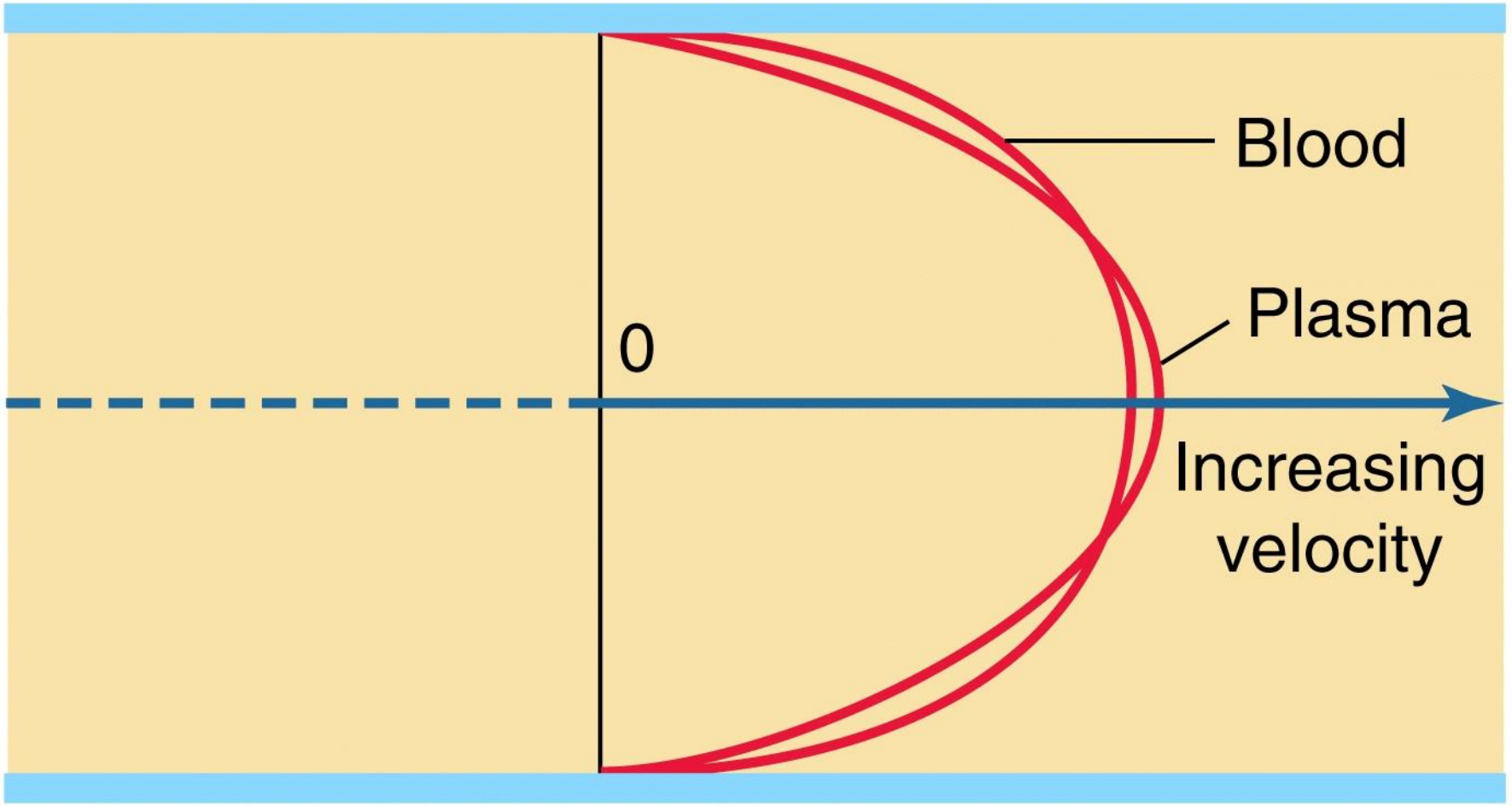


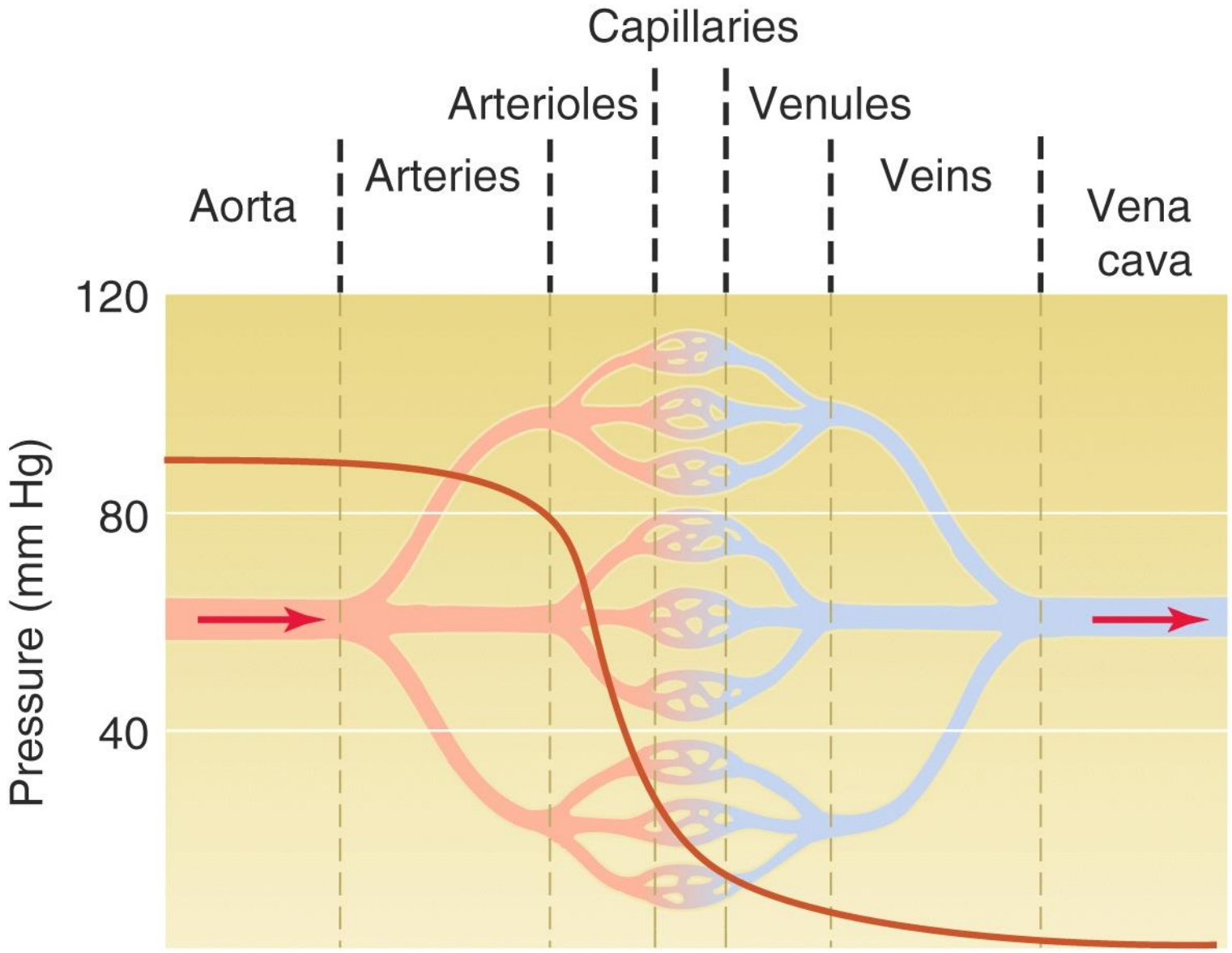


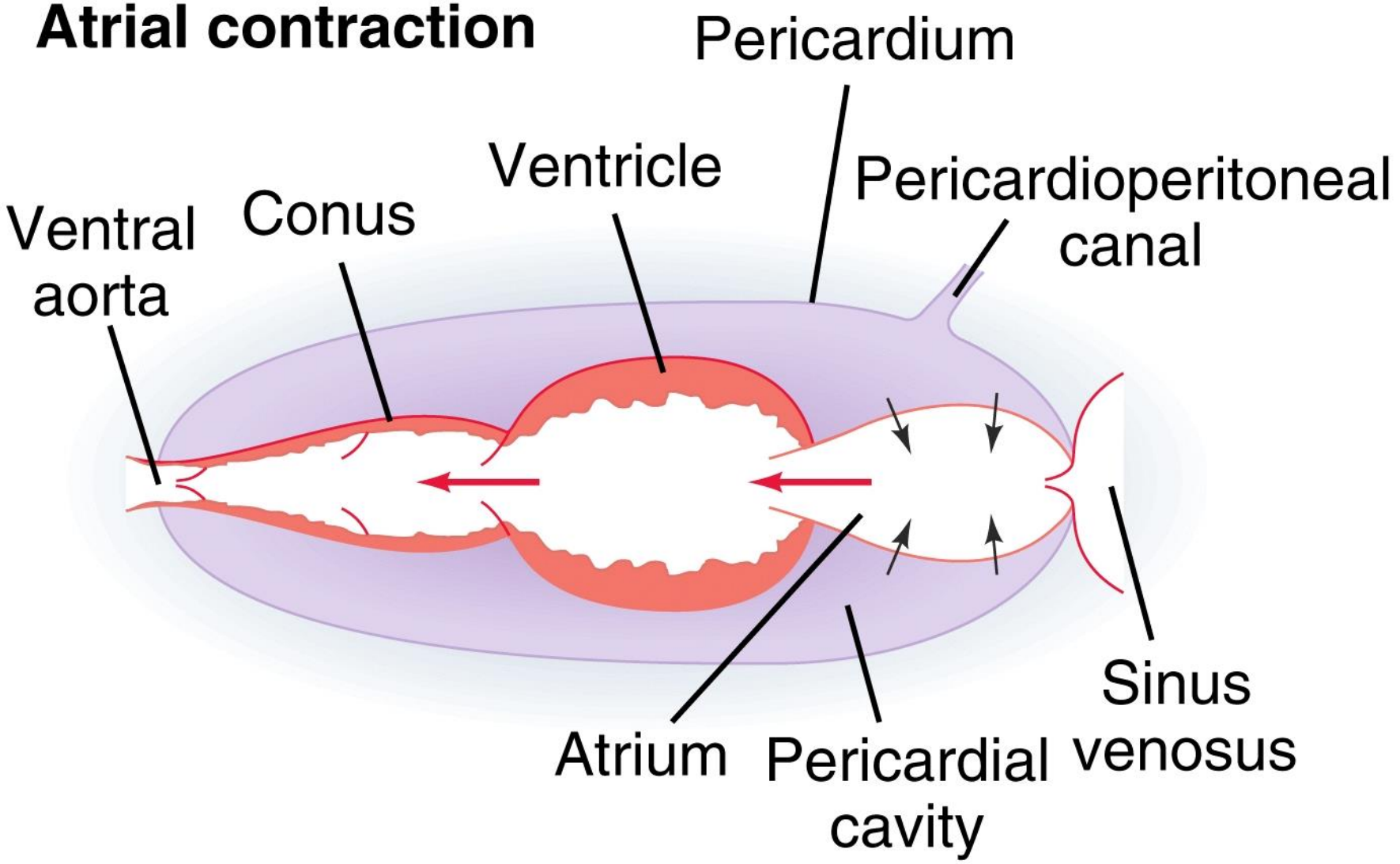

From body
Foramen ovale
Aorta
23
Ductus arteriosus
10
To lungs
23
Right atrium
60
7
70
From lungs
33
7
26
Left atrium
70
67
33
From body and placenta
Right ventricle
Left ventricle


Capillaries
Arterioles
Venules
Aorta
Arteries
Veins
Vena cava
5000
4000
3000
2000
1000
0
Area (cm²)
50
40
30
20
10
0
Velocity (cm • s⁻¹)
Velocity
Area

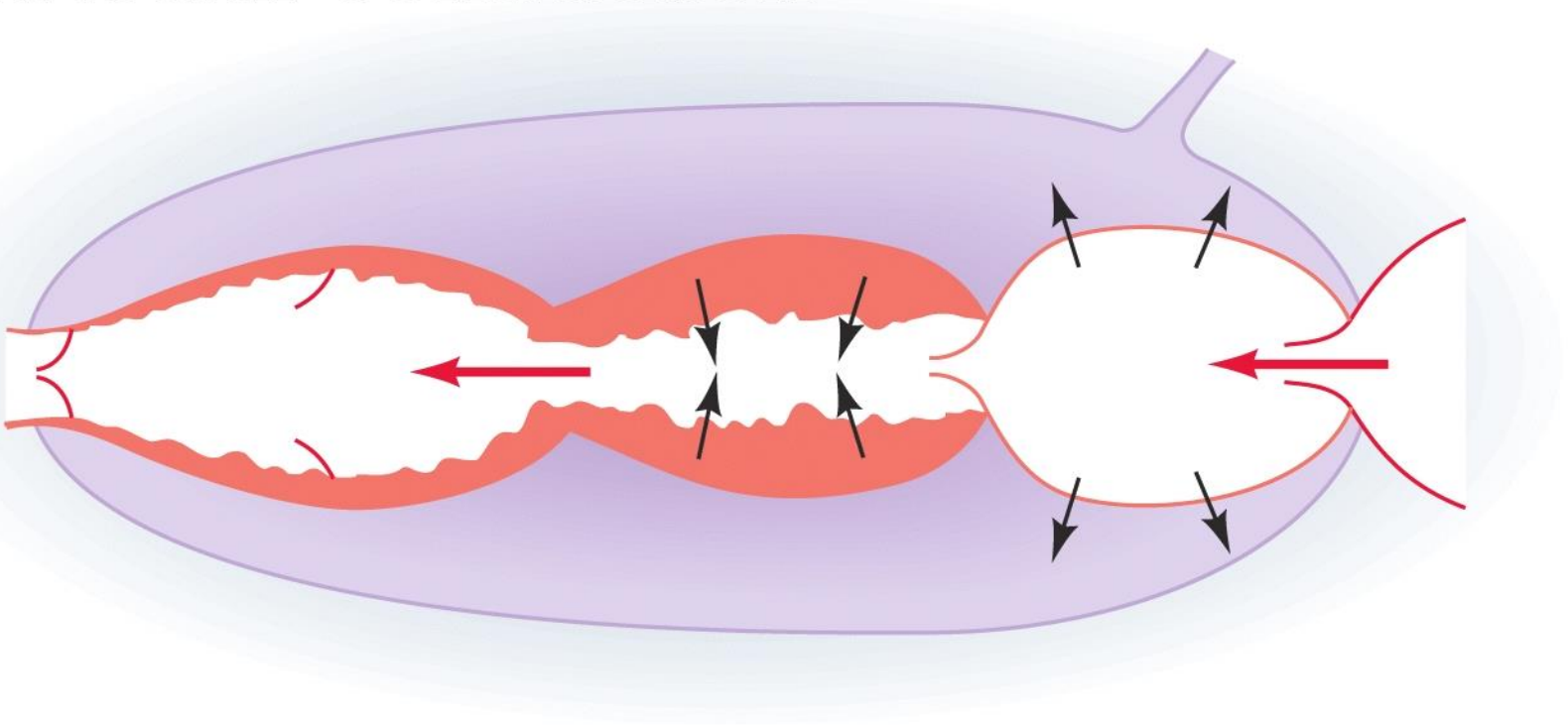
(a) Continous laminar flow




Capillaries
Arterioles
Venules
Aorta
Arteries
Veins
Vena cava
120
80
40
Pressure (mm Hg)


Atrial contraction
Pericardium
Ventricle
Pericardioperitoneal canal
Ventral aorta
Conus
Atrium
Pericardial cavity
Sinus venosus

Ventricular contraction



Conal contraction