- συμπάθεια/sympathia(=>συν/syn=together, with) +πάθος / pathos =passion, sorrow, strong emotion
- Galen (Greek physician) – sympathetic nervous system coordinates body function
- Nerves were considered as hollow tubes
- Distribute animal spirit
- Foster concerned action or “syphathy”

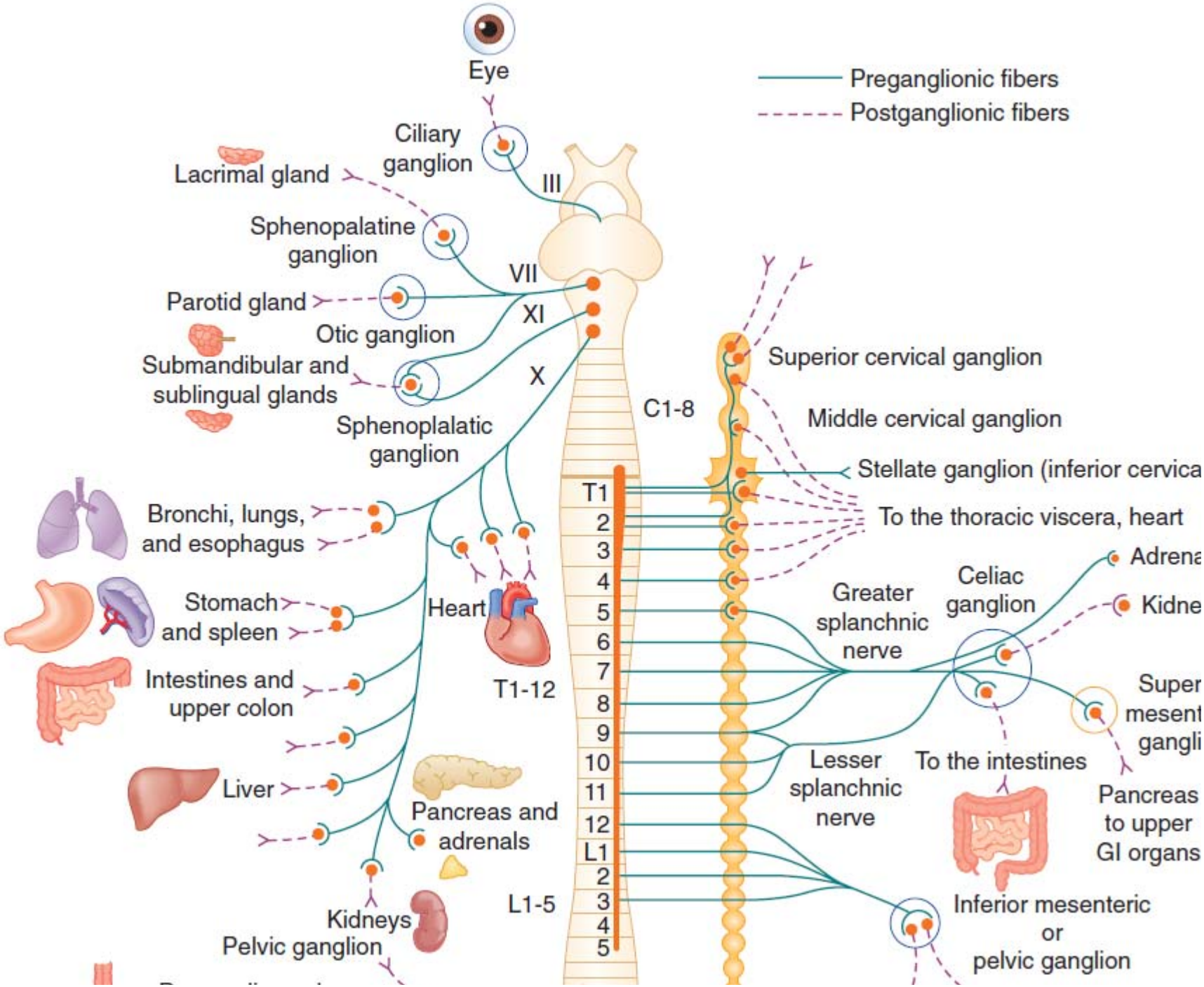
- The term sympathetic nervous system coined by Winslow (1669-1760)
  - Described the chains of ganglia and the nerves connected to the thoracic and lumbar spinal cord
- Bichat (1771-1802)
  - divided life into two distinct forms,
  - one governed by the brain,
  - and the other (organic, vegetative, life) by the abdominal ganglia → Little Brains

- English physiologist John Langley (1852-1925)

  introduced the term autonomous nervous system and parasympathetic nervous system

  -the cranial and sacral portions of the nervous system

- Παρά/para(= pefix denoting intentification, “beside”, “near”, “contrary of” “side by side”


Preganglionic fibers
Postganglionic fibers
Eye
Ciliary ganglion
III
Lacrimal gland
Sphenopalatine ganglion
VII
Parotid gland
Otic ganglion
XI
Submandibular and sublingual glands
Sphenoplalatic ganglion
X
C1-8
Superior cervical ganglion
Middle cervical ganglion
Stellate ganglion (inferior cervica
To the thoracic viscera, heart
Bronchi, lungs, and esophagus
Heart
T1-12
Stomach and spleen
Intestines and upper colon
Liver
Pancreas and adrenals
Kidneys
Pelvic ganglion
L1-5
T1
2
3
4
5
6
7
8
9
10
11
12
L1
2
3
4
5
Greater splanchnic nerve
Celiac ganglion
Adrena
Kidne
Super mesent gangli
Lesser splanchnic nerve
To the intestines
Pancreas to upper GI organs
Inferior mesenteric or pelvic ganglion

AUTONOMIC NERVOUS SYSTEM

PEIPHERAL PART

Three major divisions:

- SYMPATHETIC
- PARASYMPATHETIC AND
- ENTERIC.

CENTRAL AUTONOMIC NETWORK

- SPINE
- LOWER BRAINSTEM (BULBO-PONTINE)
  - NTS
  - RVLM
  - Parabrachial Nuclei

  Reflex control of circulation, Respiration,GIT functions and Micturition
- UPPER BRAINSTEM(Ponto Mesencephalic) – Periaqueductal grey
  - Integrate autonomic control with pain
  - Behavioral response to stress and Sleep
- FOREBRAIN – Hypothalamus
- Anterior Limbic System – Insula, Anterior Cingulate gyrus and Amygdala
  - Integration of bodily sensation with emotional and goal related autonomic response

FUNDAMENTAL FEATURE

- **Convergence of**
  - Visceral afferents
  - Nociceptive Inputs
  - Thermoceptive and
  - From muscle Receptors

  All these signals inform the CAN about the physiological state of the body

  Integrated and then Parallel information is send to Parasympathetic and Sympathetic system

FUNDAMENTAL DIFFERENTIAL CRITERIA FOR PARASYMPATHETIC AND SYMPATHETIC NERVOUS SYSTEM

- **Segmental Organization of their Preganglionic Neurons**
- **The Peripheral location of the ganglia**
- **The type and Location of their end organ**
- **The effect they produce on end organs**
- **The neurotransmitters employed by their Post ganglionic neurons**

The *sympathetic and parasympathetic divisions innervate*

- cardiac muscle, smooth muscle, and glandular tissues and
- mediate a variety of visceral reflexes

These two divisions include

- the sensory neurons associated with spinal and cranial nerves
- the preganglionic and postganglionic motor neurons
- the central nervous system circuitry that connects with and modulates the sensory and motor neurons.

- The *enteric division* *has greater autonomy*
  -comprises a self-contained system, with only minimal connections to the rest of the nervous system.
  - It consists of sensory and motor neurons in the gastrointestinal tract that mediate digestive reflexes.
- Parasympathetic nervous system

  -responsible for *rest and digest*

  - maintain basal heart rate, respiration, and metabolism under normal conditions.

- *The* sympathetic nervous system
  - governs the emergency reaction, or *fight-or-flight reaction.*

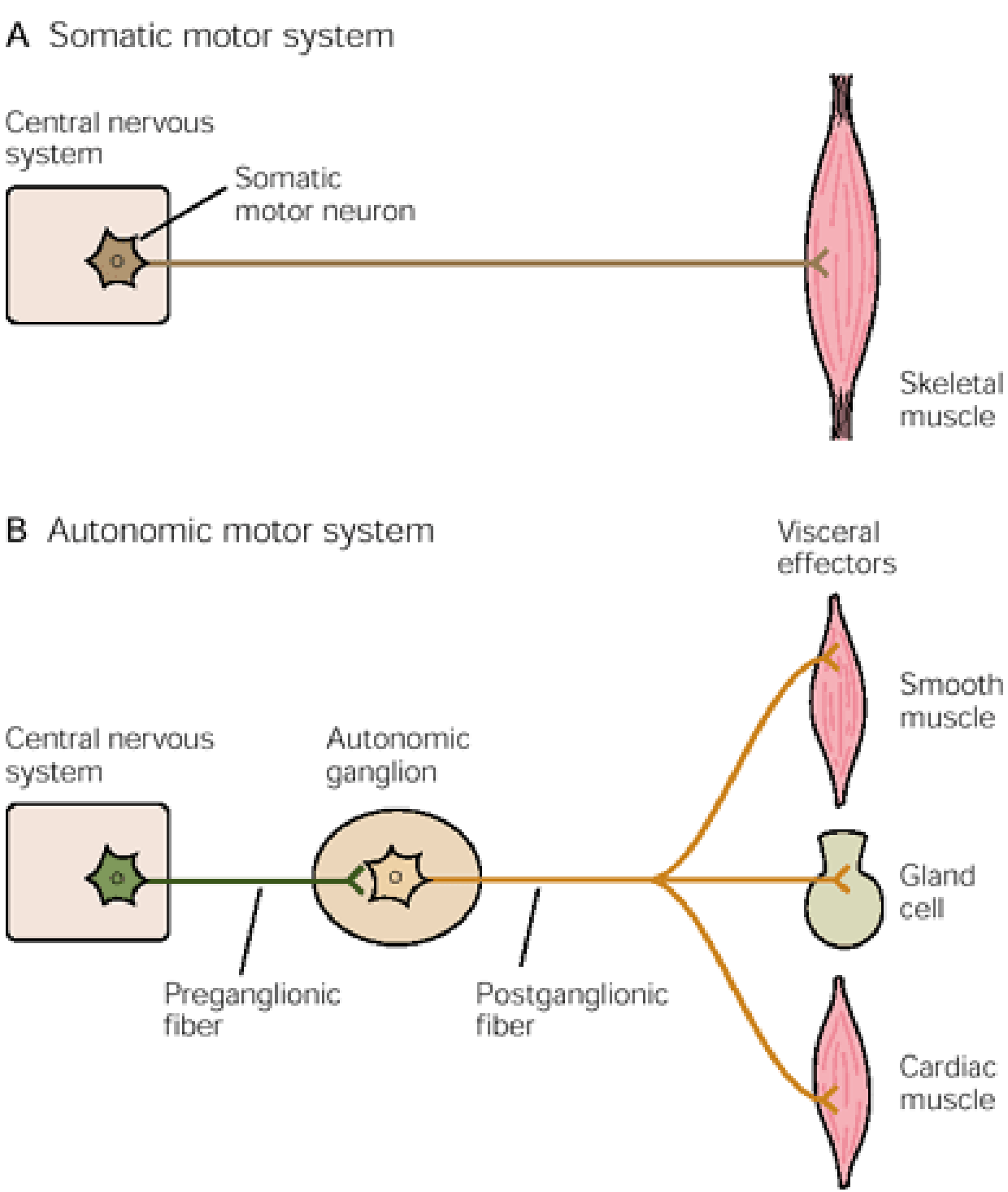
- For a person to respond effectively

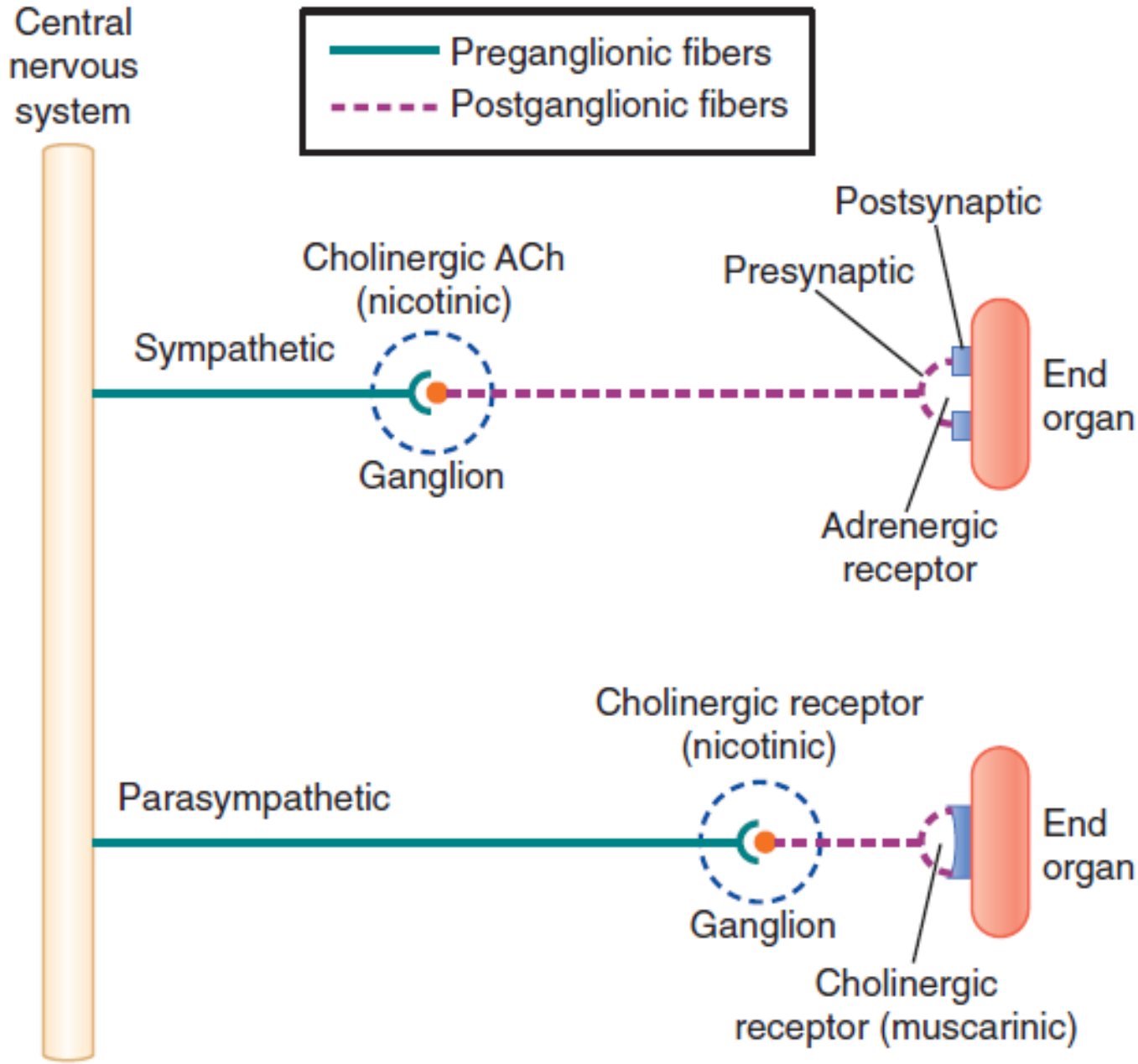
  the sympathetic nervous system increases

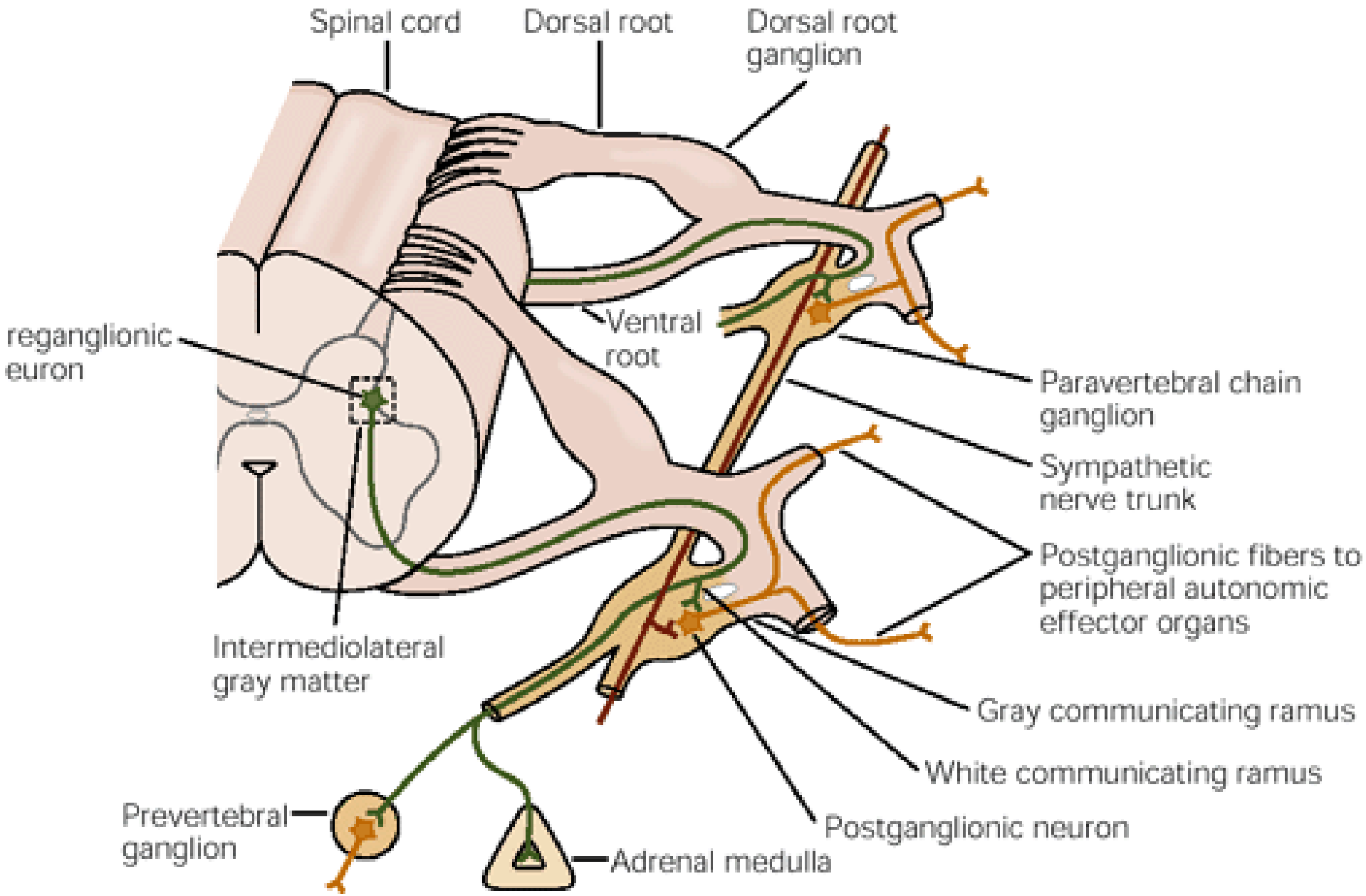
  – output to the heart and other viscera,

  – the peripheral vasculature and sweat glands,

  – and the piloerector and certain ocular muscles.


A Somatic motor system
Central nervous system
Somatic motor neuron
Skeletal muscle
B Autonomic motor system
Visceral effectors
Smooth muscle
Central nervous system
Autonomic ganglion
Gland cell
Preganglionic fiber
Postganglionic fiber
Cardiac muscle


Central nervous system
Preganglionic fibers
Postganglionic fibers
Postsynaptic
Presynaptic
Cholinergic ACh (nicotinic)
Sympathetic
End organ
Ganglion
Adrenergic receptor
Cholinergic receptor (nicotinic)
Parasympathetic
End organ
Ganglion
Cholinergic receptor (muscarinic)


Spinal cord
Dorsal root
Dorsal root ganglion
reganglionic euron
Ventral root
Paravertebral chain ganglion
Sympathetic nerve trunk
Postganglionic fibers to peripheral autonomic effector organs
Intermediolateral gray matter
Gray communicating ramus
White communicating ramus
Postganglionic neuron
Prevertebral ganglion
Adrenal medulla

SYMPATHETIC NERVOUS SYSTEM

- 22 pairs of **Paravertebral ganglia**
- Ganglia connected to each other via nerve trunk
- Ganglia connected to Spinal nerves by ***rami communicantes***

- *White rami* – from each thoracolumbar segment, carry preganlionic myelinated fibres to ganglia
- *Grey rami* – carry postganglionic unmyelinated fibres back to the spinal nerves to be distributed to
- --Sweat glands
- *--Pilomotor muscles*
- *--Blood vessels of skeletal muscle and skin*
- Follows the course of spinal nerves or blood vessels or both

- Prevertebral ganglia
  - In abdomen and Pelvis
    - Celiac, Superior mesentric, Aorticorenal and Inferior mesentric
- Terminal ganglia
  - Lie near the organs- Urinary bladder, Rectum and
  - Cervical ganglia in the neck
  - Many sympathetic preganglionic fibers from 5^{th} to last thoracic segment pass through paravertebral ganglia –form Splanchnic nerves– Reach celiac ganglia and then synapse
  - Some pass directly to the Adrenal medulla
    - Post ganglionic fibers secrete epinephrine

Segments	Output Ganglia	Effectors	Effect (Neurotransmitter)
T1–T3	Superior cervical	Eye	Pupil dilation (NE)
		Salivary glands	Contraction of tarsal muscle (NE)
		Face sweat glands	Increase in salivary protein (NE)
		Blood vessels	Facial sweating (ACh)
		Pineal gland	Vasoconstriction (NE)
			Melatonin secretion (NE)
T1–T8	Stellate and upper thoracic (upper limb, and thoracic viscera)	Sweat glands	Sweating (ACh)
		Skin blood vessels	Skin vasoconstriction (NE) or vasodilation (NO)
		Piloerector muscles	Piloerection
		Muscle blood vessels	Muscle vasoconstriction (NE) or vasodilation
		Periosteum, bone	Bone marrow activation (NE)
		Heart	Cardiac stimulation (NE)
		Respiratory tract	Bronchodilation (NE)
T5–T12	Celiac	Abdominal viscera	Inhibition of GI motility
	Mesenteric	Blood vessels	Vasoconstriction
	Adrenal medulla	Endocrine cells	Renin secretion
			Glucagon secretion
			Epinephrine secretion
T10–L2	Lumbar paravertebral	Sweat glands	Sweating (ACh)
		Skin blood vessels	Skin vasoconstriction (NE) or vasodilation (NO?)
		Piloerector muscles	Piloerection
		Muscle blood vessels	Muscle vasoconstriction (NE) or vasodilation
T2–L2	Inferior mesenteric Hypogastric	Pelvic viscera and blood vessels	Urine storage
			Rectal inhibition
			Ejaculation

- Post ganglionic fibers supply visceral structures of thorax, abdomen, head and neck.
- The trunk and limbs get their sympathetic supply in spinal nerves
- Many of upper thoracic sympathetic fibers from vertebral ganglia form terminal plexuses like Cardiac, Esophageal and Pulmonary
- Head and Neck – Cervical sympathetic chain and its three ganglia
  - All preganglionic fibers arise from upper thoracic segments

Parasympathetic System

- Cranial component
  - Supply Sphincter of Iris
  - Ciliary muscle
  - Salivary glands
  - Lacrimal glands
  - Mucous glands of nose , mouth and pharynx
- The Vagus nerve
  - supply viscera of thorax and abdomen
- Parasympathetic Sacral Outflow
  - Pelvic nerve→ Bladder, Rectum and Sex organs

- Axons of preganglionic neurons exit the spinal cord at the level at which their cell bodies are located,
- →*they may innervate sympathetic ganglia situated either above or below in the sympathetic nerve trunk that connects the ganglia*
- **Most of the preganglionic axons are relatively slow-conducting, small-diameter myelinated fibers.**
- Each preganglionic fiber forms synapses with many postganglionic neurons in different ganglia, the ratio
- 1:10 →Divergence →coordinated activity in sympathetic neurons at several different spinal levels

- *The axons of postganglionic neurons - unmyelinated* → Exit the ganglia in the *gray rami*.
- *The postganglionic cells innervateing the* head are located in the superior cervical ganglion
- ***The axons of these cells travel along branches of the carotid arteries to their targets in the head.***
- The postganglionic fibers innervating the rest of the body travel in spinal nerves to their targets;
- In an average spinal nerve, about *8% of the fibers are sympathetic postganglionic axons*.

- *Some neurons of the cervical and upper thoracic ganglia innervate cranial blood vessels, sweat glands, and hair follicles*

- others innervate the glands and visceral organs of the head and chest, lacrimal and salivary glands, heart, lungs, and blood vessels

- Neurons in the lower thoracic and lumbar paravertebral ganglia innervate peripheral blood vessels, sweat glands, and pilomotor smooth muscle

- Some preganglionic fibers pass through the sympathetic ganglia and branches of the splanchnic nerves to synapse on neurons of the *prevertebral ganglia*- the coeliac ganglion and the superior and inferior mesenteric ganglia

  - supply whole of the GIT and kidneys, bladder, and genitalia.

- Another group of preganglionic axons runs in the thoracic splanchnic nerve into the abdomen and innervates the adrenal medulla.

- The central, preganglionic cells of the parasympathetic nervous system are located in several brain stem nuclei and in segments S2-S4 of the sacral spinal cord
- The axons of these cells are long→ parasympathetic ganglia lie close to or embedded in visceral target organs.
- The preganglionic parasympathetic nuclei in the brain stem –
- Edinger-Westphal nucleus
- Superior and inferior salivary Nuclei
- Dorsal vagal nucleus and the nucleus ambiguus

- Preganglionic axons exit the brain stem through cranial nerves III, VII, and IX → postganglionic neurons in the ciliary, pterygopalatine, submandibular, and otic ganglia

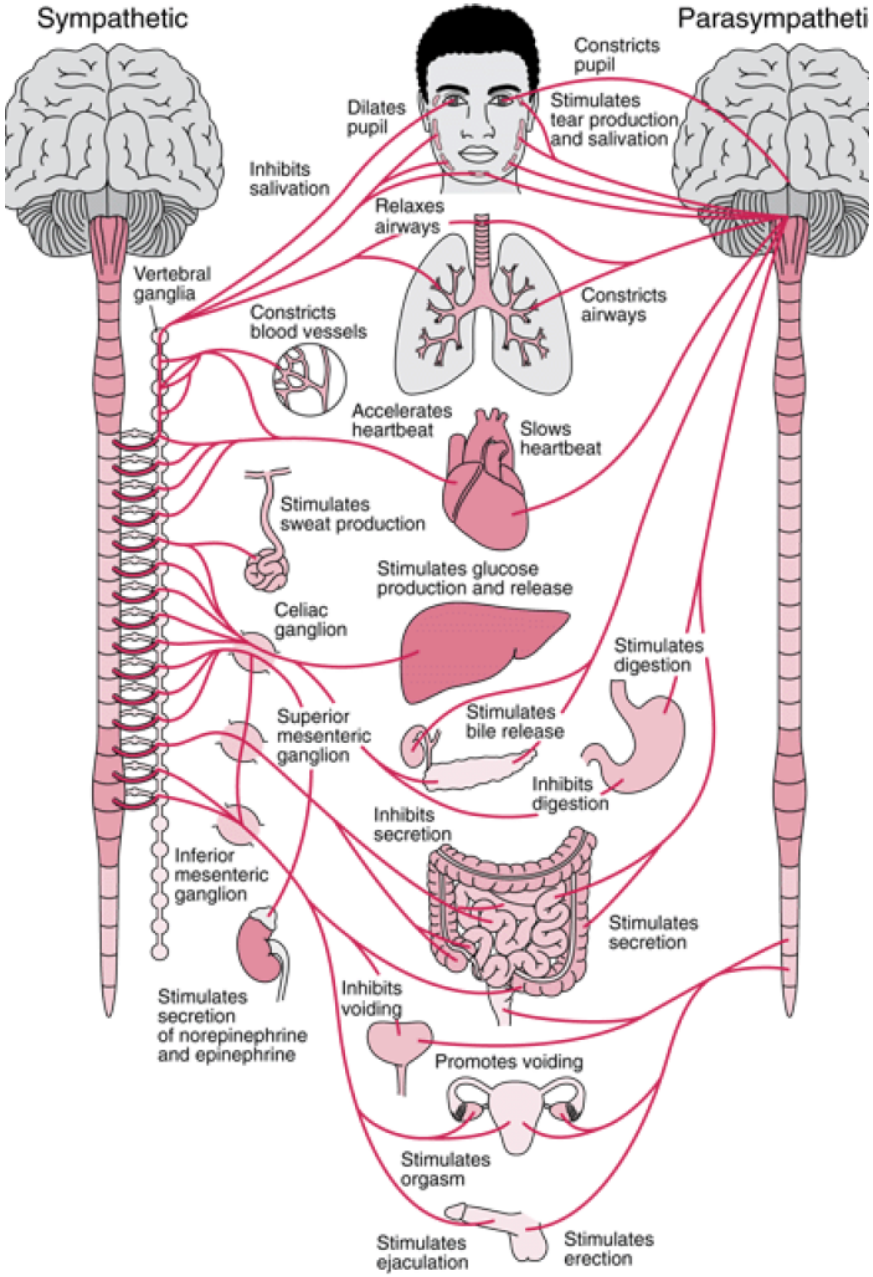
- From the dorsal vagal nucleus→ nerve X to postganglionic neurons in -- stomach, liver, gall bladder, pancreas, and upper intestinal tract

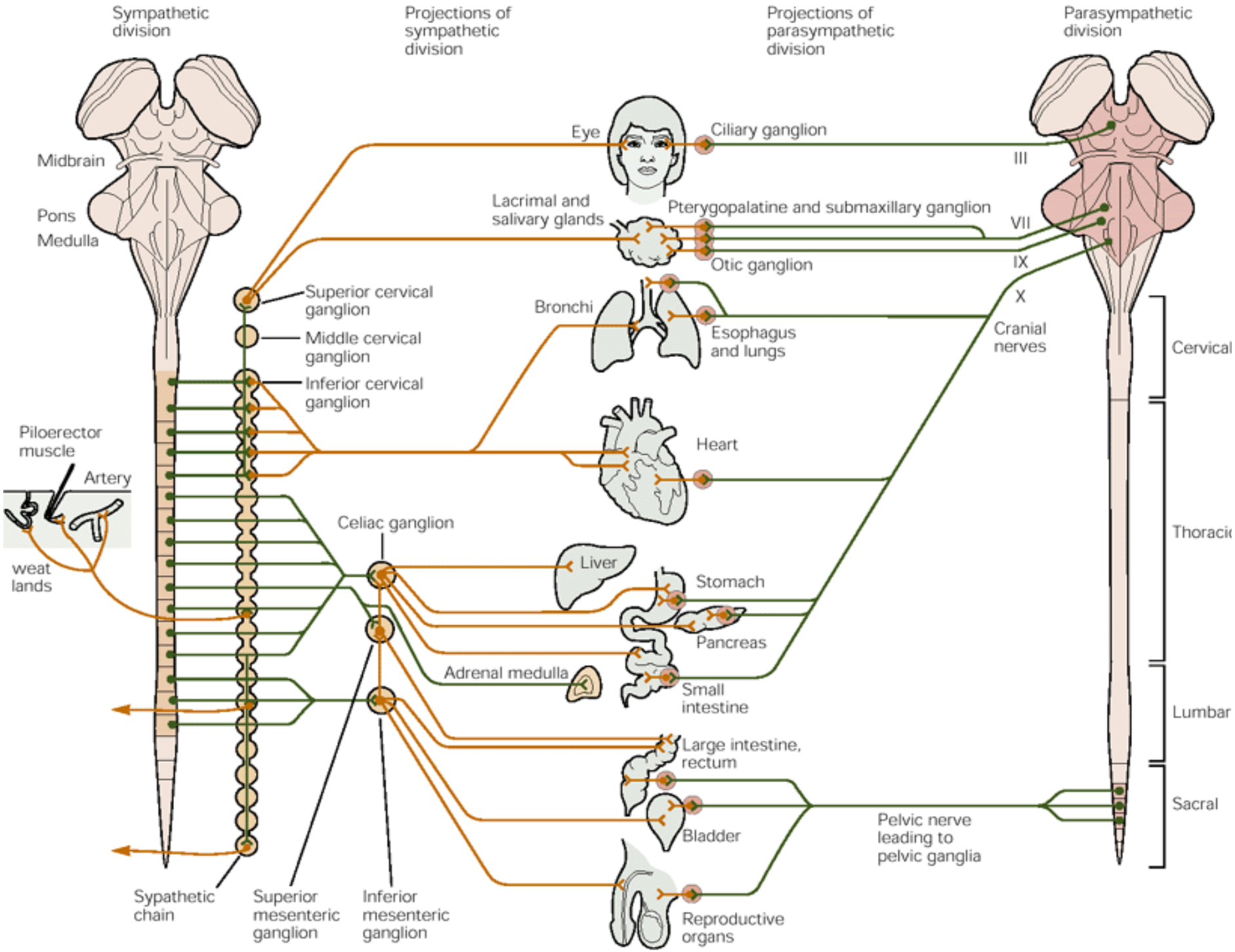
- Ventrolateral nucleus ambiguus →the principal parasympathetic innervation of the cardiac ganglia- which innervate the heart, esophagus, and respiratory airways.

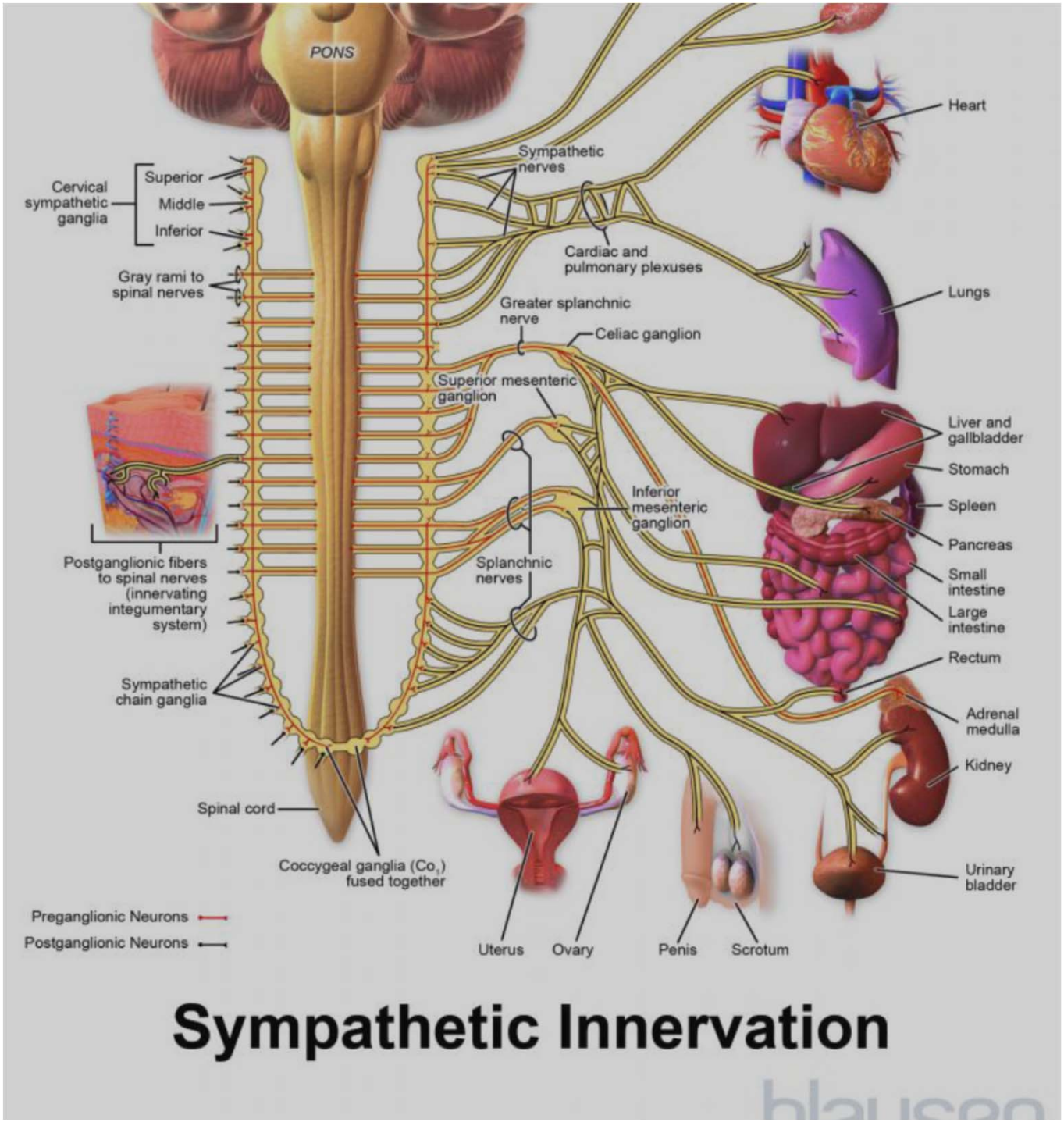
- In the sacral spinal cord -the parasympathetic preganglionic neurons are present in the intermediolateral column.

- Spinal parasympathetic nerves leave the spinal cord through the ventral roots → project in the pelvic nerve →pelvic ganglion plexus→ innervate the descending colon, bladder, and external genitalia

The autonomic nervous s

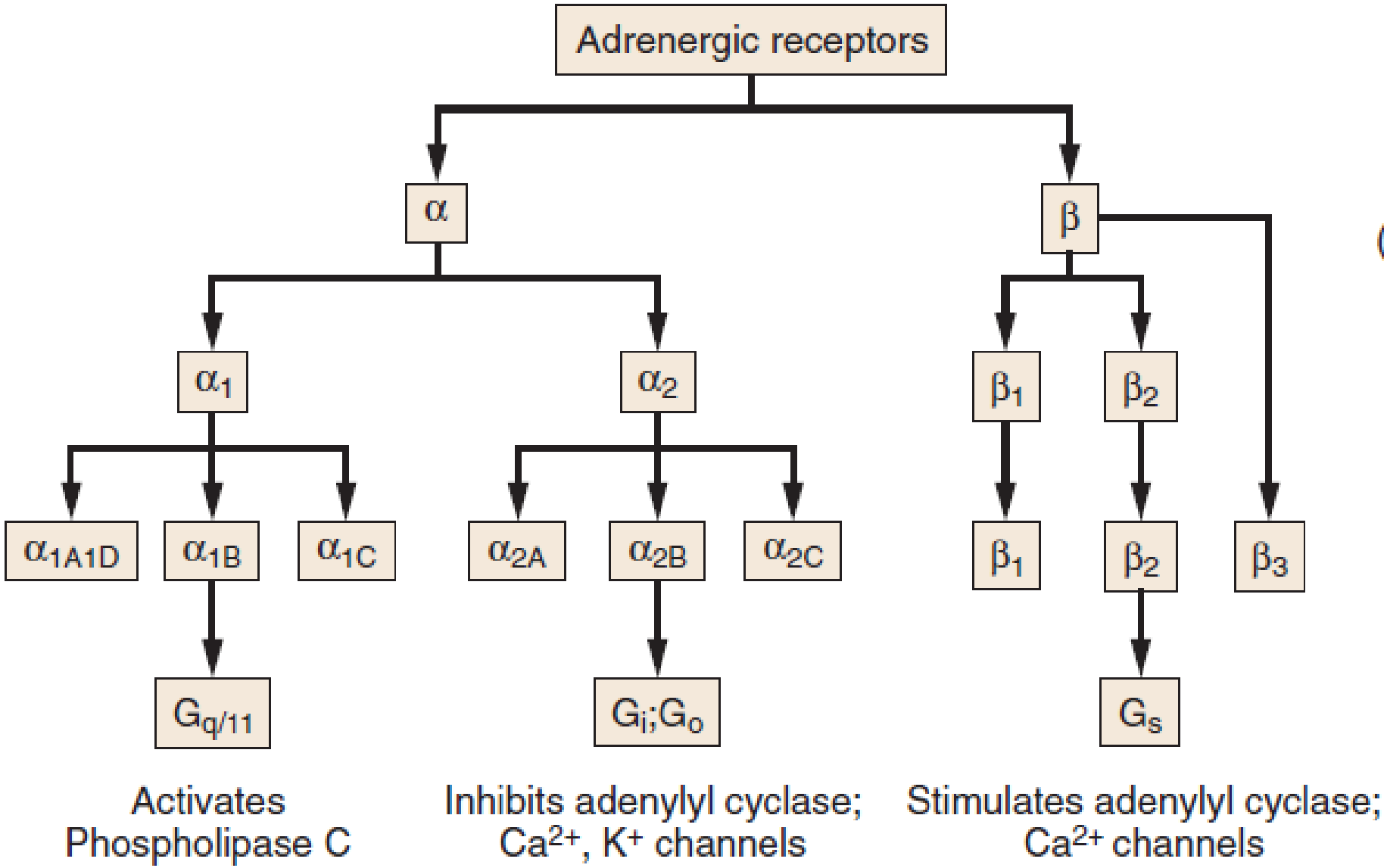



Sympathetic division
Projections of sympathetic division
Projections of parasympathetic division
Parasympathetic division
Midbrain
Pons
Medulla
Eye
Ciliary ganglion
III
Lacrimal and salivary glands
Pterygopalatine and submaxillary ganglion
VII
Otic ganglion
IX
X
Cranial nerves
Superior cervical ganglion
Middle cervical ganglion
Inferior cervical ganglion
Bronchi
Esophagus and lungs
Heart
Piloerector muscle
Artery
weat lands
Celiac ganglion
Liver
Stomach
Pancreas
Adrenal medulla
Small intestine
Large intestine, rectum
Bladder
Pelvic nerve leading to pelvic ganglia
Reproductive organs
Cervical
Thoracic
Lumbar
Sacral
Sypathetic chain
Superior mesenteric ganglion
Inferior mesenteric ganglion

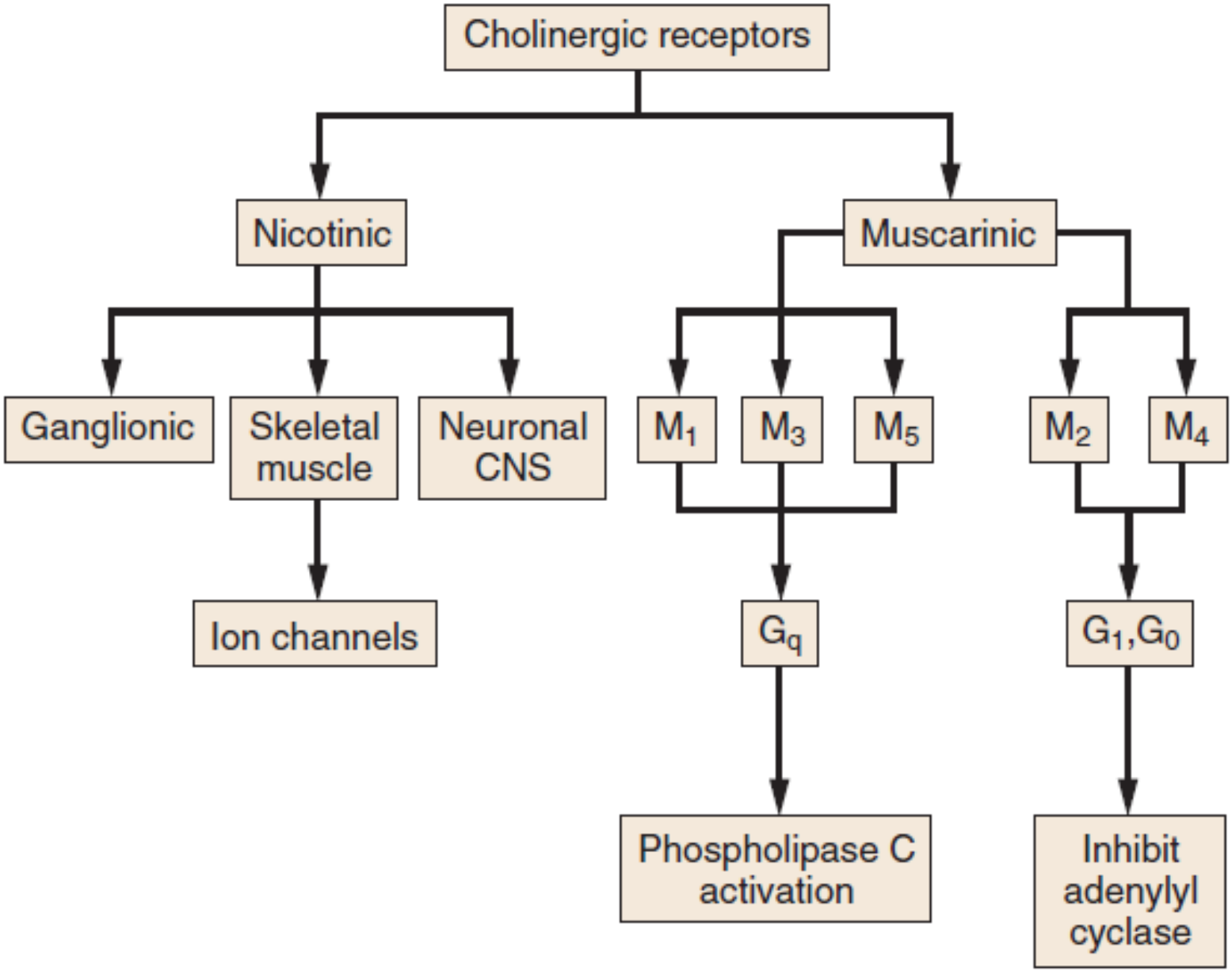


Sympathetic Innervation

RECEPTOR	EFFECTOR	RESPONSE TO STIMULATION
Sympathetic Nervous System		
α_1	Smooth muscle (vascular, iris radial, ureter, trigone, bladder sphincters)	Constriction
α_2	Presynaptic SNS nerve endings	Inhibition of NE release
	Brain	Neurotransmission
β_1	Heart	Increase rate, contractility, conduction
	Adipose tissue	Lipolysis
β_2	Blood vessels	Dilation
	Bronchioles	Dilation
	Kidney	Renin secretion
	Liver	Gluconeogenesis, glycogenolysis
	Endocrine pancreas	Insulin secretion
	Uterus	Relaxation
D_1	Blood vessels	Dilation
D_2	Presynaptic SNS nerve endings	Inhibition of NE release


Adrenergic receptors
α
β
α1
α2
β1
β2
α1A1D
α1B
α1C
α2A
α2B
α2C
β1
β2
β3
Gq/11
Gi;Go
Gs
Activates Phospholipase C
Inhibits adenylyl cyclase; Ca2+, K+ channels
Stimulates adenylyl cyclase; Ca2+ channels

Parasympathetic Nervous System		
M_1	Skeletal prejunctional nerve endings	Facilitate ACh release
M_2	Lung–presynaptic PNS nerve endings	Inhibits ACh release
	Visceral organs	Increase
M_3	Lung smooth muscle, postsynaptic	Bronchoconstriction
N_1	PNS and SNS ganglion	Ganglionic blockade
N_2	Skeletal muscle	Muscle contraction


Cholinergic receptors
Nicotinic
Muscarinic
Ganglionic
Skeletal muscle
Neuronal CNS
M1
M3
M5
M2
M4
Ion channels
Gq
G1,G0
Phospholipase C activation
Inhibit adenylyl cyclase

ORGAN SYSTEM	EFFECTOR	SNS STIMULATION	PNS STIMULATION
Cardiovascular	Sinoatrial node	Increase heart rate	Decrease heart rate
	Atrioventricular node	Increase conduction velocity	Decrease conduction velocity
	His-Purkinje fiber	Increase automaticity, conduction	None or minimal
	Myocardial tissue	Increase contractility	None or minimal
	Coronary arterioles	Constriction (α_2), Dilation (β_2)	Dilation and constriction
Gastrointestinal	Salivary glands	Little increase in secretion	Stimulates secretion
	Gall bladder	Relaxation	Contraction
	Smooth muscle	Inhibits	Stimulates
	Sphincters	Constricts	Relaxes
Ophthalmologic	Iris	Mydriasis	Miosis
	Ciliary muscle	Relaxation (for far vision)	Contraction (for near vision)
Pulmonary	Bronchial smooth muscle	Relaxation	Contraction
Genitourinary	Bladder walls	Relaxes smooth muscle	Smooth muscle contraction
	Bladder sphincter	Contraction	Relaxation
	Ductus deferens, seminal vesicle, prostatic and uterine musculature	Contraction of smooth muscle	Vasodilation and erection
Thermal regulation	Blood vessels	Constriction	Dilation
	Sweat glands	Diaphoresis (postganglionic sympathetic fibers are cholinergic)	Little effect

Autonomic reflexes

- Thermogenesis reflex
- Baroreceptor reflex
- Chemoreceptor reflex
- Bainbridge reflex
- Bezold –Zarisch reflex
- Oculocardiac reflex
- Valsava maneuvre
- Cushing reaction

- The ANS receives input from parts of the CNS that process and integrate stimuli from the body and external environment.
- **Through direct projection to preganglionic neurons-**
  - Paraventricular nuclei of hypothalamus,
  - Nucleus of the solitary tract,
  - reticular formation,
  - Parabrachial nuclei
  - Ventrolateral Medulla,
  - Medullary Raphe
  - amygdala, hippocampus, and olfactory cortex.

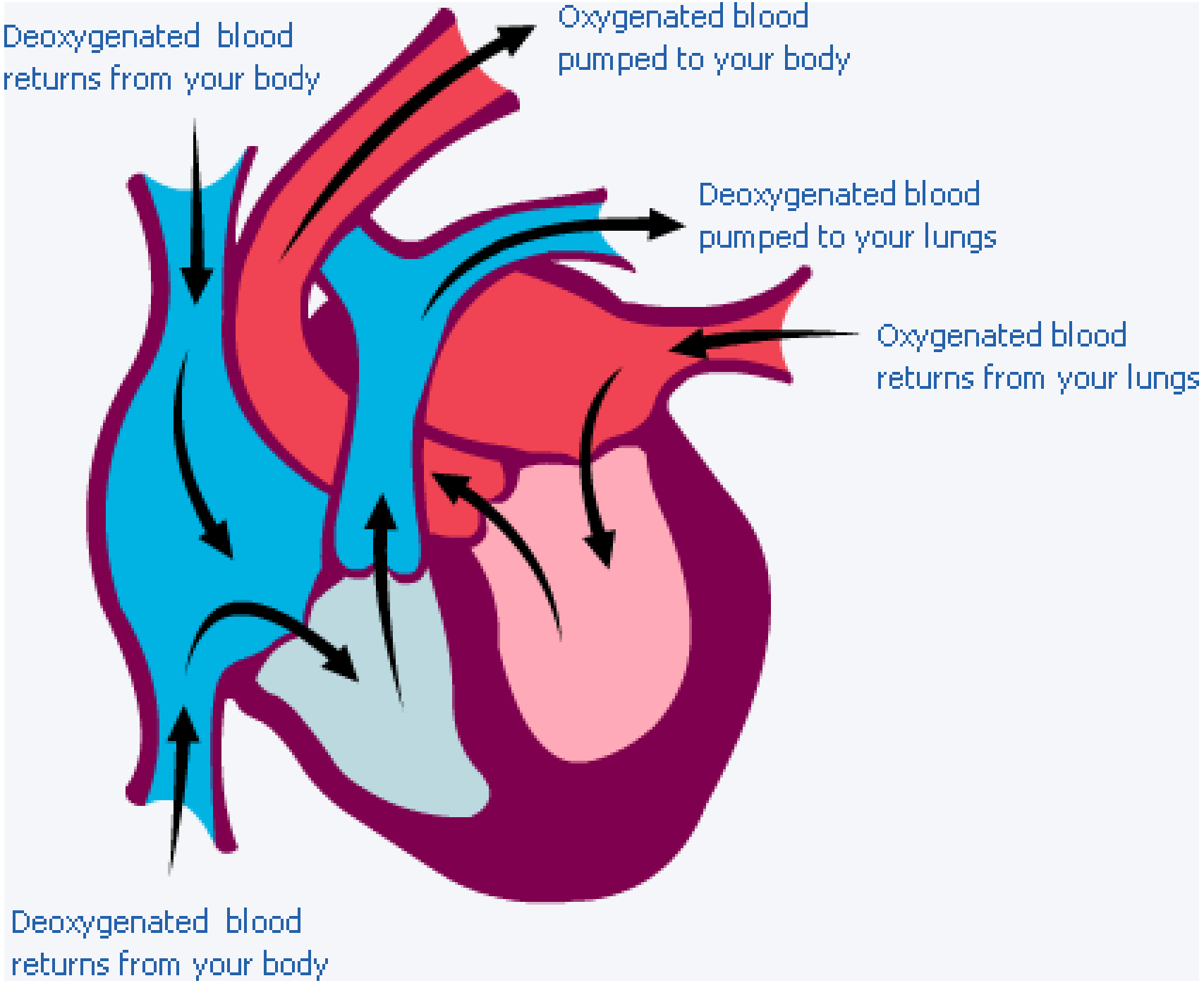
- **Through indirect Projections**:
  - Cerebral cortex
  - Amygdala
  - Periaqueductal grey Matter

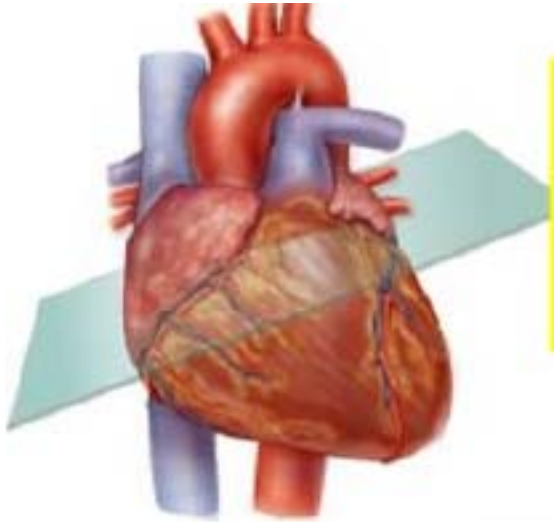
CARDIOVASCULAR SYSTEM

"It has been shown by reasons and experiments that blood by the beat of the ventricles flows through the lungs and heart and is pumped to the whole body... the blood in the animal body moves around in the circle continuously, and ..the action of the heart is to accomplish this by pumping. This is the only reason for the motion and beat of the heart."

-William Harvey (1628)

- Two pumps – Operating in series
- All four valves lie in a plane within a connective tissue skeleton which seperates atria and ventricle
- Mitral, tricuspid and aortic valves surround a fibrous triangle “ central fibrous tendon/body”


Deoxygenated blood returns from your body
Oxygenated blood pumped to your body
Deoxygenated blood pumped to your lungs
Oxygenated blood returns from your lungs
Deoxygenated blood returns from your body



The **fibrous skeleton** of the heart is located between the atria and the ventricles, and is formed from dense irregular connective tissue. It is <u>electrically non-conductive!</u>

Posterior

Right atrioventricular valve

Aortic semilunar valve

Openings to coronary arteries

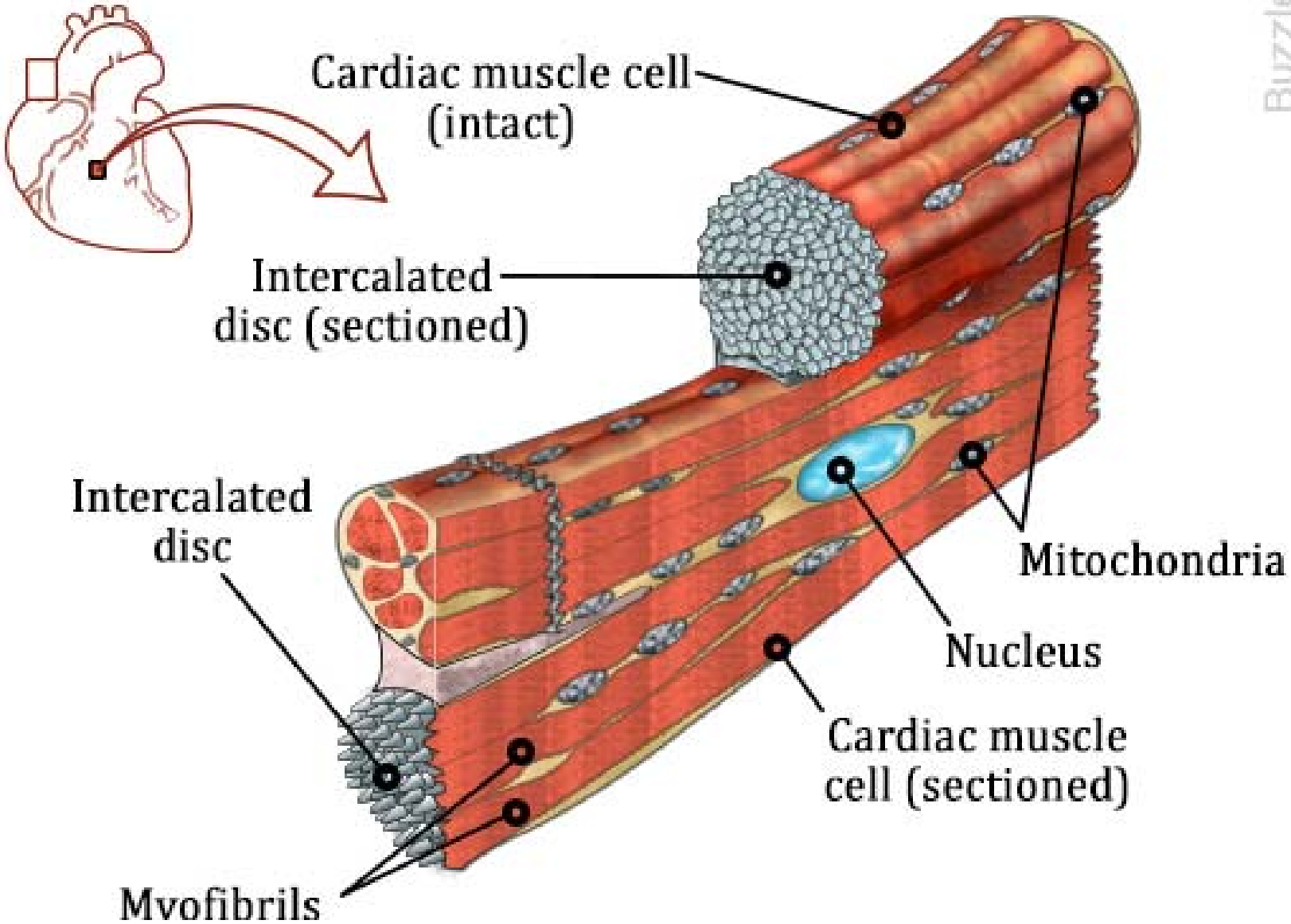
Pulmonary semilunar valve

Left atrioventricular valve

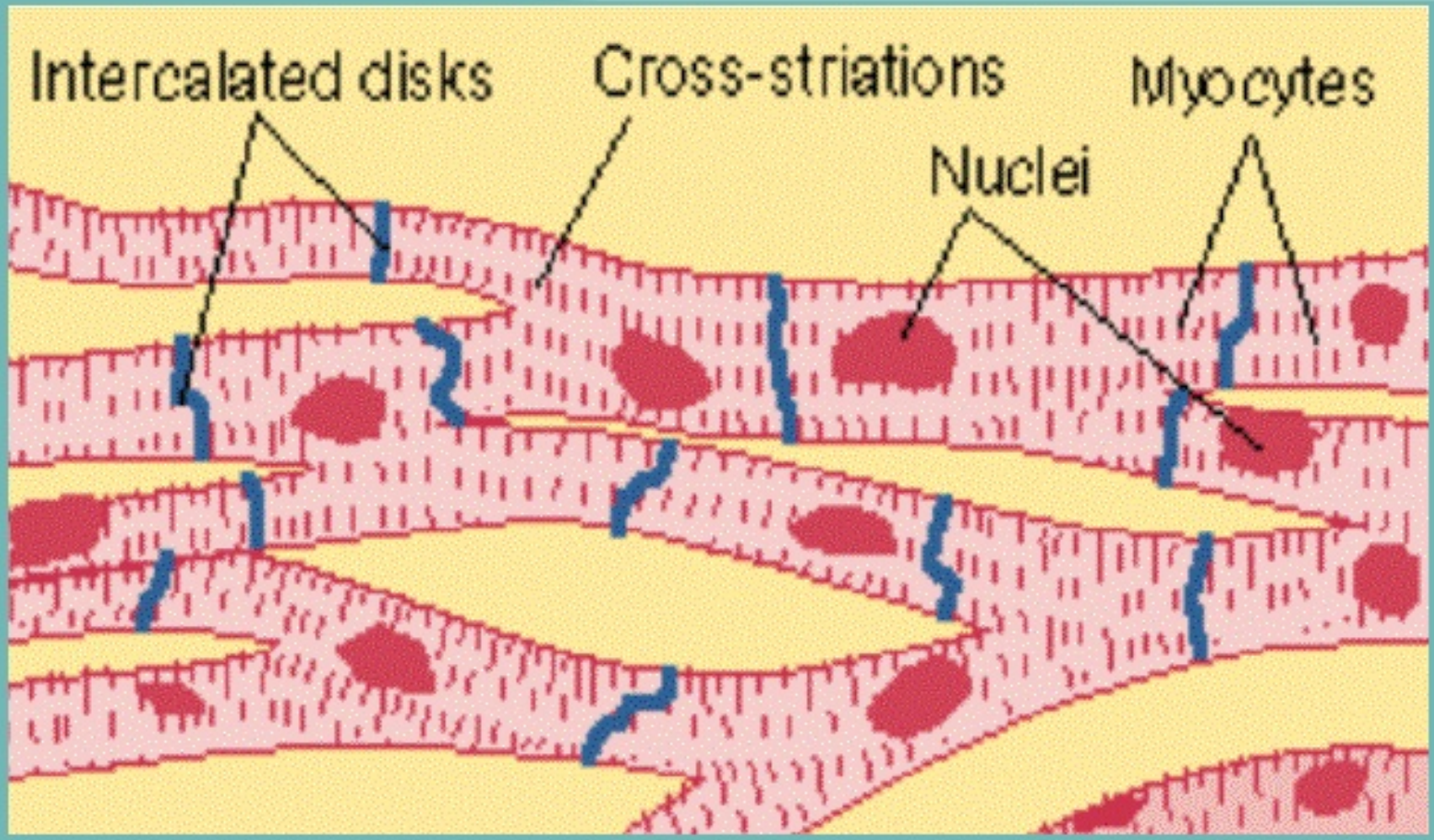
Fibrous skeleton

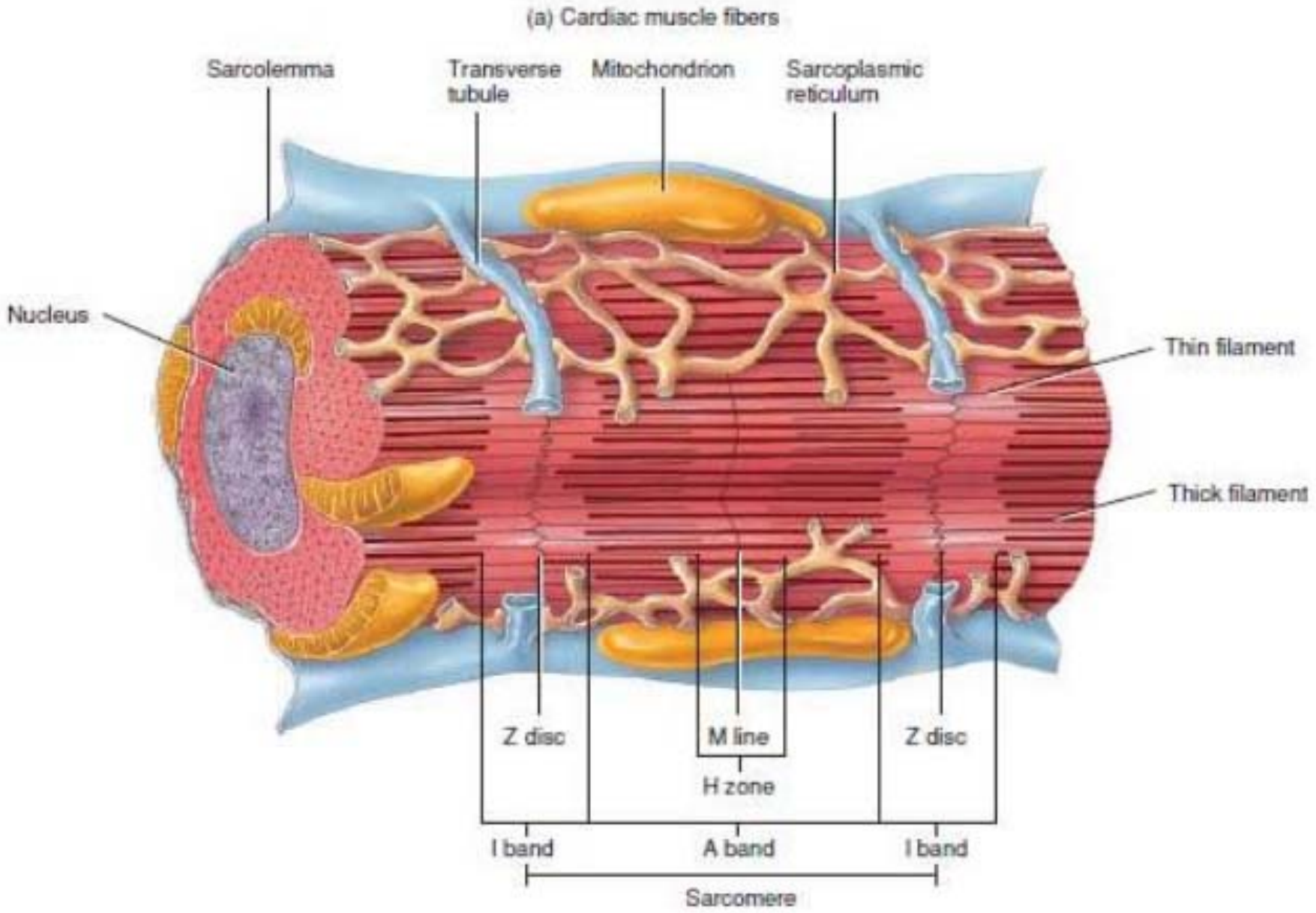
Anterior

Cardiac Muscle Cross Section



Cardiac Muscle




(a) Cardiac muscle fibers
Sarcolemma
Transverse tubule
Mitochondrion
Sarcoplasmic reticulum
Nucleus
Thin filament
Thick filament
Z disc
M line
Z disc
H zone
I band
A band
I band
Sarcomere

CARDIAC MUSCLE

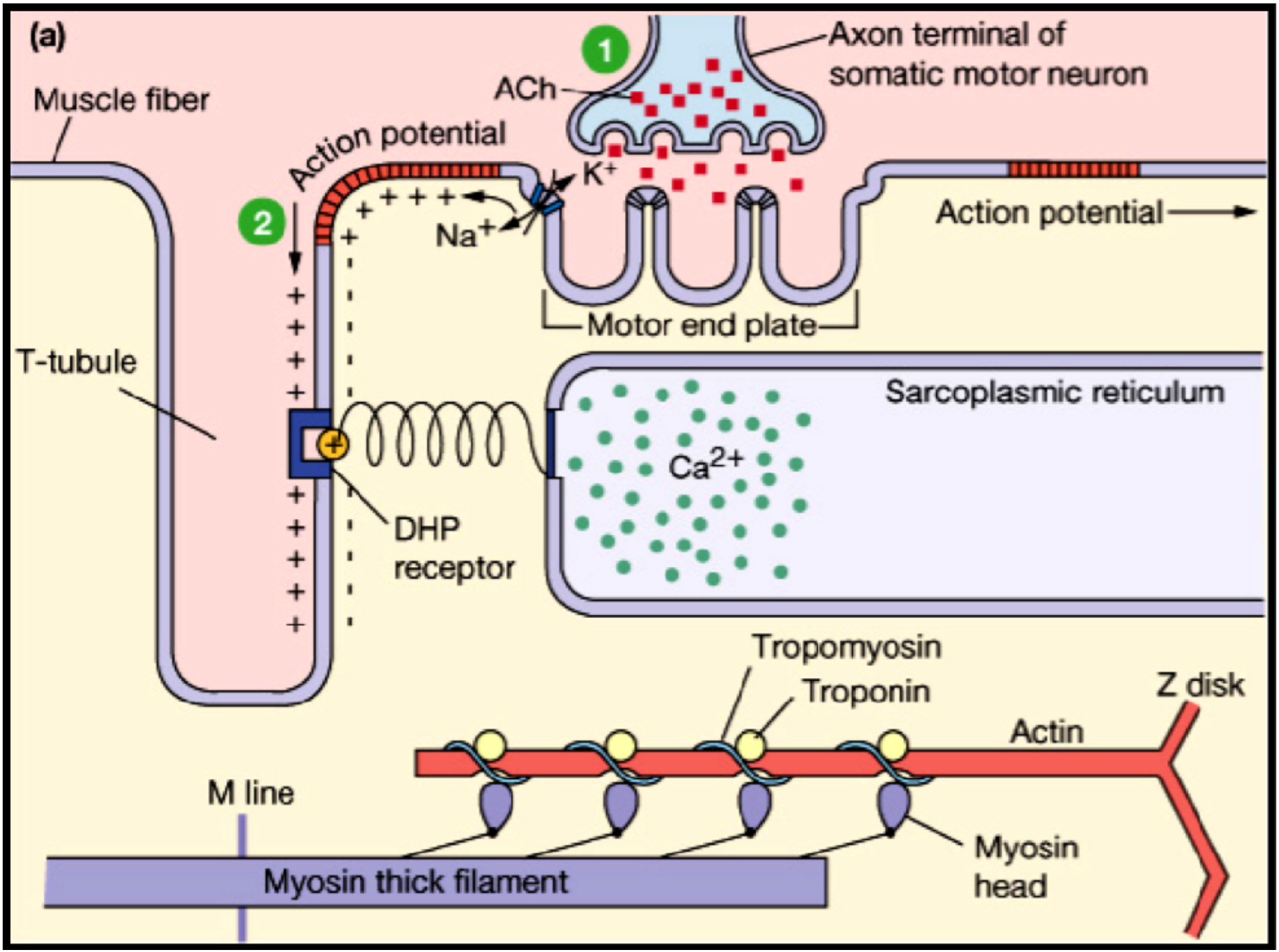
- **Epicardium**- A layer of squamous cells overlying a network of fibroelastic connective tissue .
- Continuous with inner layer of pericardium.
- **Endocarium –** A squamous cell layer, a mesh of collagen and elastic fibres and rudimentary smooth muscle.
- **Myocardium** – Cardiac myocytes,
  - 70% are non myocyte small cells like vascular smooth muscle, endothelial cells and fibroblasts.

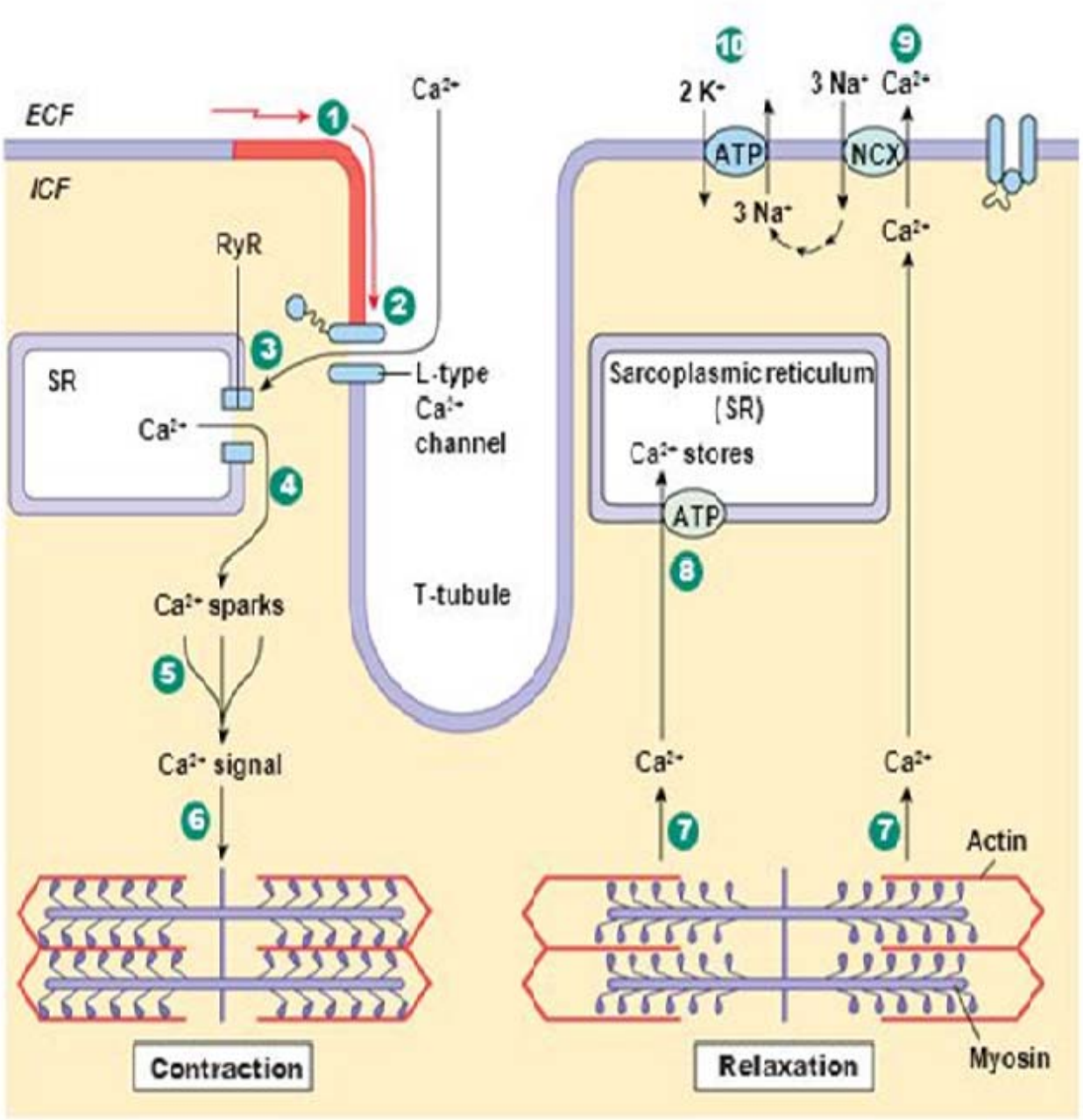
- **Fibroblast** – Secrete and maintain connective tissue → contribute to heart's tensile strength and stiffness.
- **Cardiac Myocytes**
  - **Working Myocytes-** Specialized contractile cardiac muscle
  - **Purkinje Fibres –** large pale, glycogen rich
  - Specialized for rapid conduction.
  - **Nodal cells –** Contain fewer myofilaments
    - **Round cells – P**robably the pacemakers
    - **Slender / Transitional cells –** conduct the impulse within the node and nodal margin

- Intercalated disc – Mechanical and electrical connection between cardiac muscle
- Mechanical _ fascia adherens
  - Sarcomeric actin is connected to cytoskeletal actin and desmosomes connecting intermediate filament
- Gap junction – least resistance for free diffusion of ions and small molecules

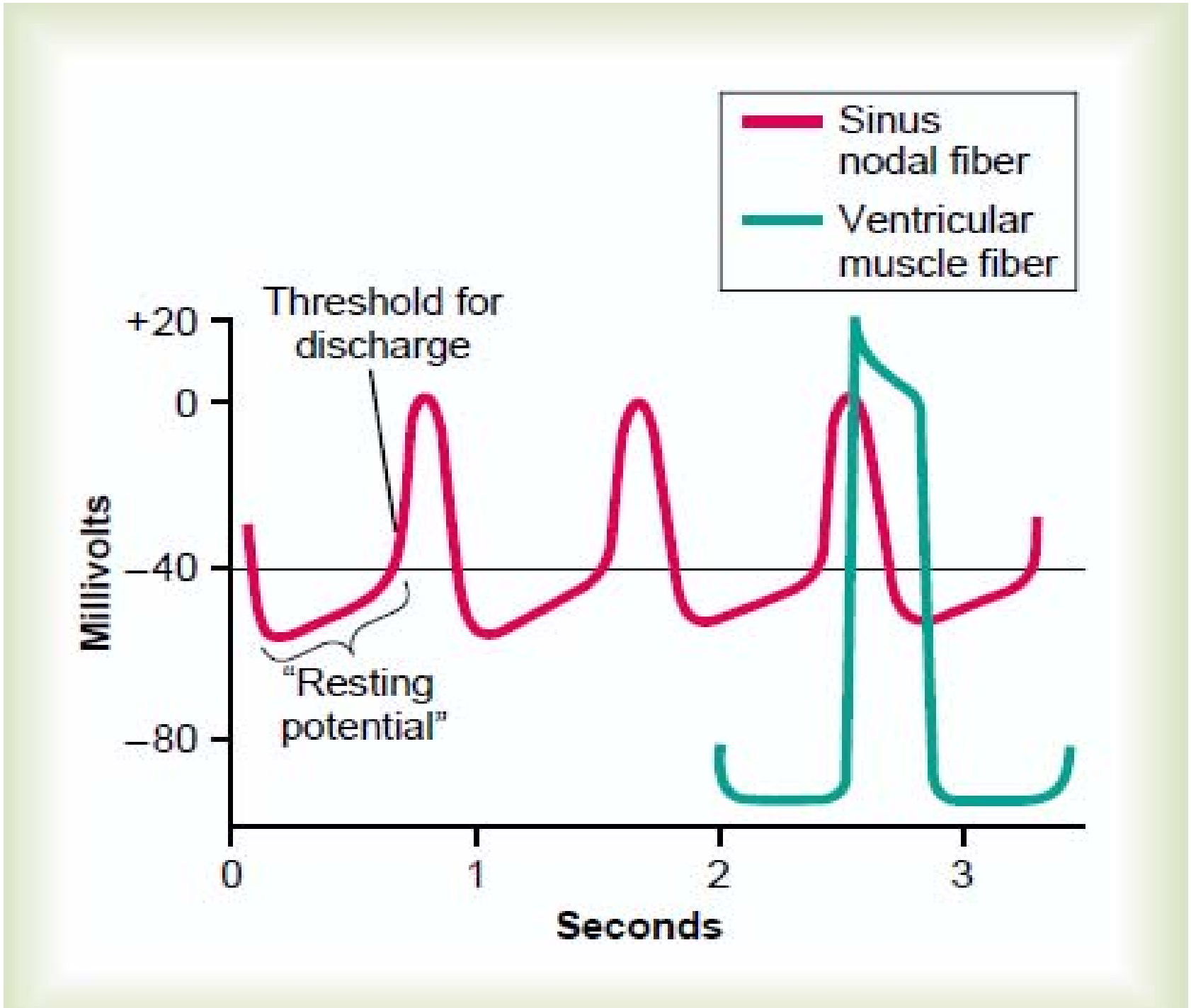
- Cardiac myocytes – depend on oxidatve metabolism for energy
- Conducting tissues – have developed anaerobic energy metabolism.

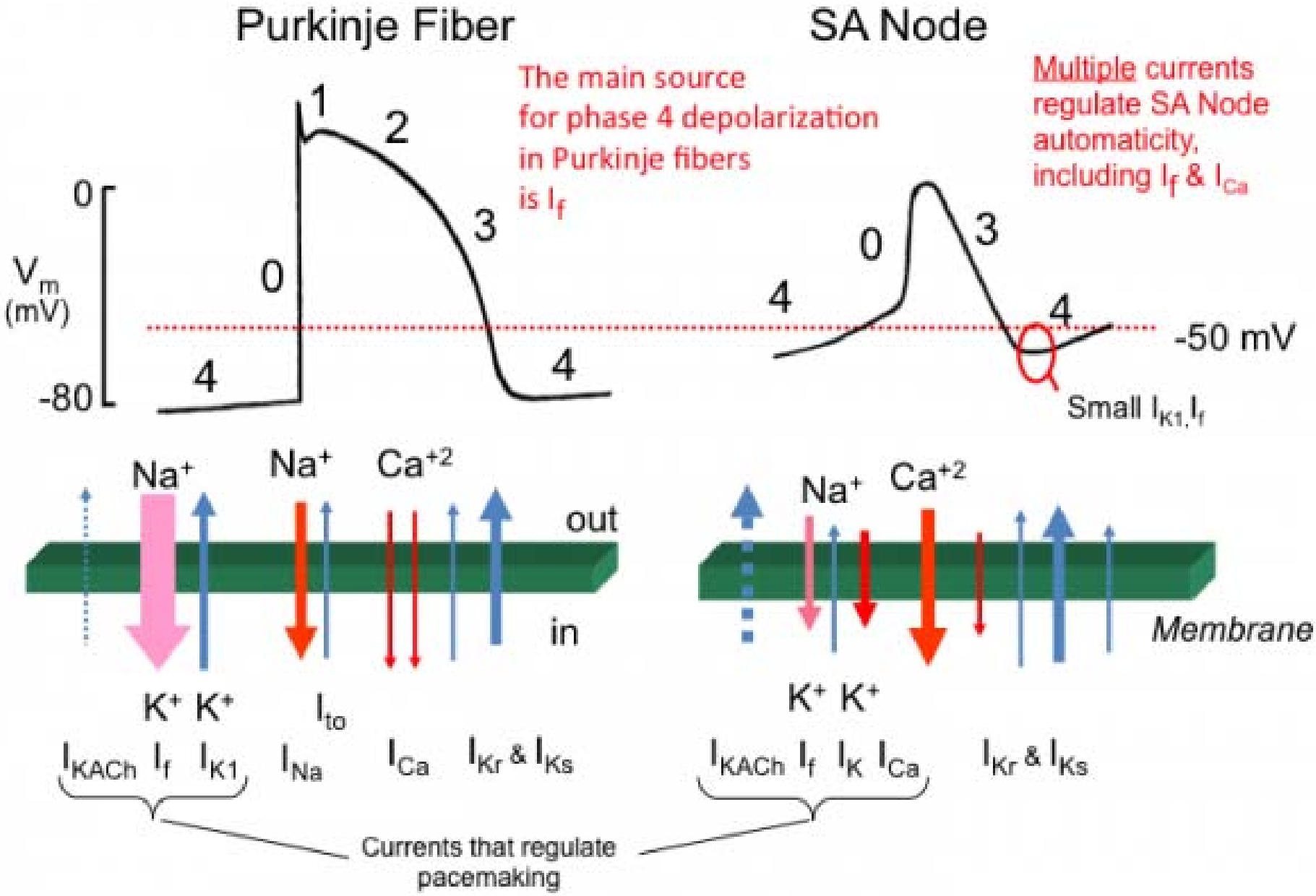
- Pace maker cells
- Overdrive suppression – due to overactivity of Na-K pump

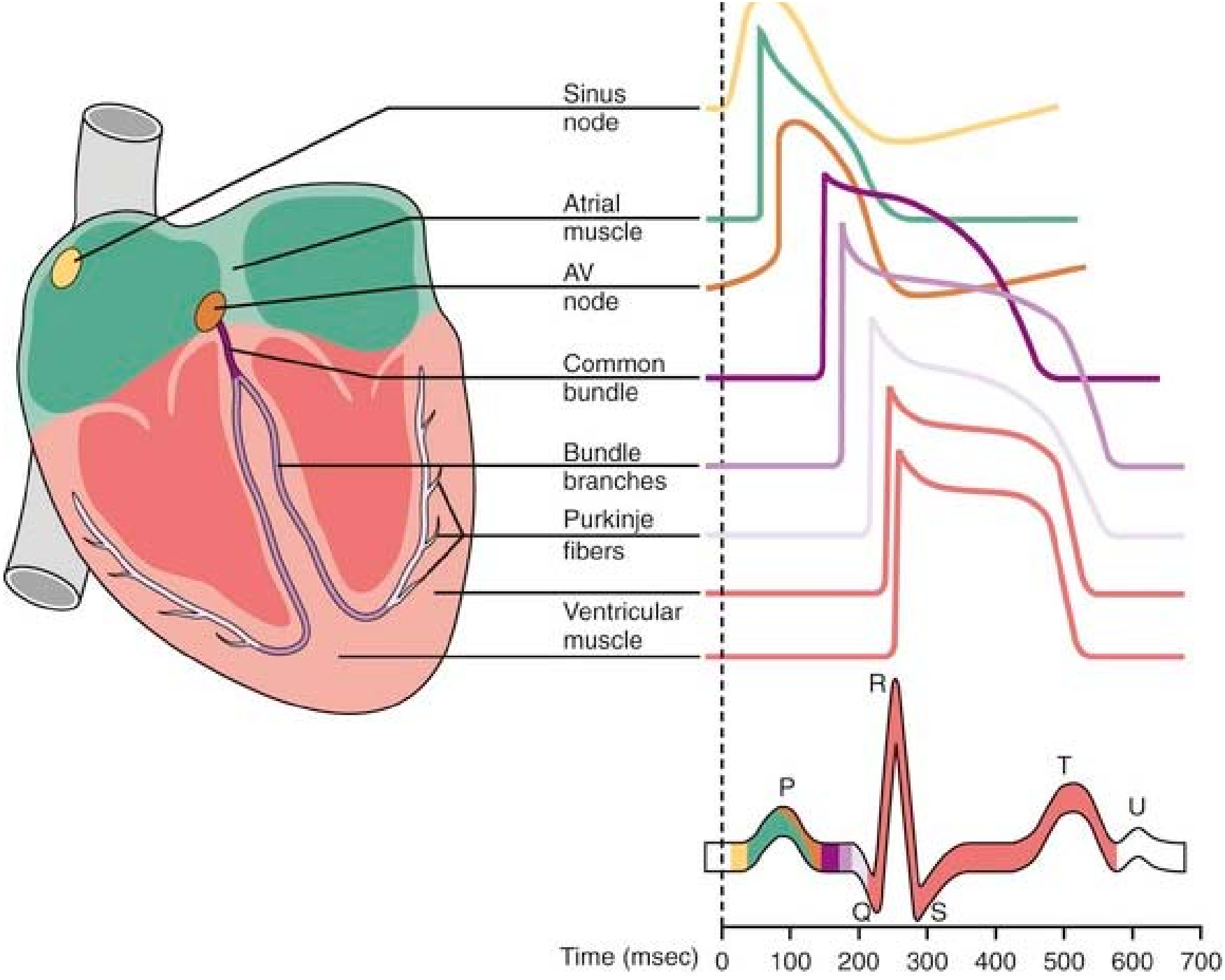

(a)
Muscle fiber
1
ACh
Axon terminal of somatic motor neuron
Action potential
2
K+
Na+
Action potential
Motor end plate
T-tubule
Sarcoplasmic reticulum
Ca2+
DHP receptor
Tropomyosin
Troponin
Z disk
Actin
M line
Myosin thick filament
Myosin head



1. Action potential enters from adjacent cell.
2. Voltage-gated Ca^{2+} channels open. Ca^{2+} enters cell.
3. Ca^{2+} induces Ca^{2+} release through ryanodine receptor-channels (RyR).
4. Local release causes Ca^{2+} spark.
5. Summed Ca^{2+} sparks create a Ca^{2+} signal.
6. Ca^{2+} ions bind to troponin to initiate contraction.
7. Relaxation occurs when Ca^{2+} unbinds from troponin.
8. Ca^{2+} is pumped back into the sarcoplasmic reticulum for storage.
9. Ca^{2+} is exchanged with Na^+ by the NCX antiporter.
10. Na+ gradient is maintained by the Na^+-K^+-ATPase.

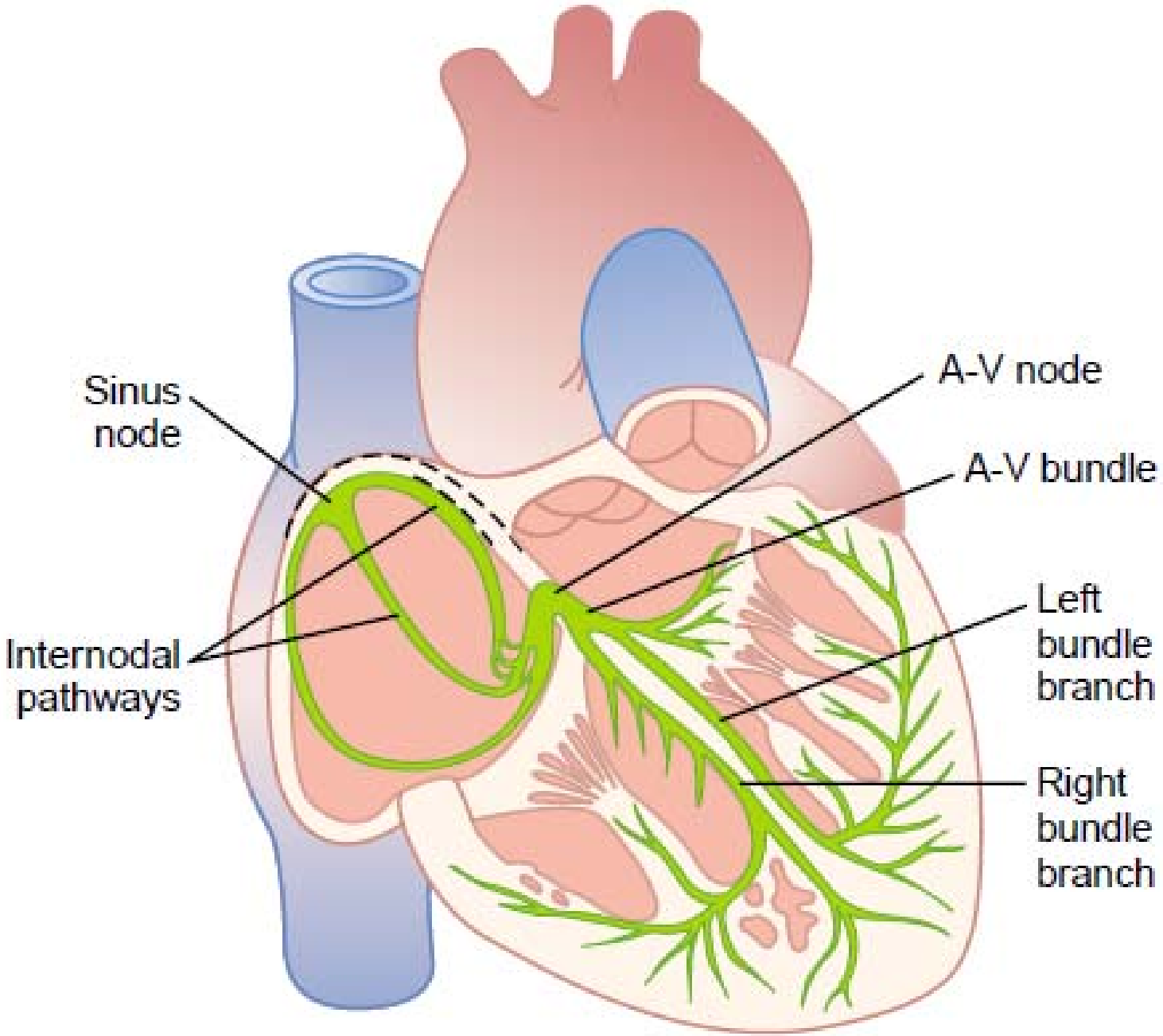

Sinus nodal fiber
Ventricular muscle fiber
Threshold for discharge
+20
0
−40
−80
Millivolts
"Resting potential"
0
1
2
3
Seconds

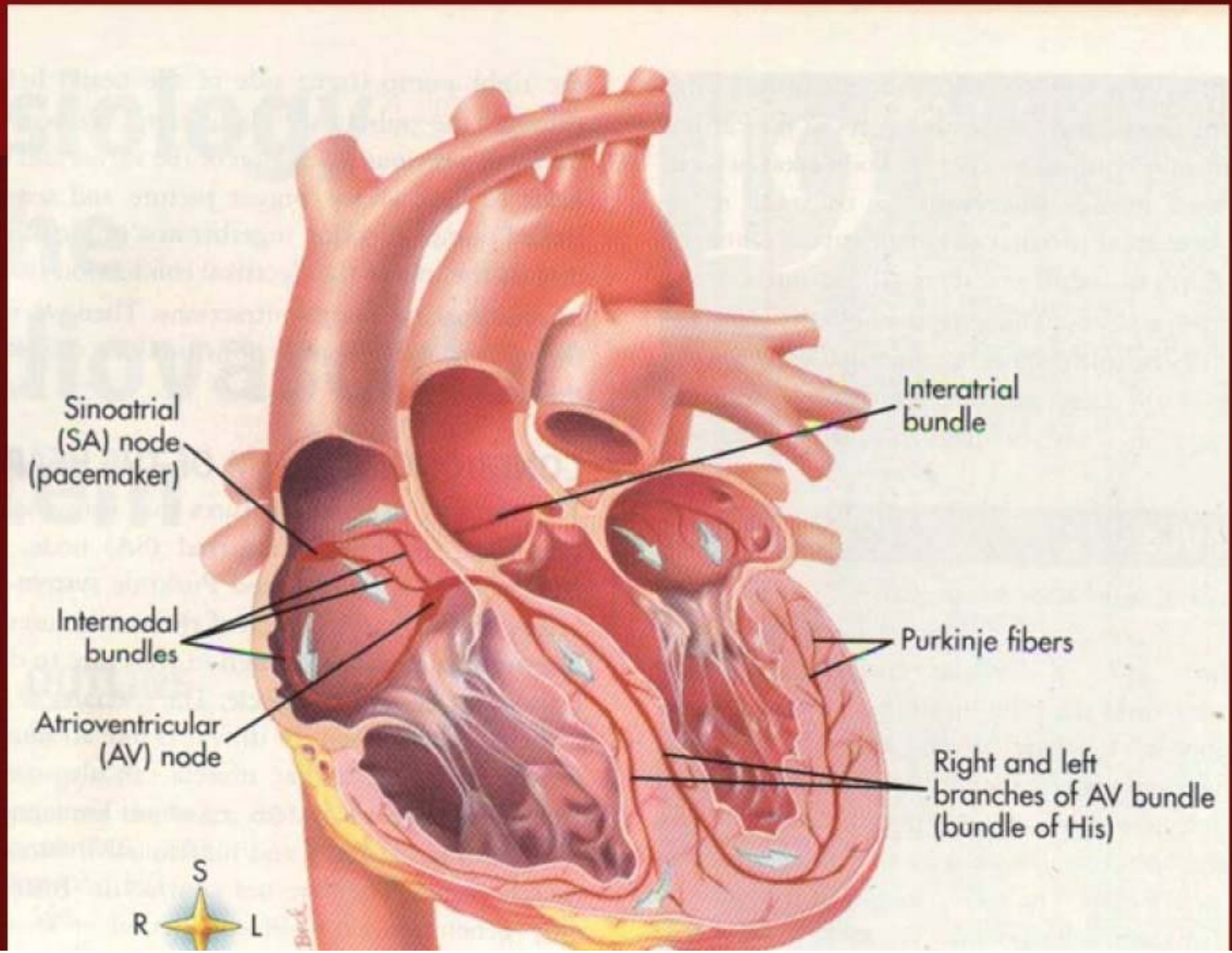

Purkinje Fiber
SA Node
The main source for phase 4 depolarization in Purkinje fibers is I_f
Multiple currents regulate SA Node automaticity, including I_f & I_{Ca}
V_m (mV)
0
-80
1
2
3
0
4
4
0
3
4
4
-50 mV
Small I_{K1}, I_f
Na^+
Na^+
Ca^{+2}
out
in
K^+ K^+
I_{to}
I_{KACh} I_f I_{K1}
I_{Na}
I_{Ca}
I_{Kr} & I_{Ks}
Na^+
Ca^{+2}
Membrane
K^+ K^+
I_{KACh} I_f I_K I_{Ca}
I_{Kr} & I_{Ks}
Currents that regulate pacemaking

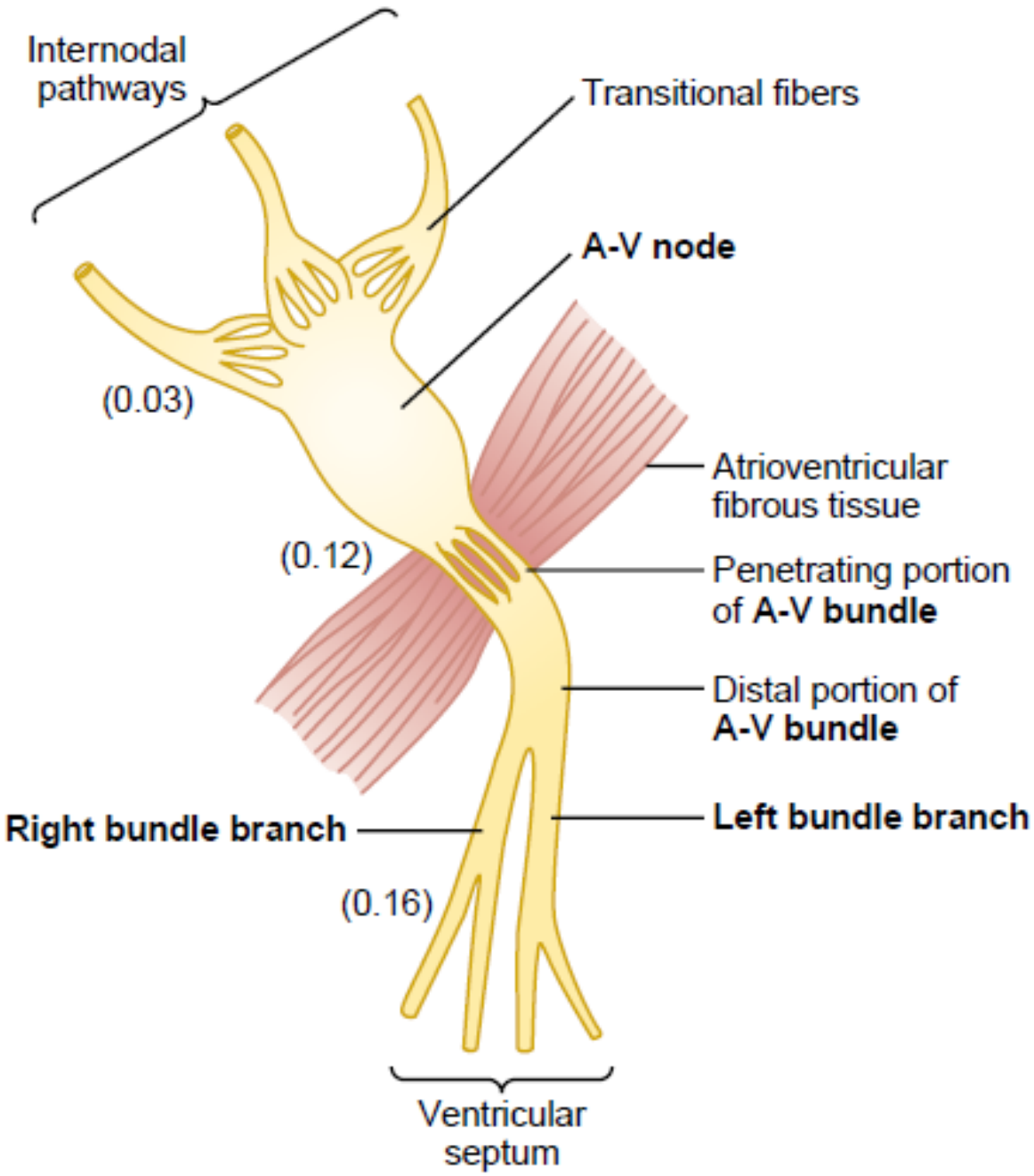

Sinus node
Atrial muscle
AV node
Common bundle
Bundle branches
Purkinje fibers
Ventricular muscle
R
P
T
U
Q
S
Time (msec)
0
100
200
300
400
500
600
700

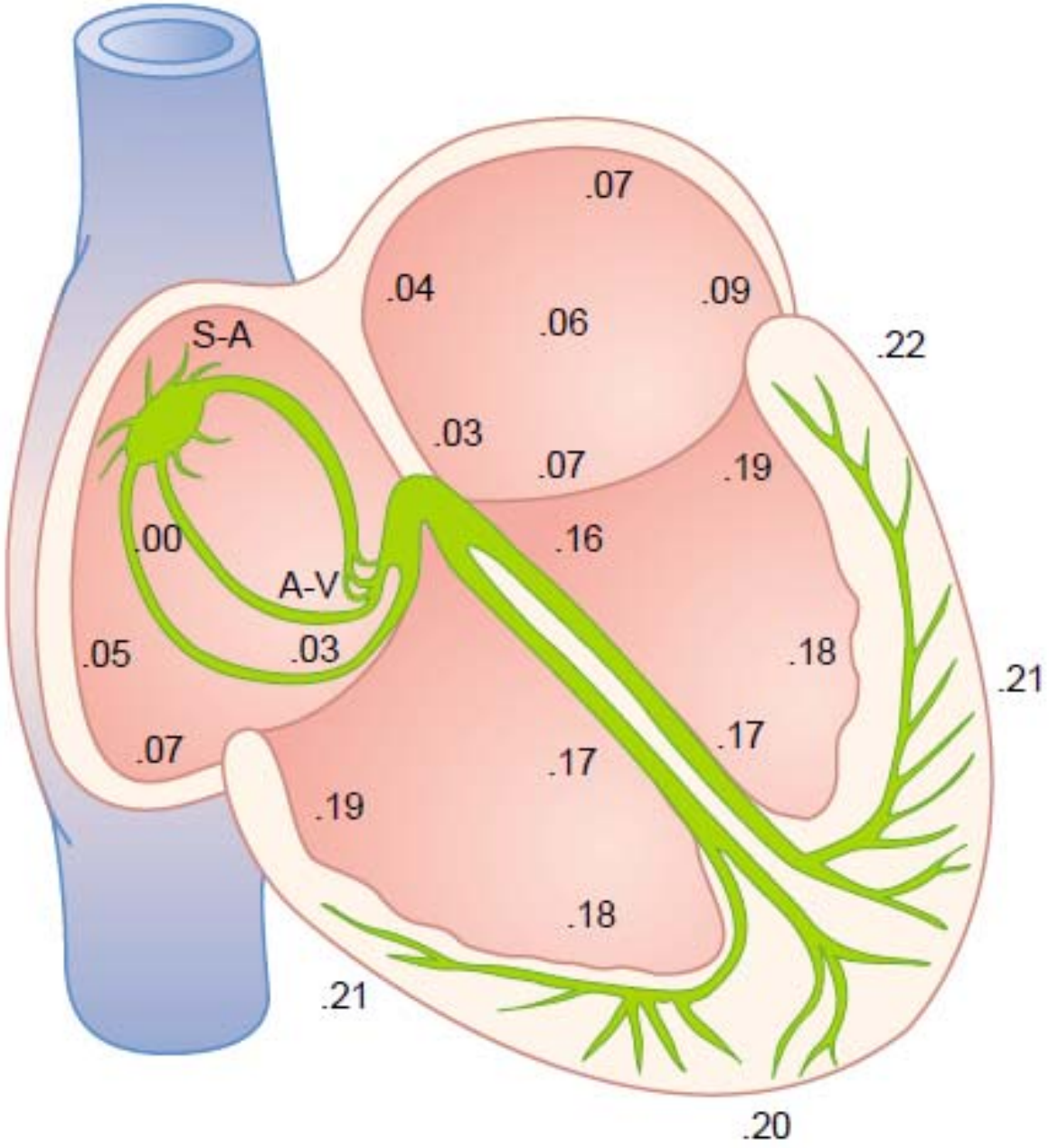
CHANNEL	CHARACTERISTICS
Sodium Channels	
Fast Na^+	Phase 0 depolarization of non-pacemaker cardiac action potentials
Slow Na^+	"Funny" pacemaker current (I_f) in cardiac nodal tissue
Potassium Channels	
Inward rectifier (I_{ir} or I_{K1})	Maintains phase 4 negative potential in cardiac cells and contributes to late repolarization
Transient outward (I_{to})	Contributes to phase 1 of non-pacemaker cardiac action potentials
Delayed rectifier (I_{Kr})	Phase 3 repolarization of cardiac action potentials
ATP-sensitive ($I_{K, ATP}$)	K_{ATP} channels; inhibited by ATP; therefore, open when ATP decreases during hypoxia; in vascular smooth muscle, adenosine removes the ATP inhibition and opens these channels, producing hyperpolariation and vasodilation.

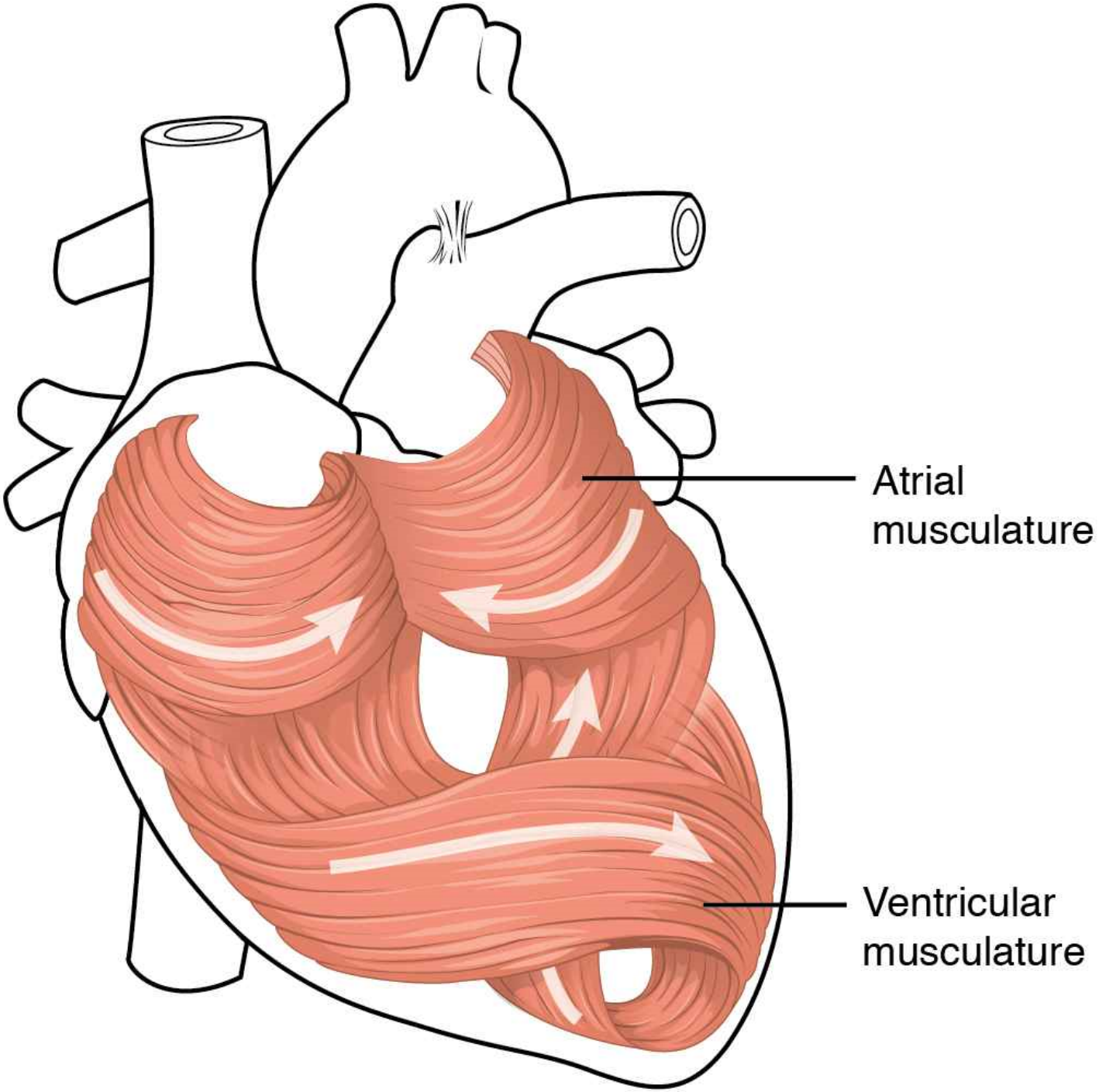
Acetylcholine-activated ($I_{K,ACh}$)	Activated by acetylcholine; Gi-protein coupled
Calcium-	
ıctivated ($I_{K,}$ $_{Ca}$ or BK_{Ca})	Open in response to Ca^{++} influx in vascular smooth muscle
Calcium Channels	
L-type (I_{Ca-L})	Slow inward, long-lasting current; phase 2 non-pacemaker cardiac action potentials and late phase 4 and phase 0 of SA and AV nodal cells; important in vascular smooth muscle contraction
T-type (I_{Ca-T})	Transient current that contributes to early phase 4 pacemaker currents in SA and AV nodal cells


Sinus node
A-V node
A-V bundle
Internodal pathways
Left bundle branch
Right bundle branch


Sinoatrial (SA) node (pacemaker)
Interatrial bundle
Internodal bundles
Purkinje fibers
Atrioventricular (AV) node
Right and left branches of AV bundle (bundle of His)
S
R
L


Internodal pathways
Transitional fibers
A-V node
(0.03)
Atrioventricular fibrous tissue
(0.12)
Penetrating portion of A-V bundle
Distal portion of A-V bundle
Right bundle branch
Left bundle branch
(0.16)
Ventricular septum


.07
.04
.09
.06
S-A
.22
.03
.07
.19
.00
.16
A-V
.05
.03
.18
.21
.07
.17
.17
.19
.18
.21
.20


Atrial
musculature
Ventricular
musculature

CONDUCTING SYSTEM

Tissue	Conduction Velocity	Time of Impulse Delay
S A Node		0
Atrial Muscle	0.3m/sec	.03sec
Inter nodal fibres	1m/sec	
AV node	.05m/sec	.09 sec
Penetrating part of AV node/Bundle of His	1m/sec	.04 sec
Purkinje Fibres	1.5– 4 m/sec	.16 sec
Termination of Purkinje Fibres		.03 sec
Ventricular muscle	1m/sec	.03 sec

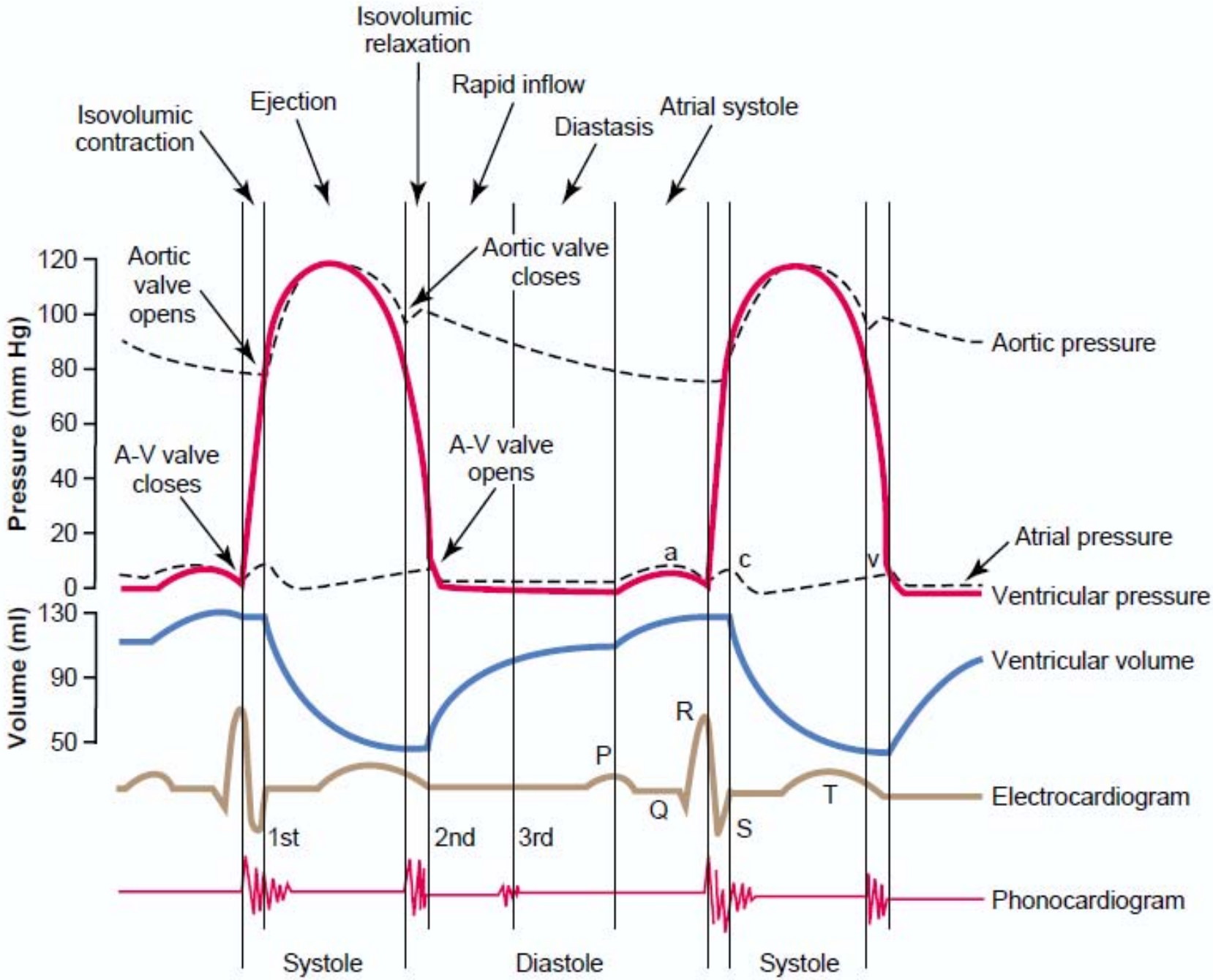
- Right atrium→Left atrium ---Bachman ‘s Bundle
- Internodal Pathway

EFFECT OF ADRENALINE ON HEART

- Effect on
  - L-type Ca^{++} Channels
  - Delayed Rectifier channels
  - Hyperpolarization – activated Cation channels (I_f)
- Also increases intracellular Ca++ in atrial, ventricular and AV cells

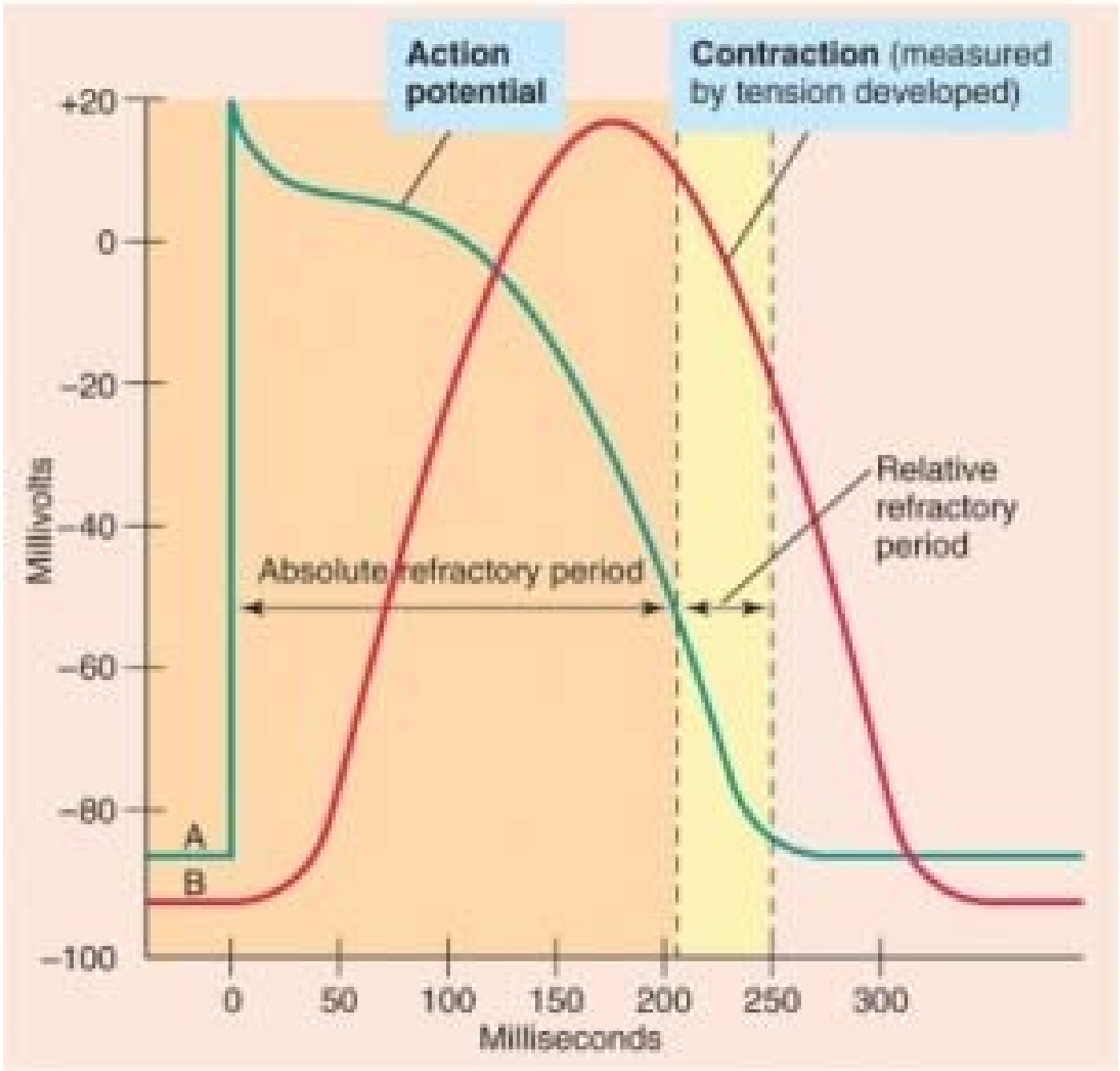
ACETYLECHOLINE

- Increases K+ conductance

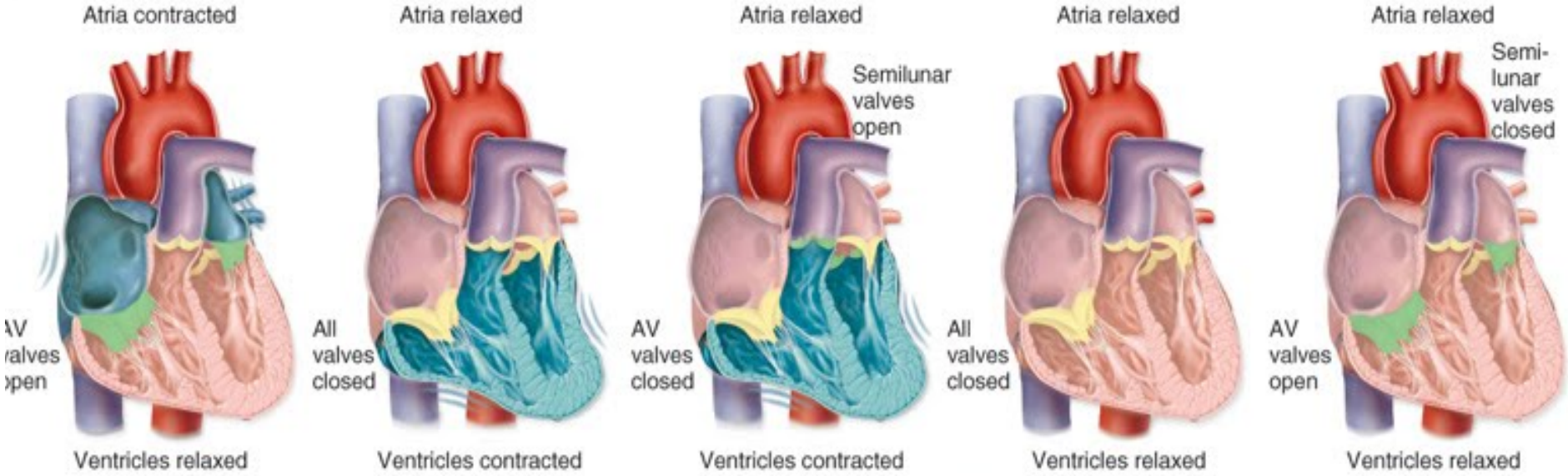

Isovolumic relaxation
Rapid inflow
Ejection
Isovolumic contraction
Diastasis
Atrial systole
Aortic valve opens
Aortic valve closes
Aortic pressure
A-V valve closes
A-V valve opens
Atrial pressure
Ventricular pressure
Ventricular volume
Electrocardiogram
Phonocardiogram
Pressure (mm Hg)
Volume (ml)
120
100
80
60
40
20
0
130
90
50
a
c
v
R
P
Q
S
T
1st
2nd
3rd
Systole
Diastole
Systole

- Isovolumetric contraction- 0.05s
- Rapid ejection – 0.20s
- Protodiastole – 0.05s

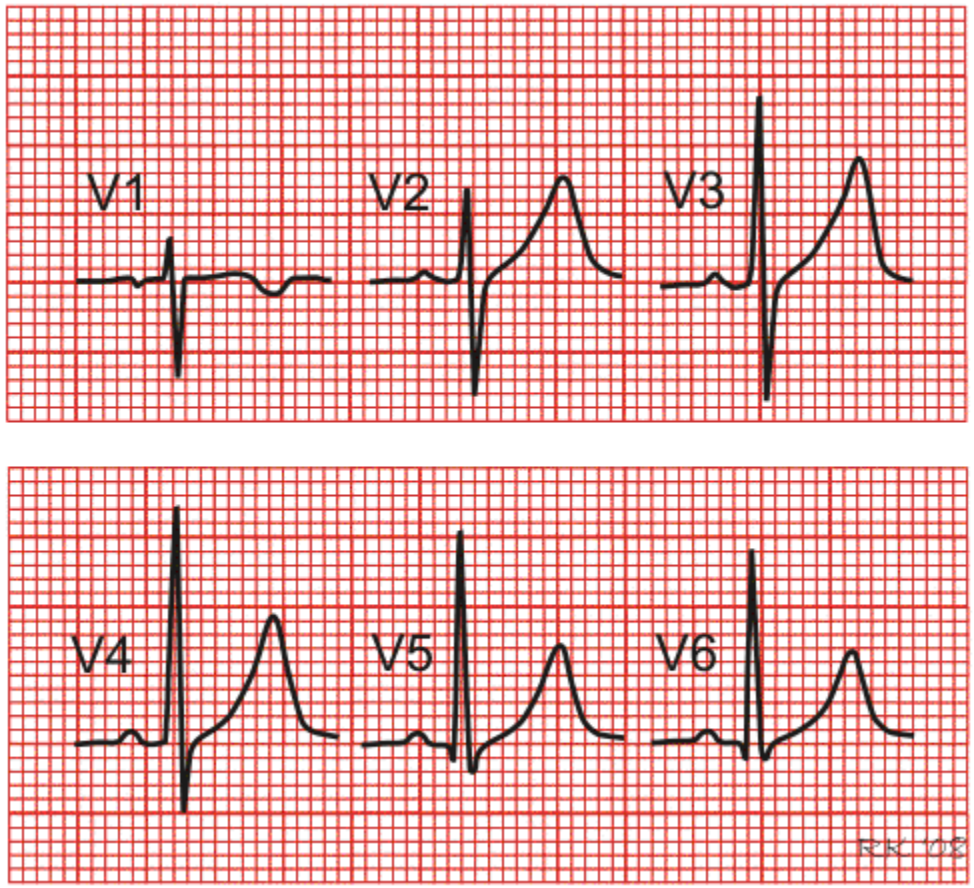
- Isovolumetric relaxation – 0.05s
- Rapid filling – 0.05s
- Diastasis – 0.30s
- Atrial systole – 0.10s

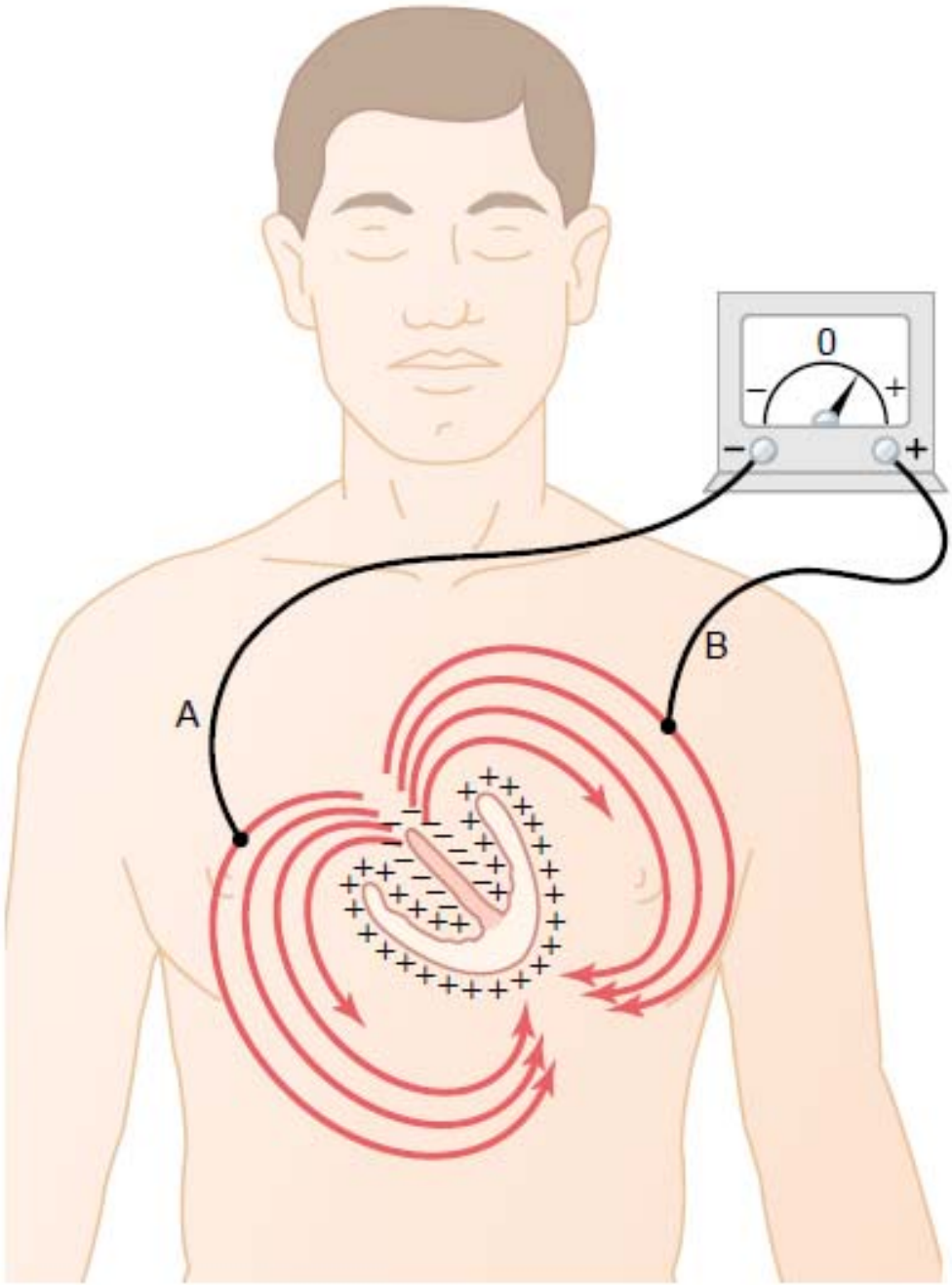


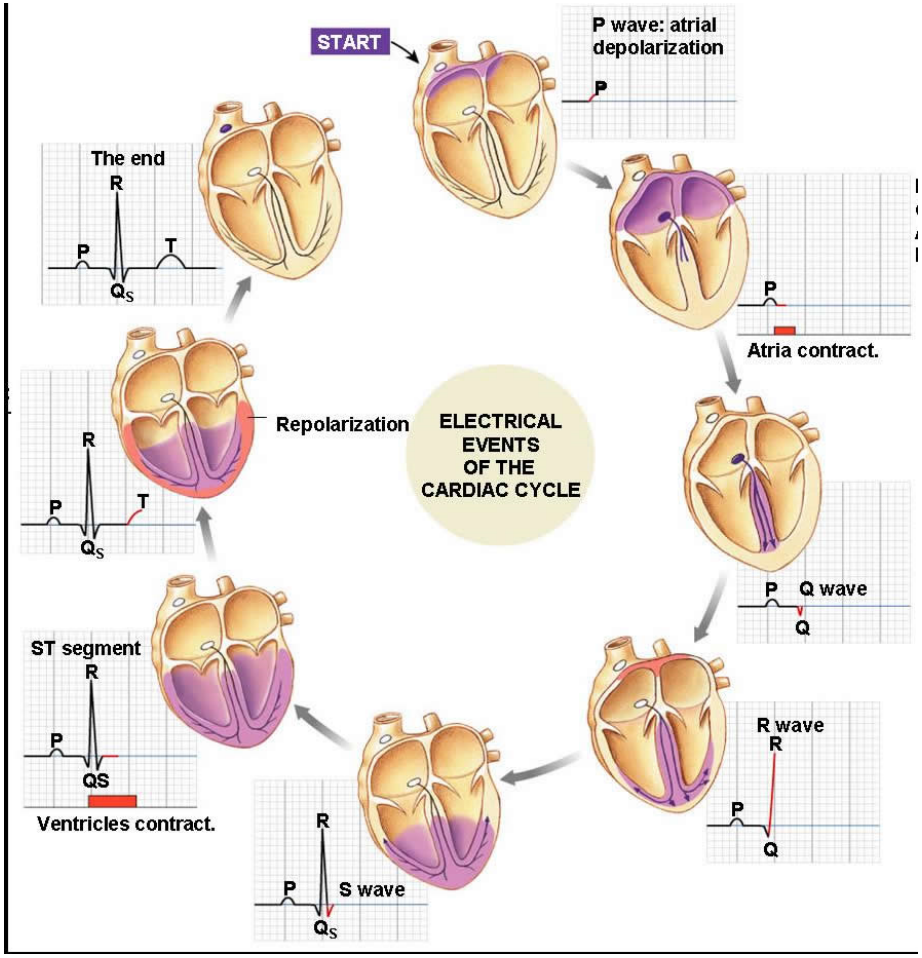
Structure \ Phase	Atrial systole	Early ventricular systole ⟷ Late ventricular systole	Early ventricular diastole ⟷ Late ventricular diastole
Atria	Contract	Relax	Relax
Ventricles	Relax	Contract	Relax
AV valves	Open	Closed	Open
Semilunar valves	Closed	Open	Closed

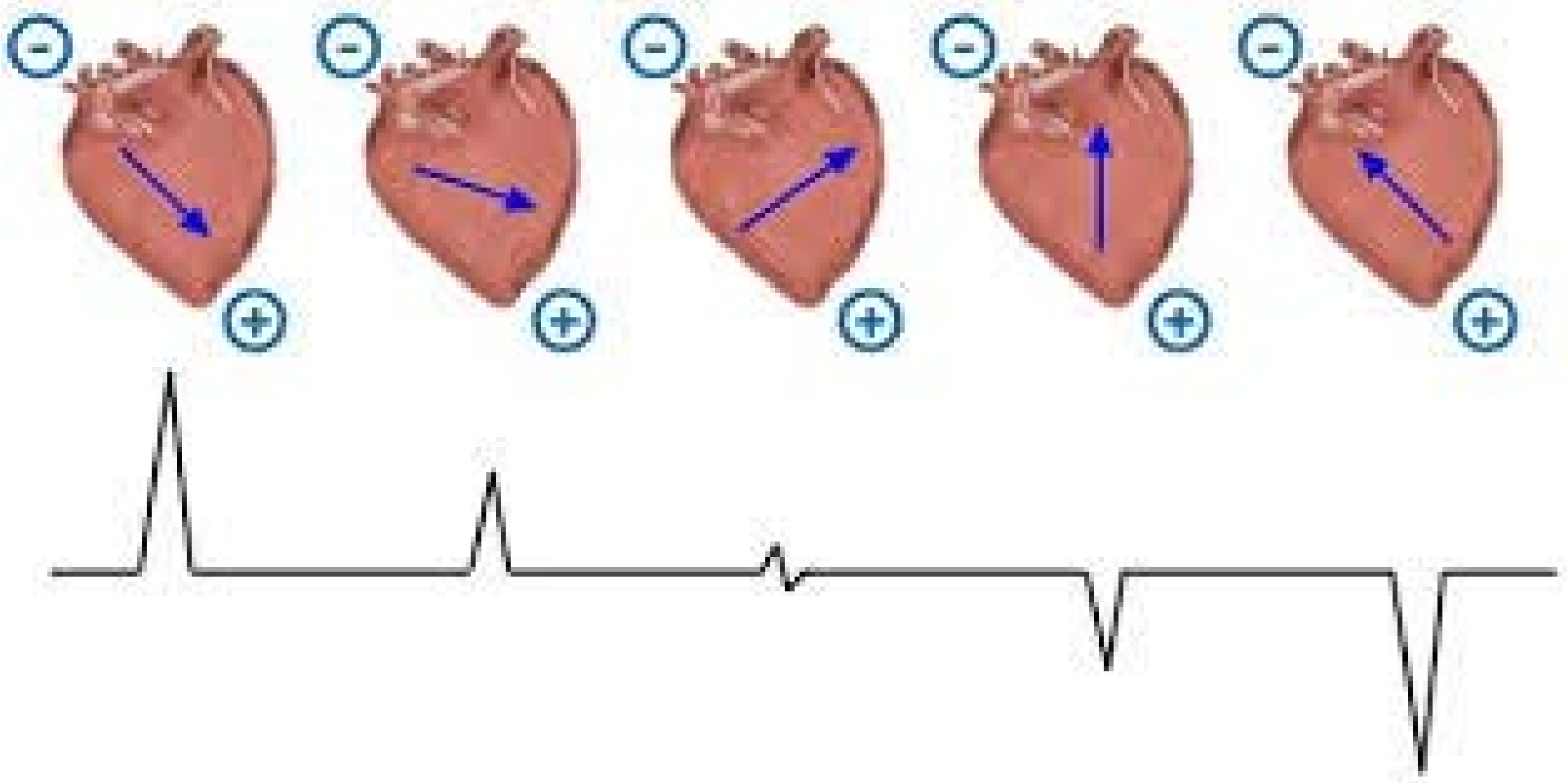


1. **Atrial systole** — Atria contract, AV valves open, semilunar valves closed
2. **Early ventricular systole** — Atria relax, ventricles contract, AV valves forced closed, semilunar valves still closed
3. **Late ventricular systole** — Atria relax, ventricles contract, AV valves remain closed, semilunar valves forced open
4. **Early ventricular diastole** — Atria and ventricles relax, AV valves and semilunar valves closed, atria begin passively filling with blood
5. **Late ventricular diastole** — Atria and ventricles relax, atria passively fill with blood as AV valves open, semilunar valves closed

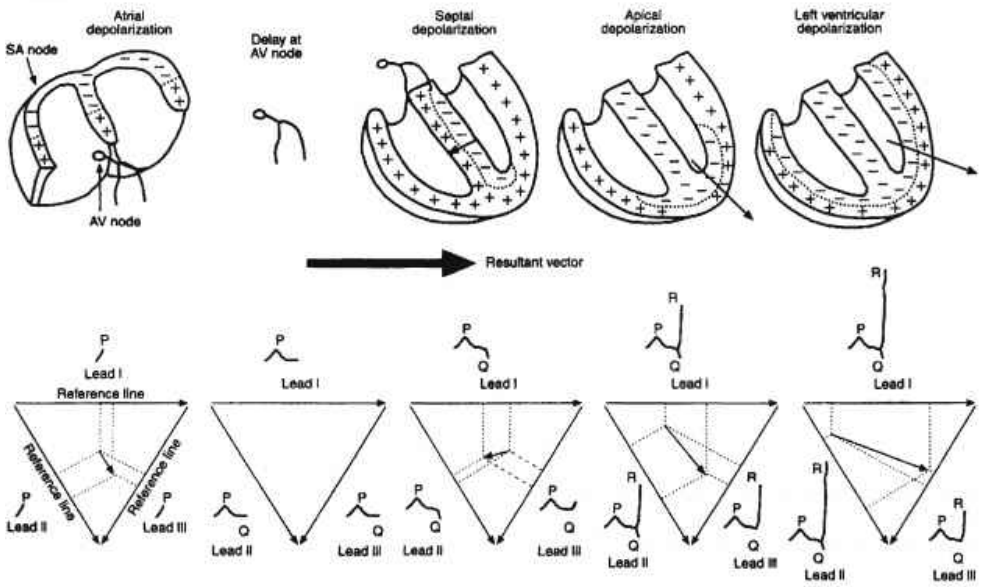

V1
V2
V3
V4
V5
V6


0
−
+
−
+
A
B

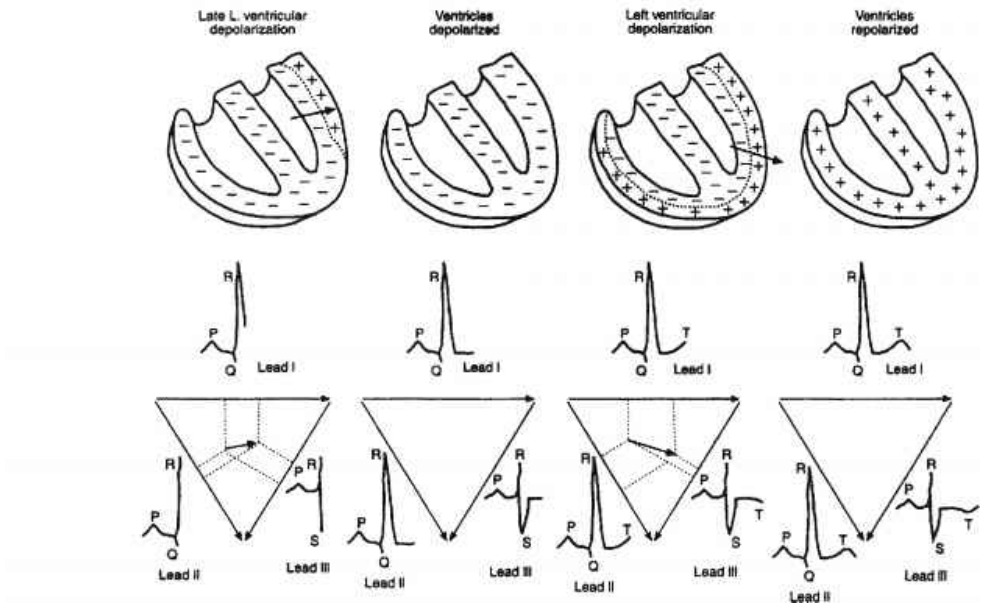

START
P wave: atrial depolarization
P
Atria contract.
P
Q wave
P
Q
R wave
R
P
Q
R
P
S wave
Qs
ST segment
R
P
QS
Ventricles contract.
Repolarization
R
P
T
Qs
The end
R
P
T
Qs
ELECTRICAL EVENTS OF THE CARDIAC CYCLE

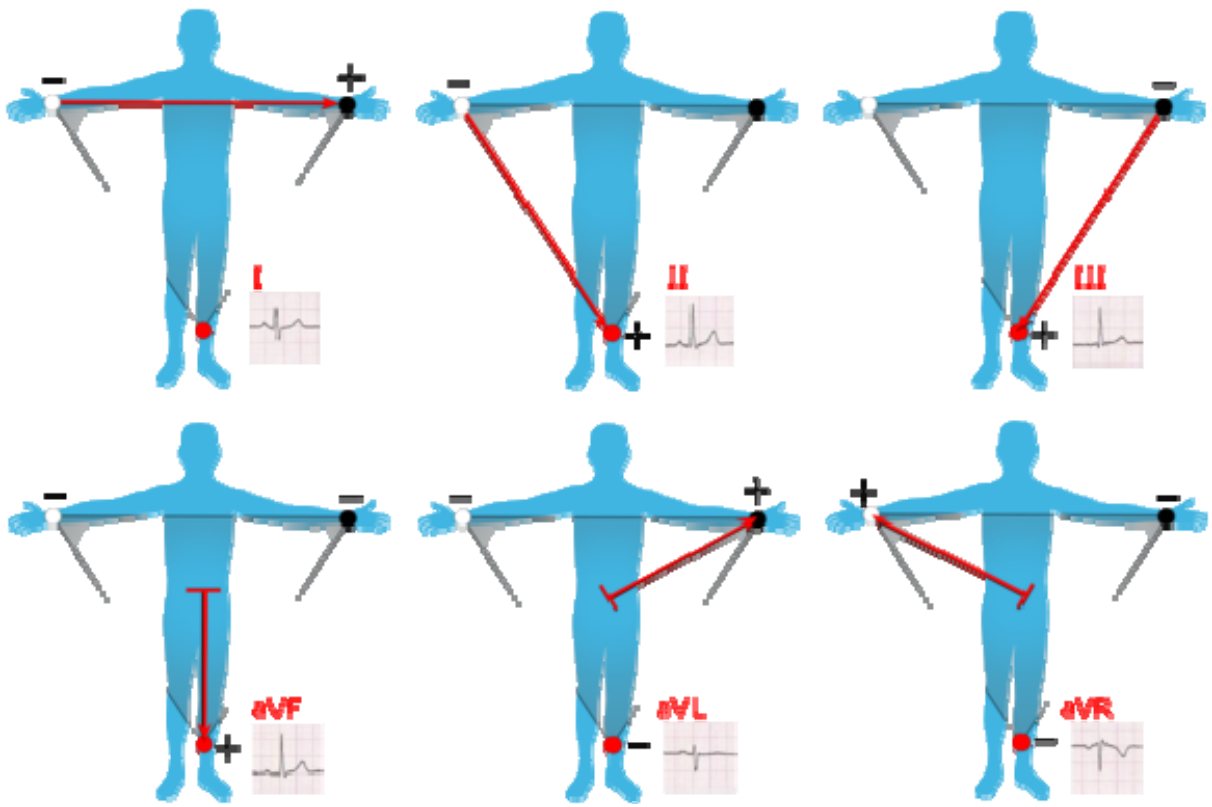


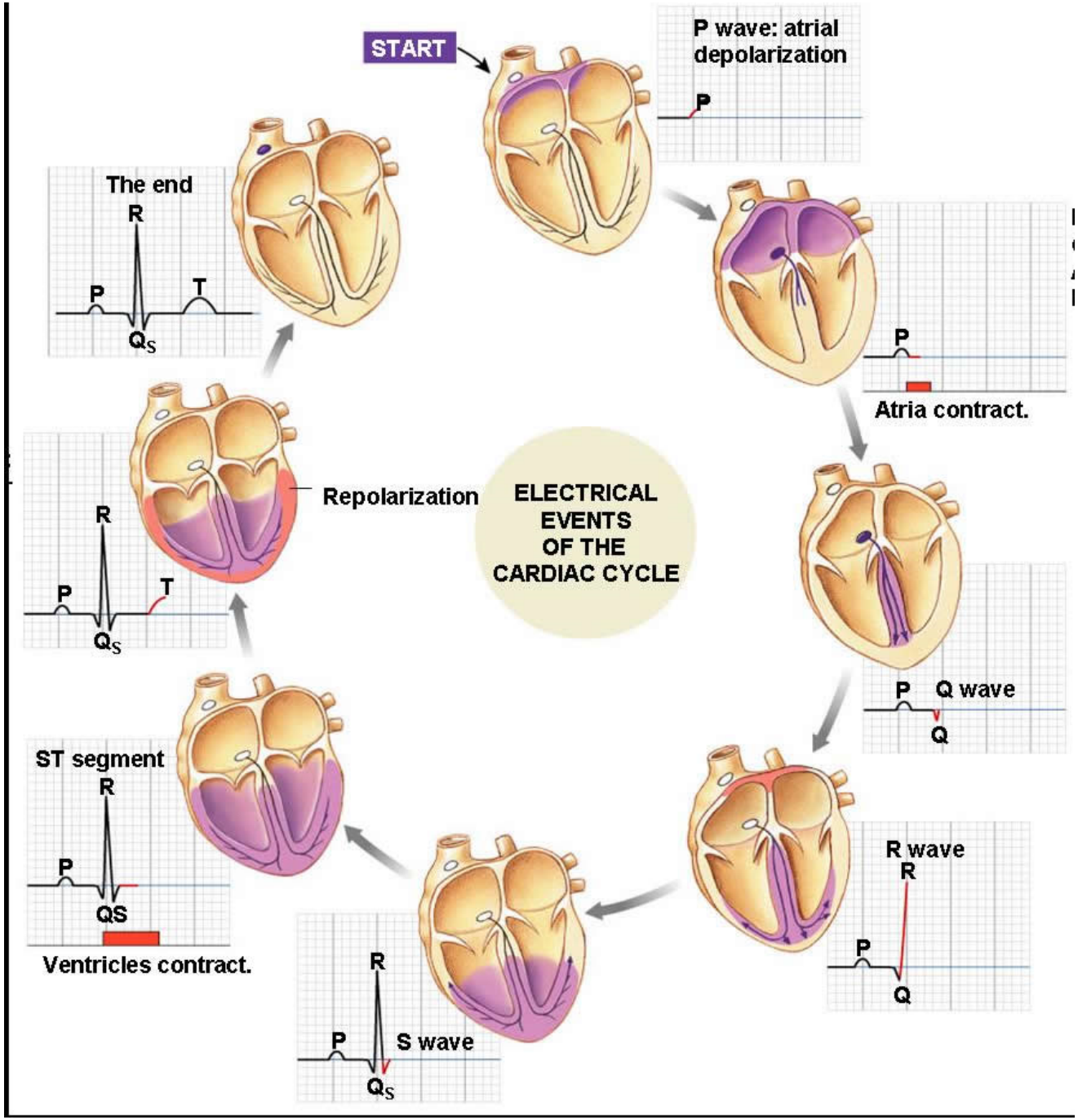
Progression of depolarization



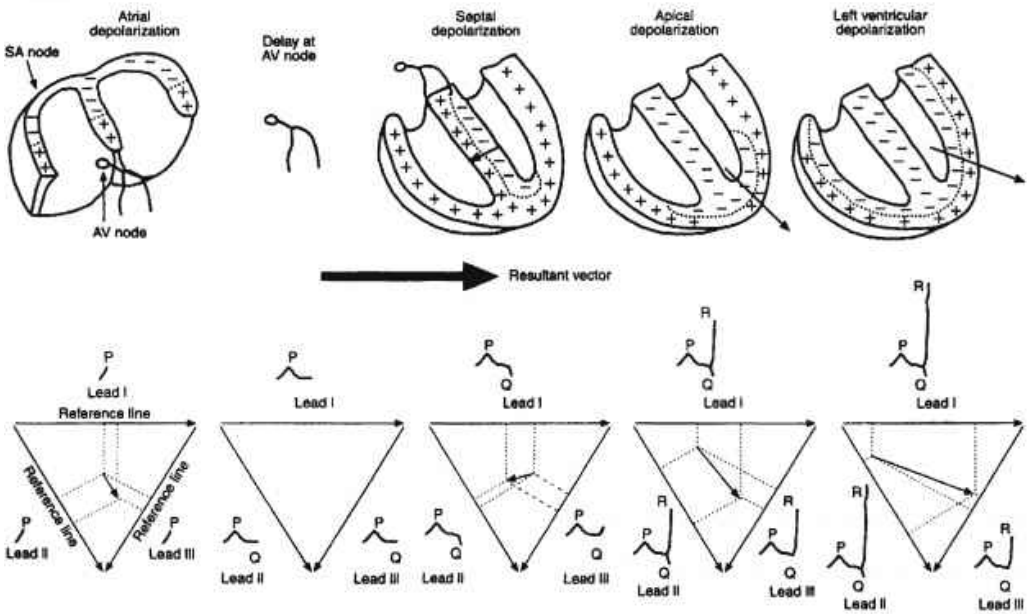
End of depolarization and repolarization



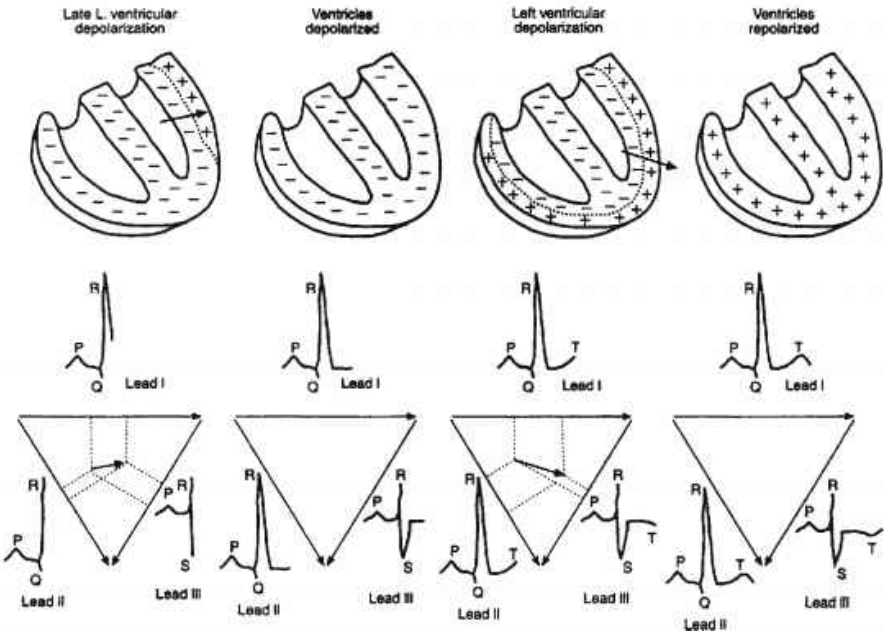

I
II
III
aVF
aVL
aVR

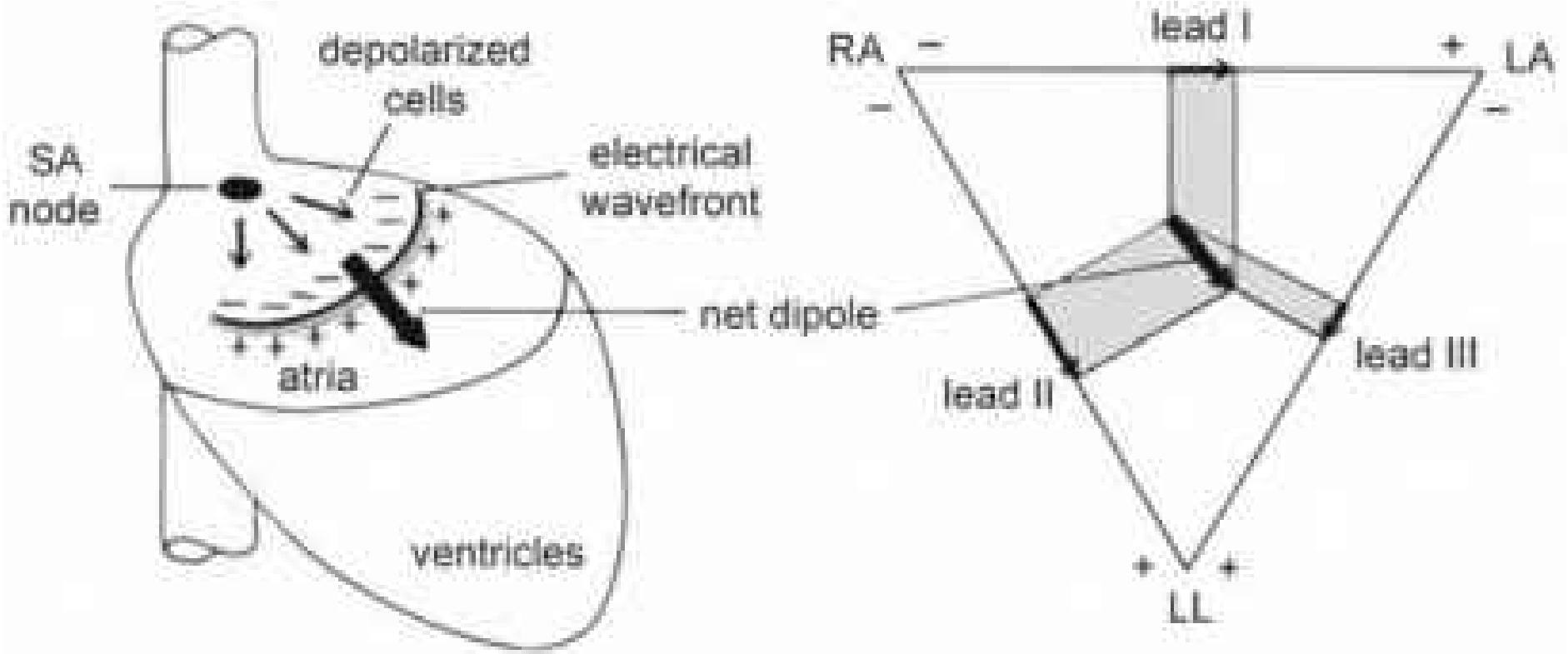

START
P wave: atrial depolarization
P
Atria contract.
P
P Q wave
Q
R wave
R
P
Q
P
S wave
QS
R
P
QS
ST segment
Ventricles contract.
R
P
T
QS
Repolarization
R
P
T
QS
The end
R
P
T
QS
ELECTRICAL EVENTS OF THE CARDIAC CYCLE

Progression of depolarization

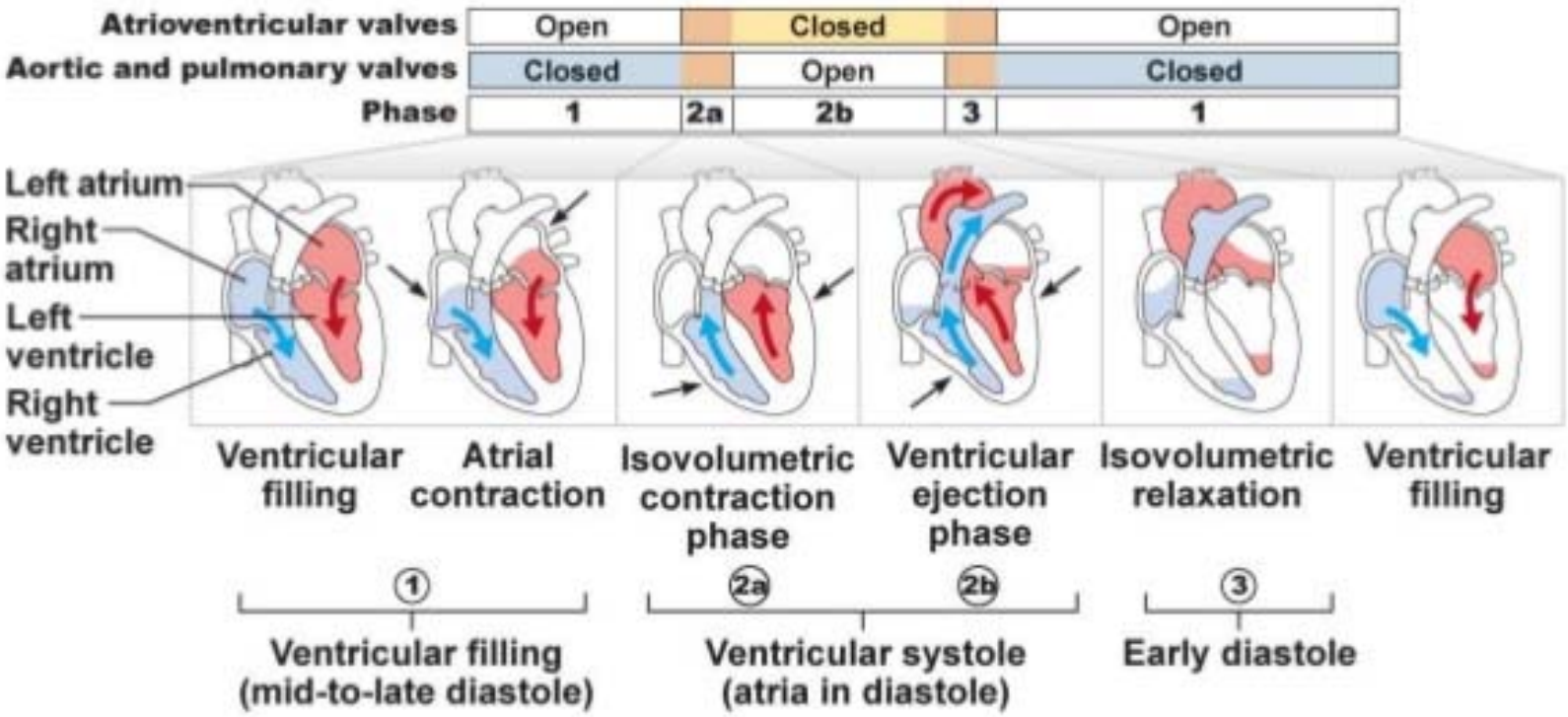


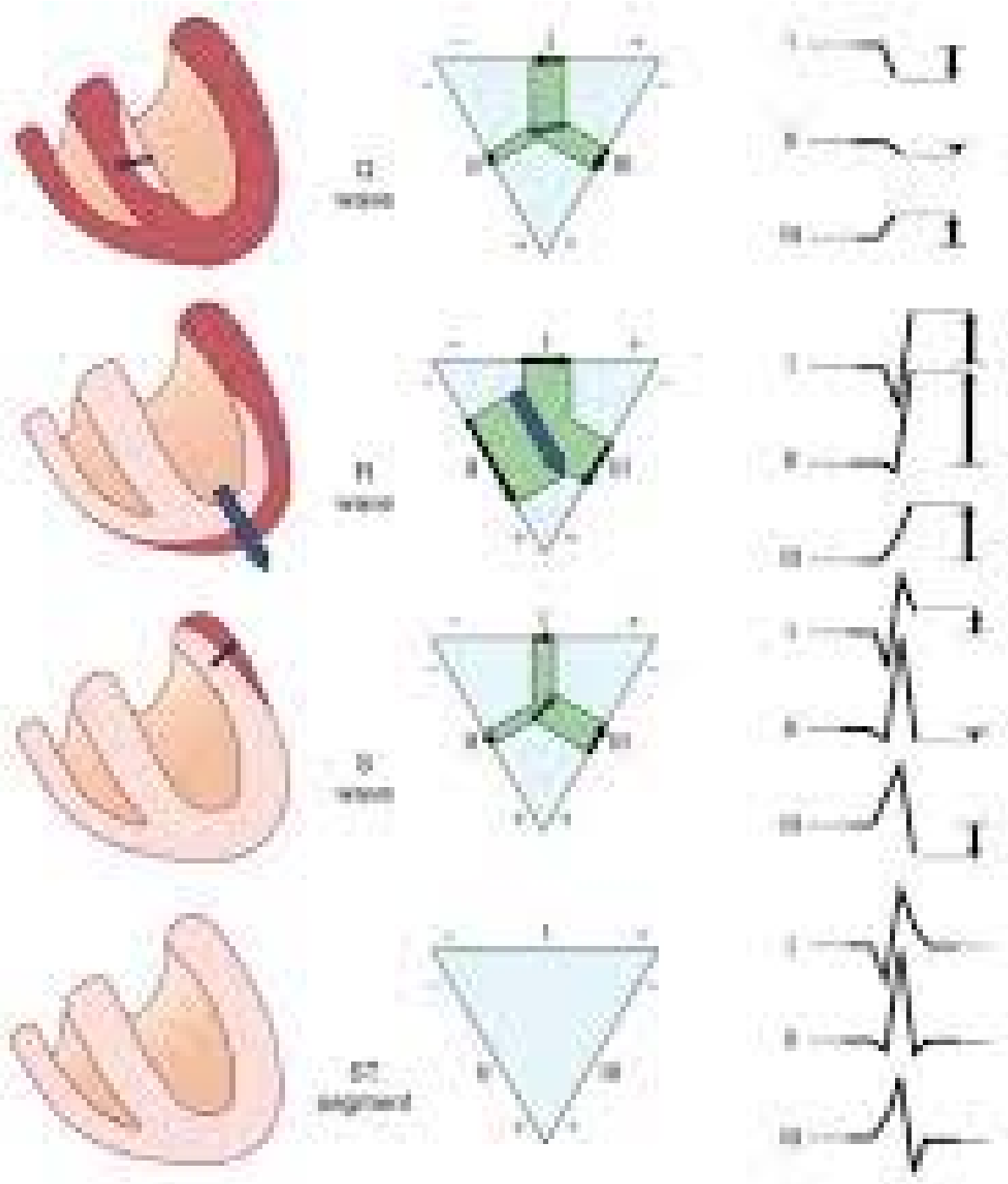
End of depolarization and repolarization

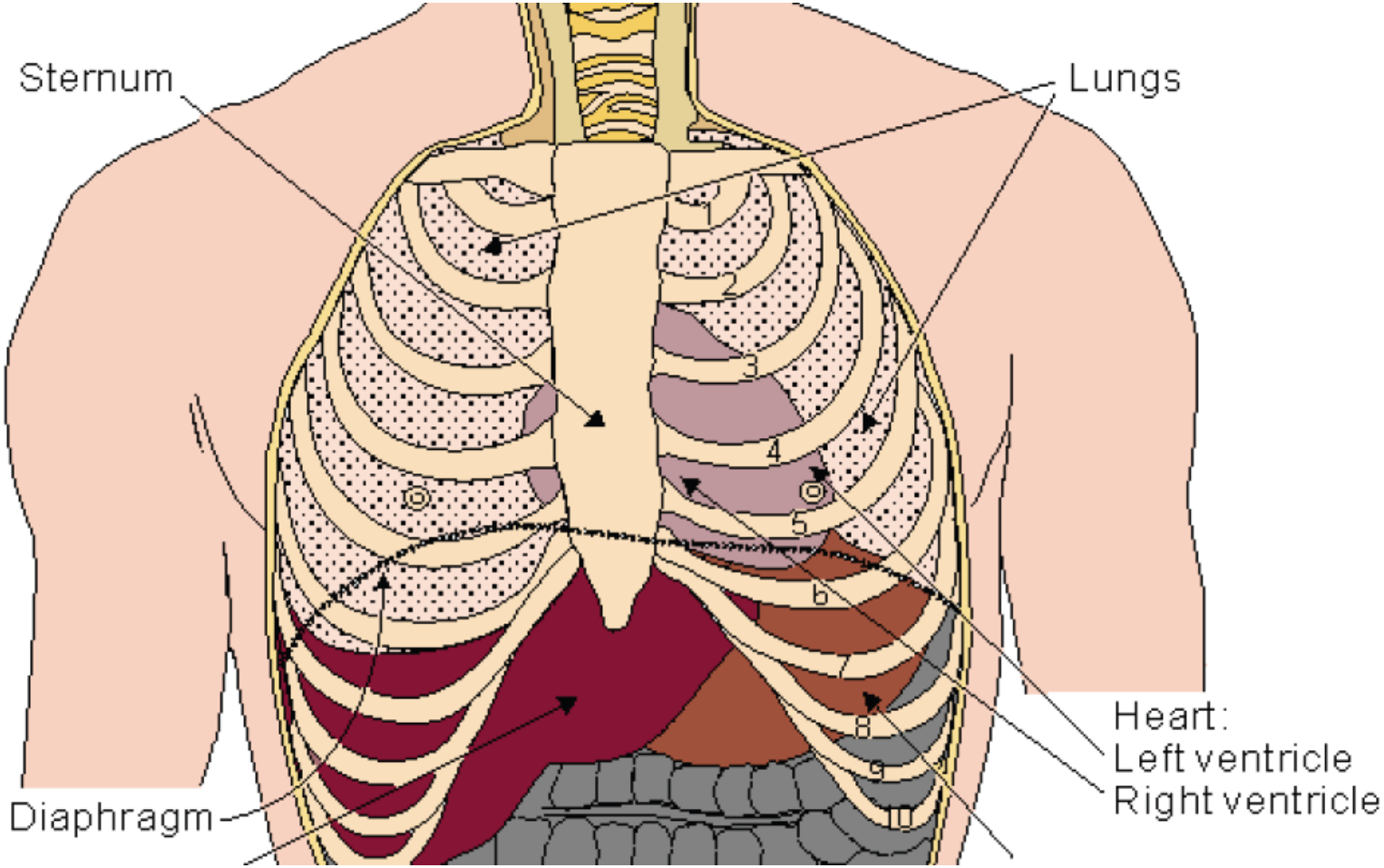



depolarized
cells
SA
node
electrical
wavefront
net dipole
atria
ventricles
RA
lead I
LA
lead II
lead III
LL

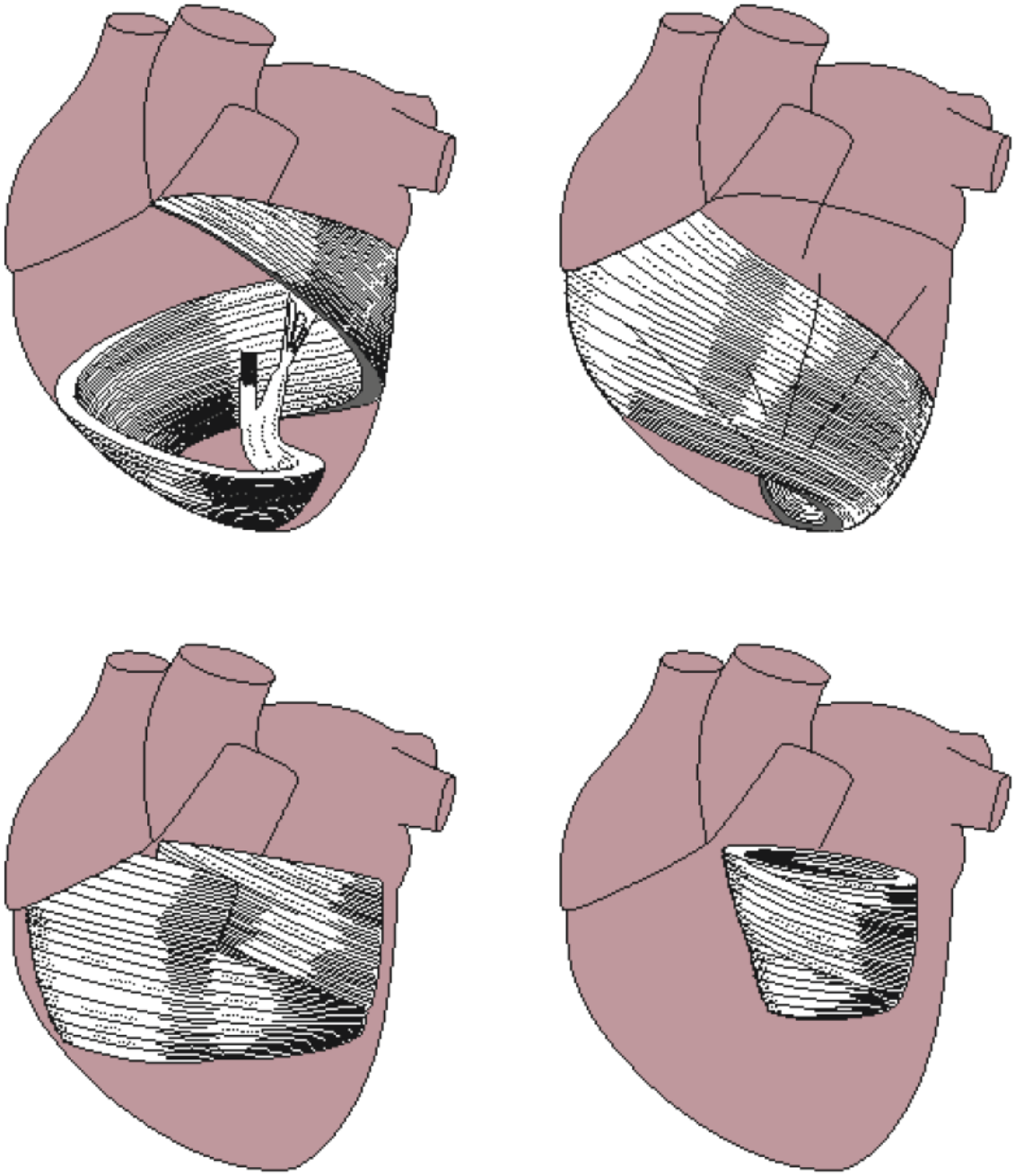
Steps of the Cardiac Cycle

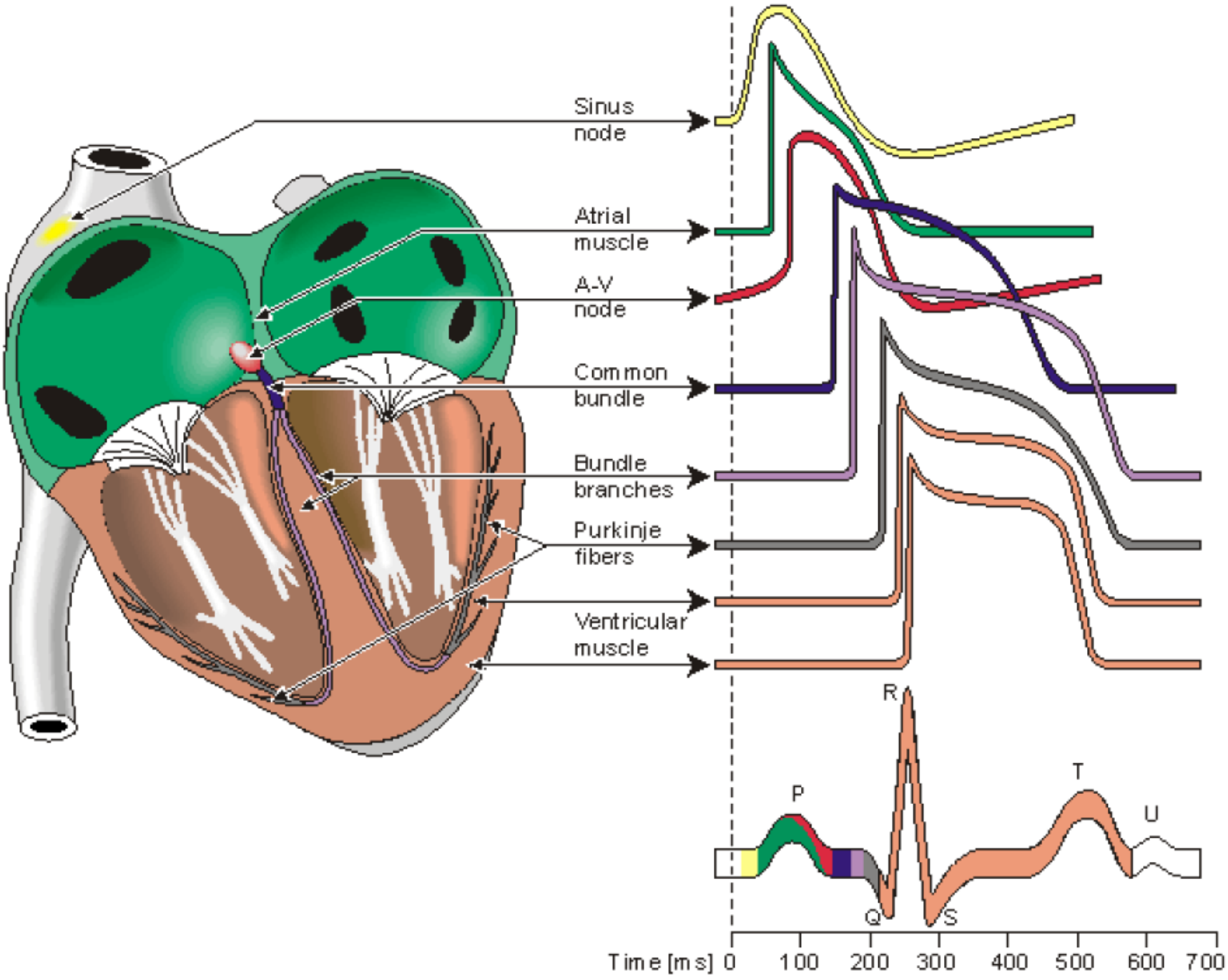


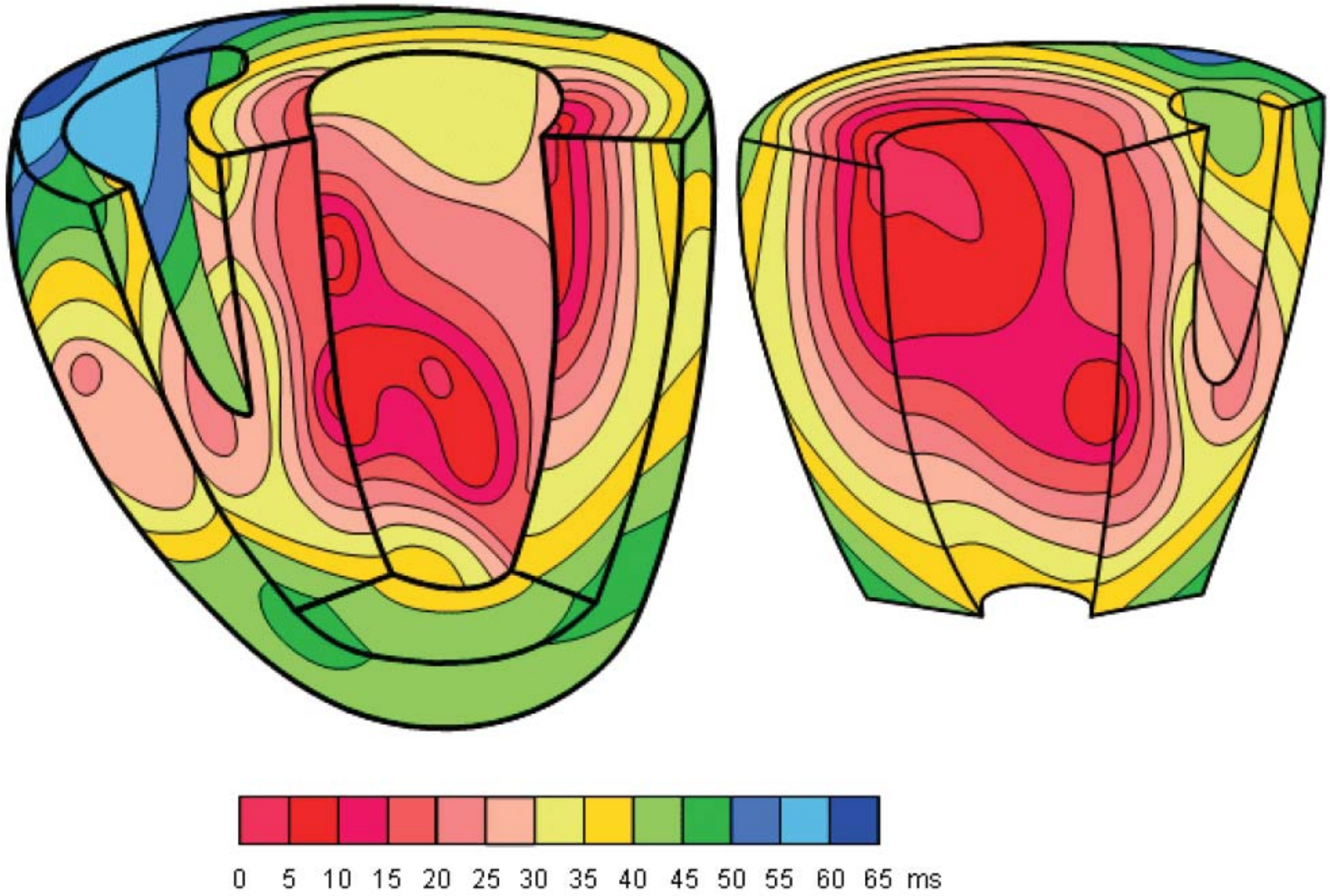


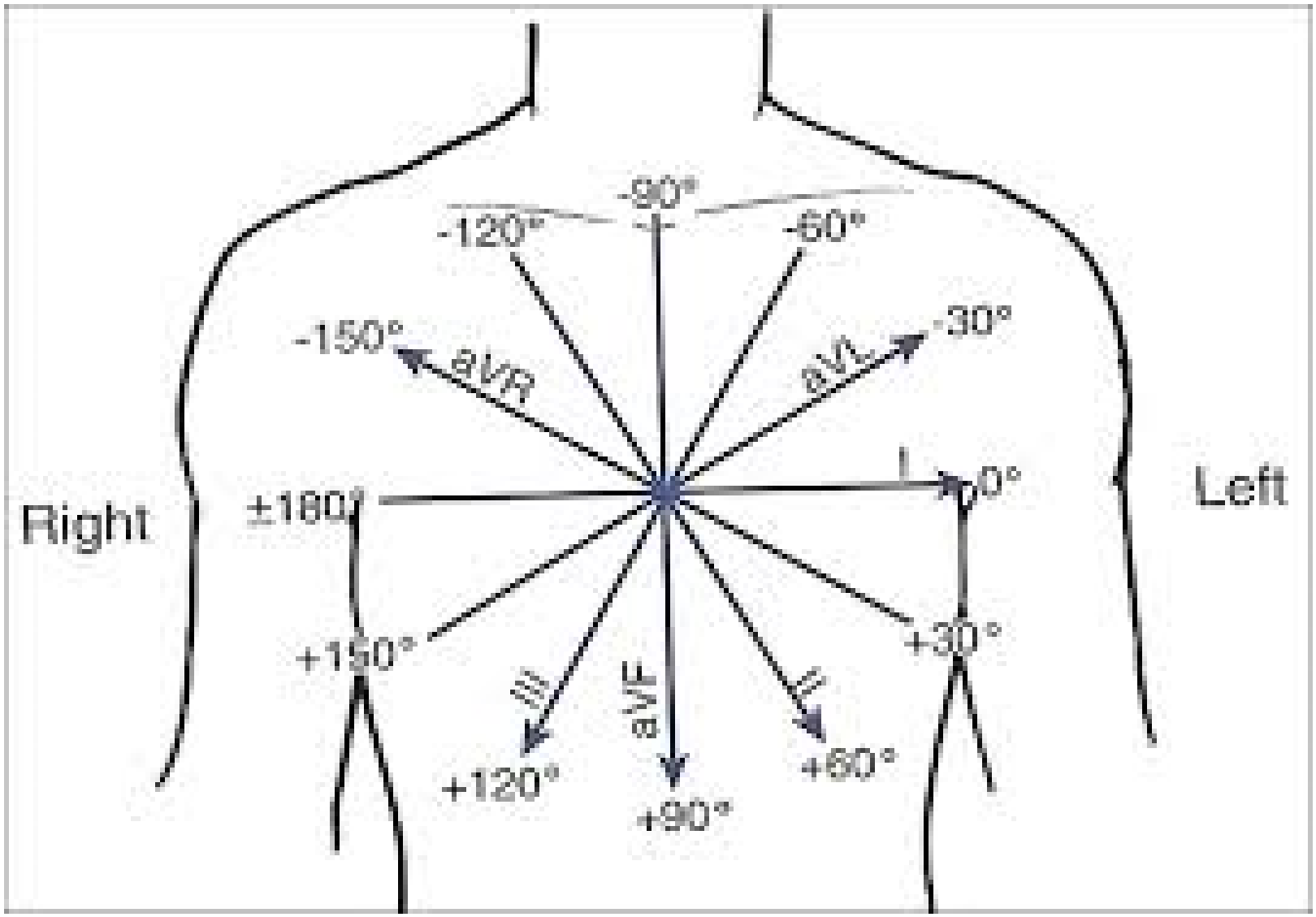

Sternum
Lungs
1
2
3
4
5
6
7
8
9
10
Heart:
Left ventricle
Right ventricle
Diaphragm

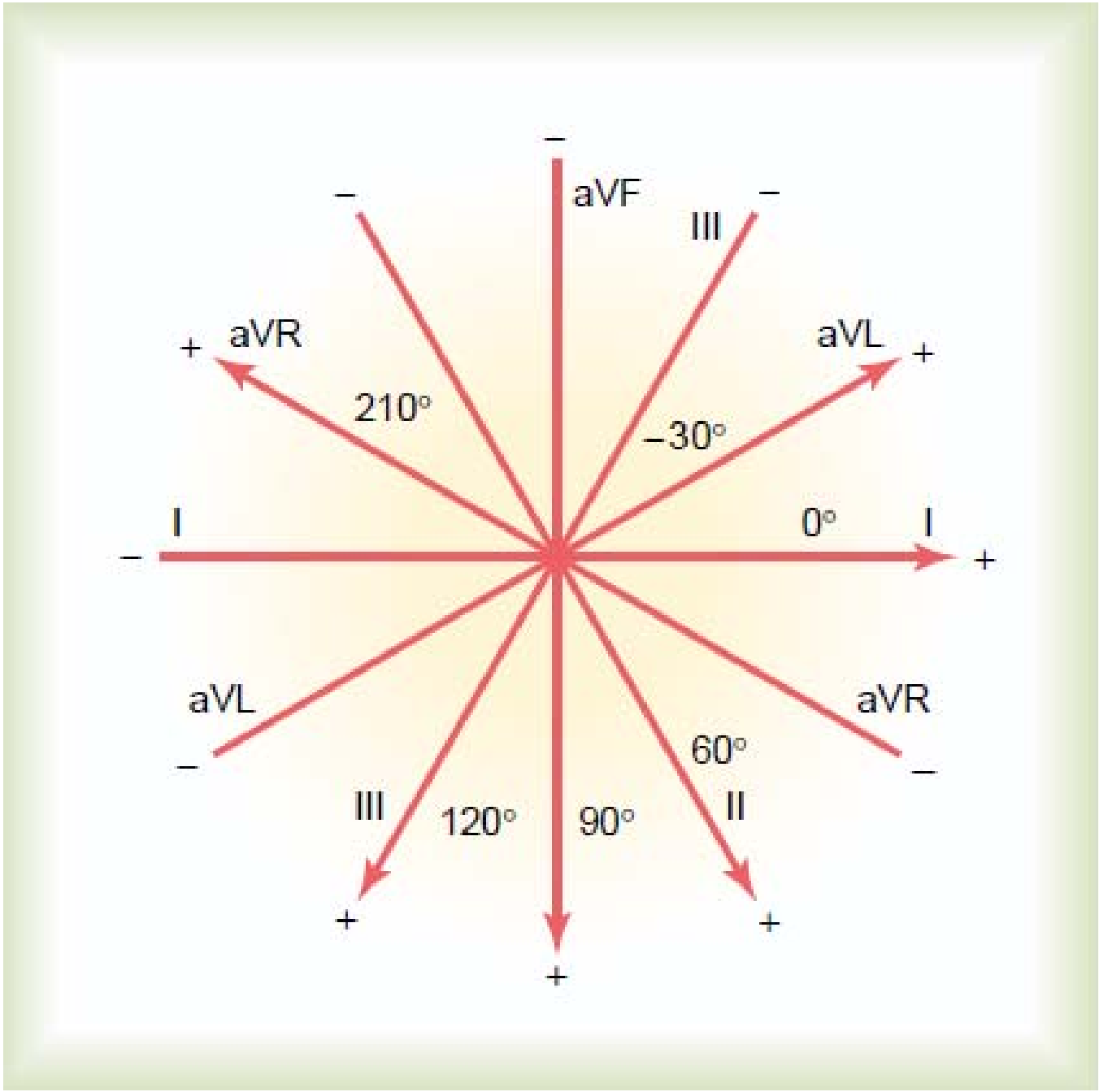
6. The Heart

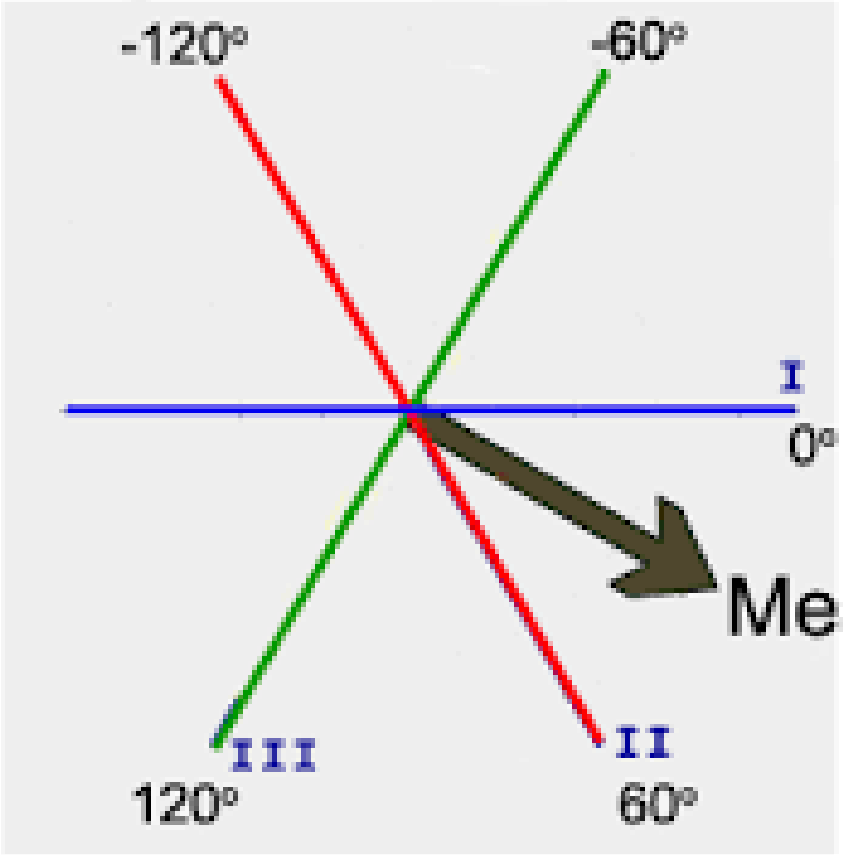


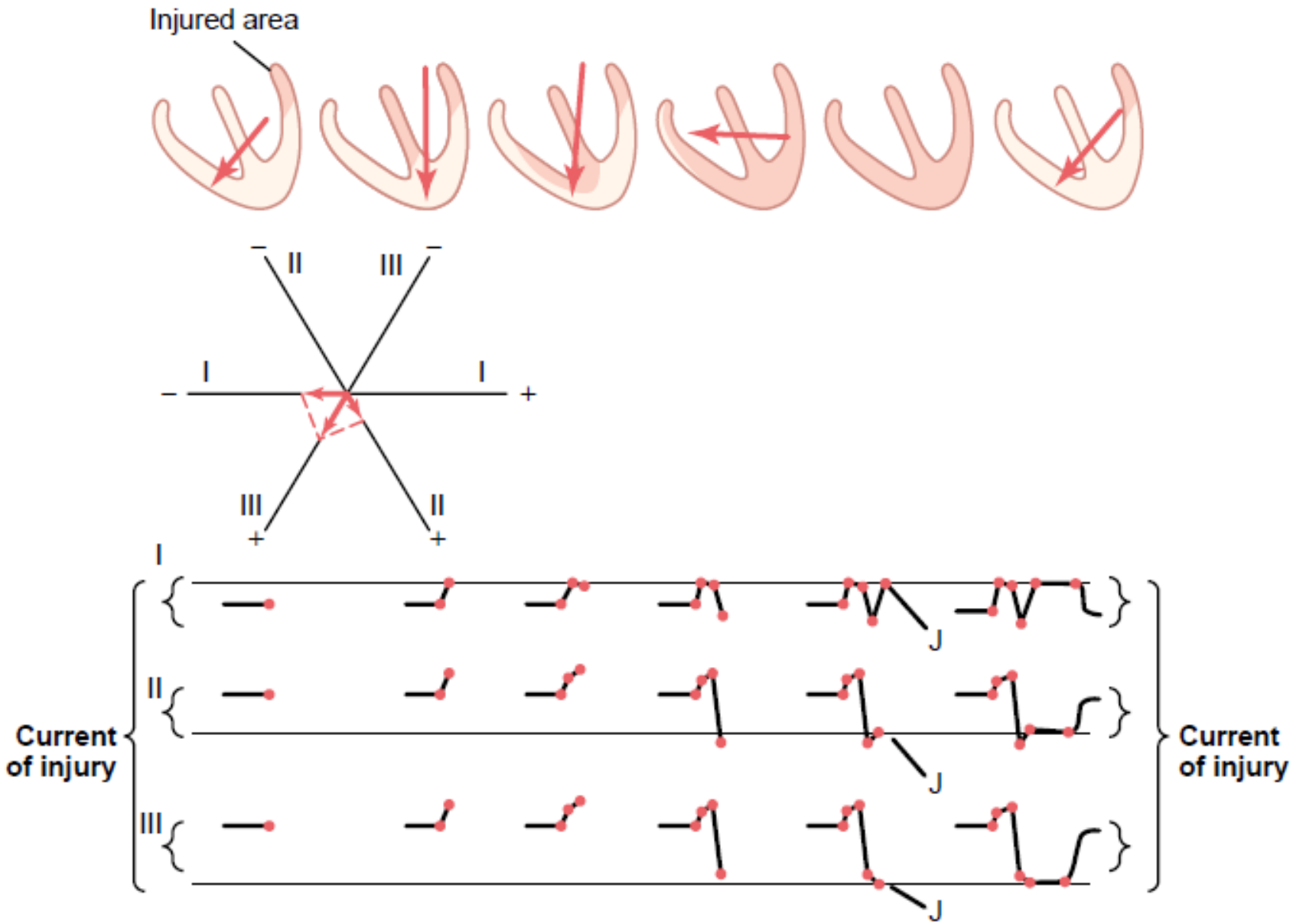

Sinus node
Atrial muscle
A-V node
Common bundle
Bundle branches
Purkinje fibers
Ventricular muscle
R
P
T
U
Q
S
Time [ms] 0
100
200
300
400
500
600
700


0 5 10 15 20 25 30 35 40 45 50 55 60 65 ms


-90°
-120°
-60°
-150°
aVR
-30°
aVL
I
0°
±180°
Right
Left
+150°
+30°
III
aVF
II
+120°
+60°
+90°


aVF
III
aVR
aVL
210°
−30°
I
0°
I
aVL
aVR
60°
III
120°
90°
II


-120°
-60°
I
0°
Mean QRS axis
III
II
120°
60°

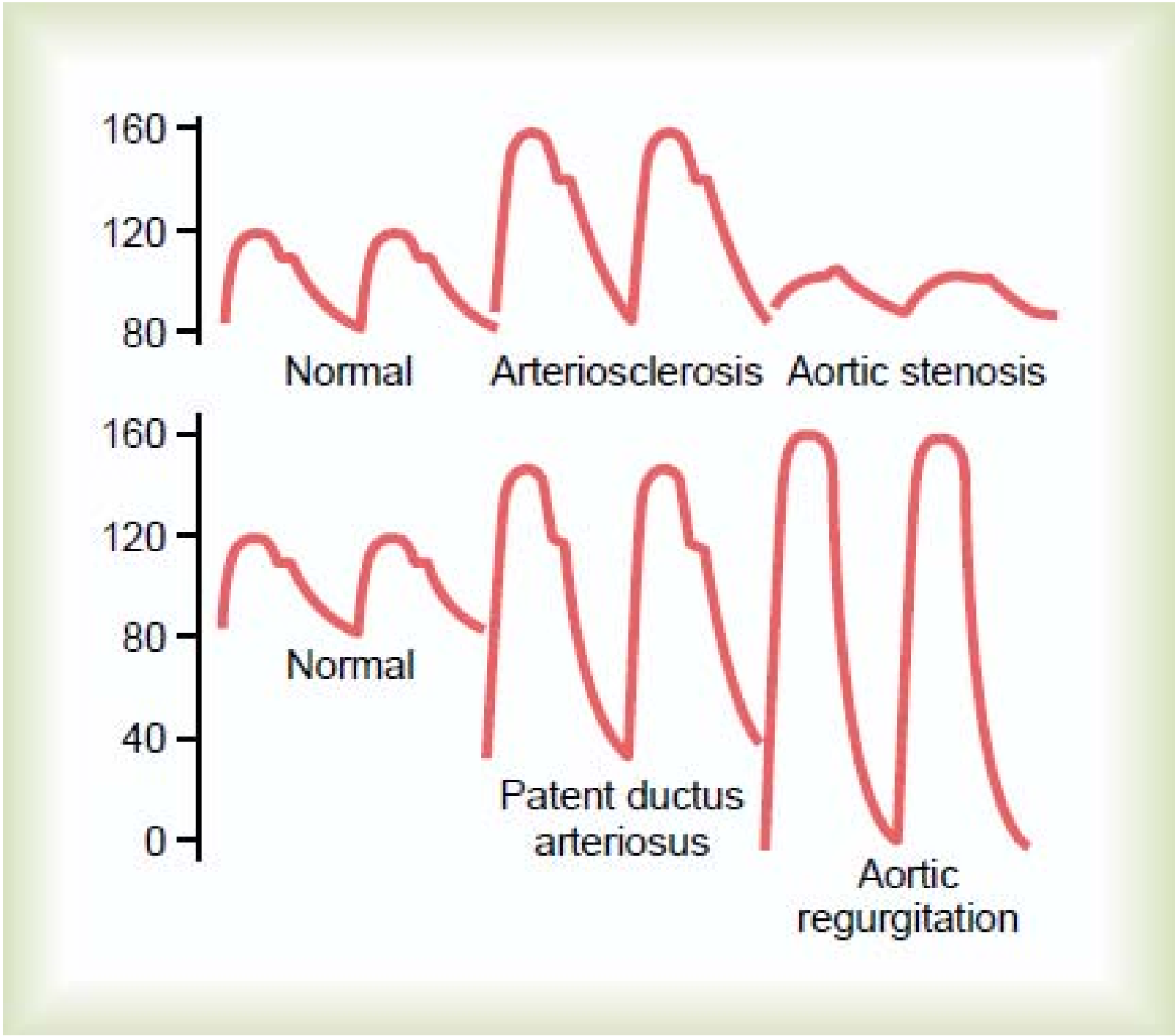

Injured area
II
III
I
I
III
II
I
II
III
J
J
J
Current of injury
Current of injury

Arterial Blood Pressure

- Systolic
- Diastolic
- Pulse Pressure
- Mean pressure

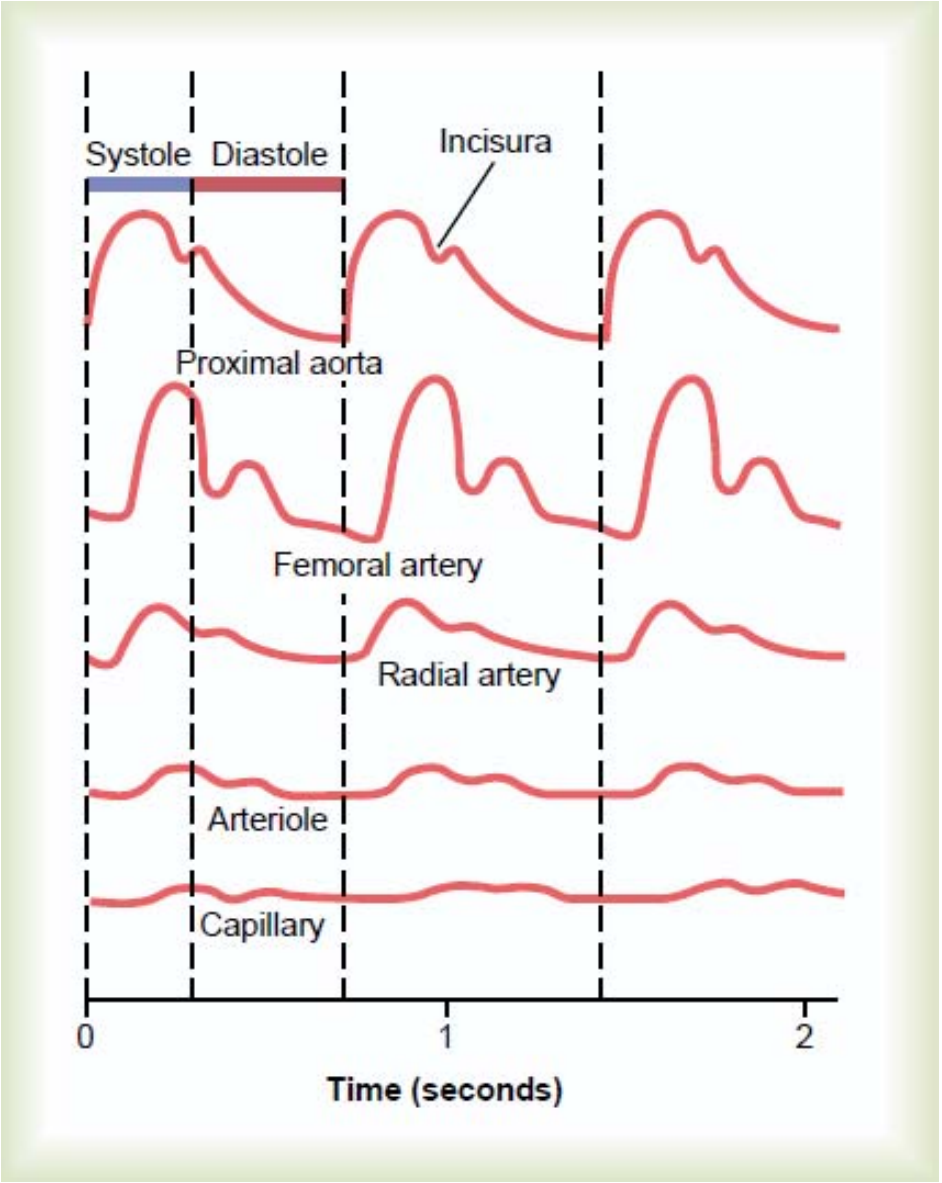
Pulse pressure

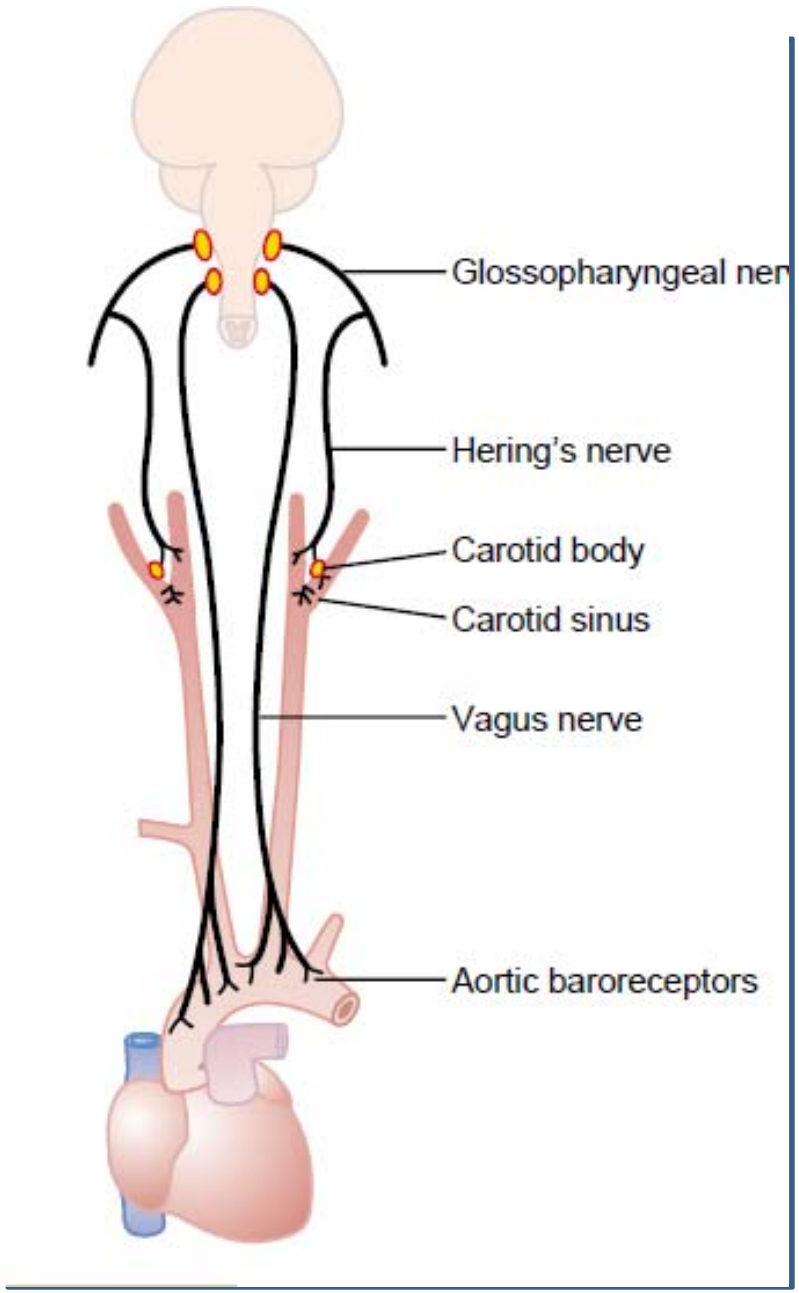
- Determinants
  - Stroke volume output
  - Arterial compliance
  - Character of ejection during systole
  - Ratio of stroke volume and arterial compliance

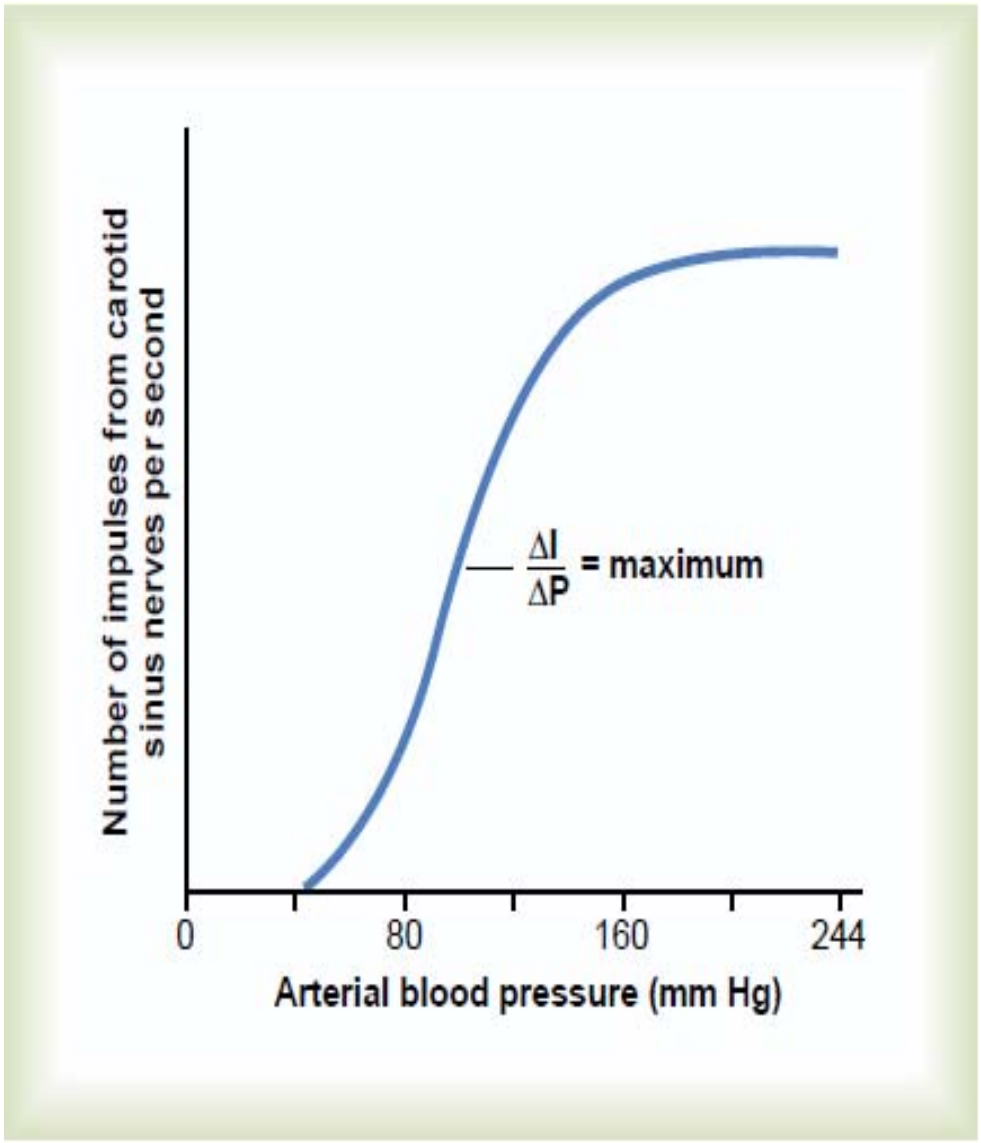

160
120
80
Normal
Arteriosclerosis
Aortic stenosis
160
120
80
40
0
Normal
Patent ductus arteriosus
Aortic regurgitation

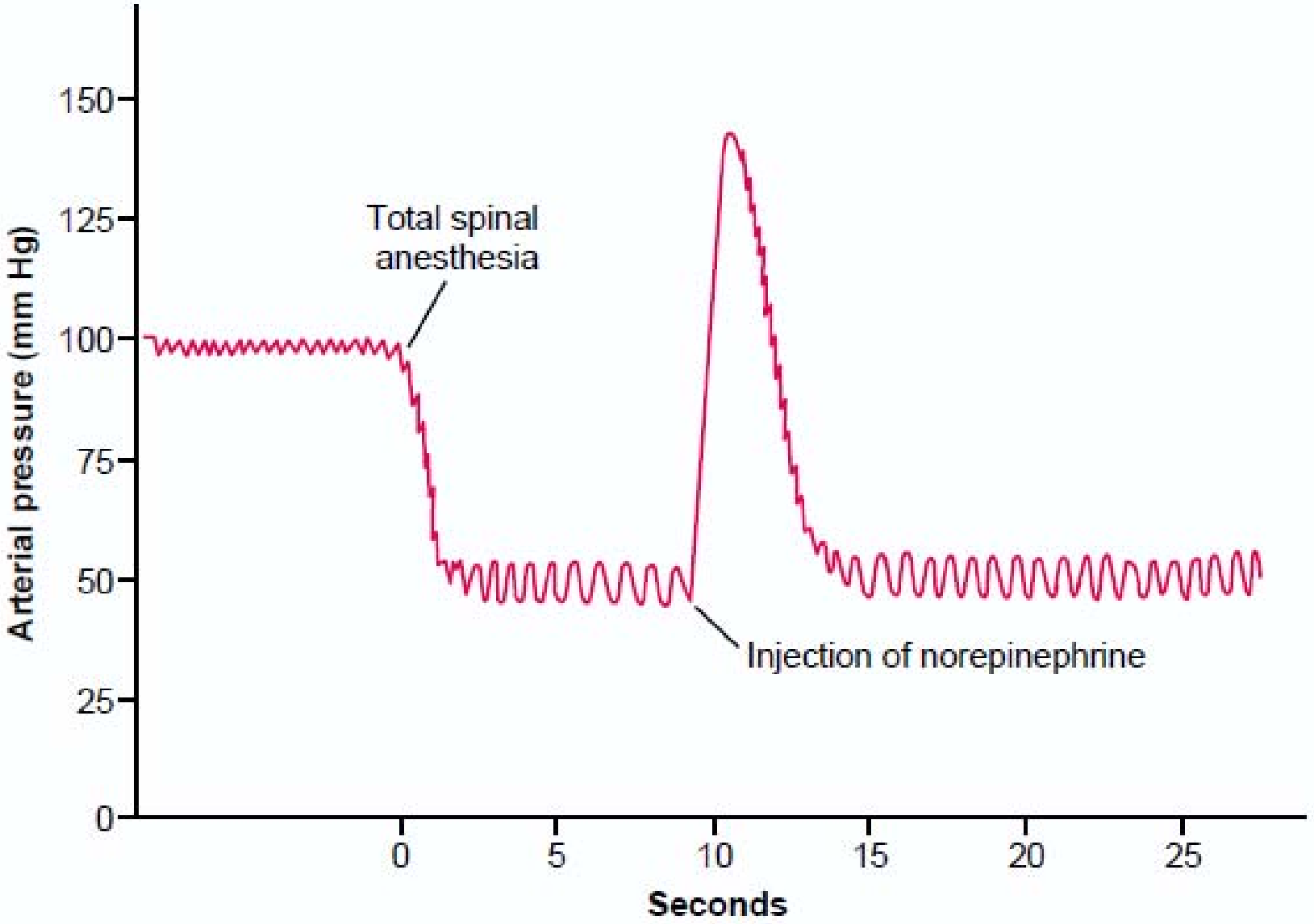
Damping of the pressure pulse

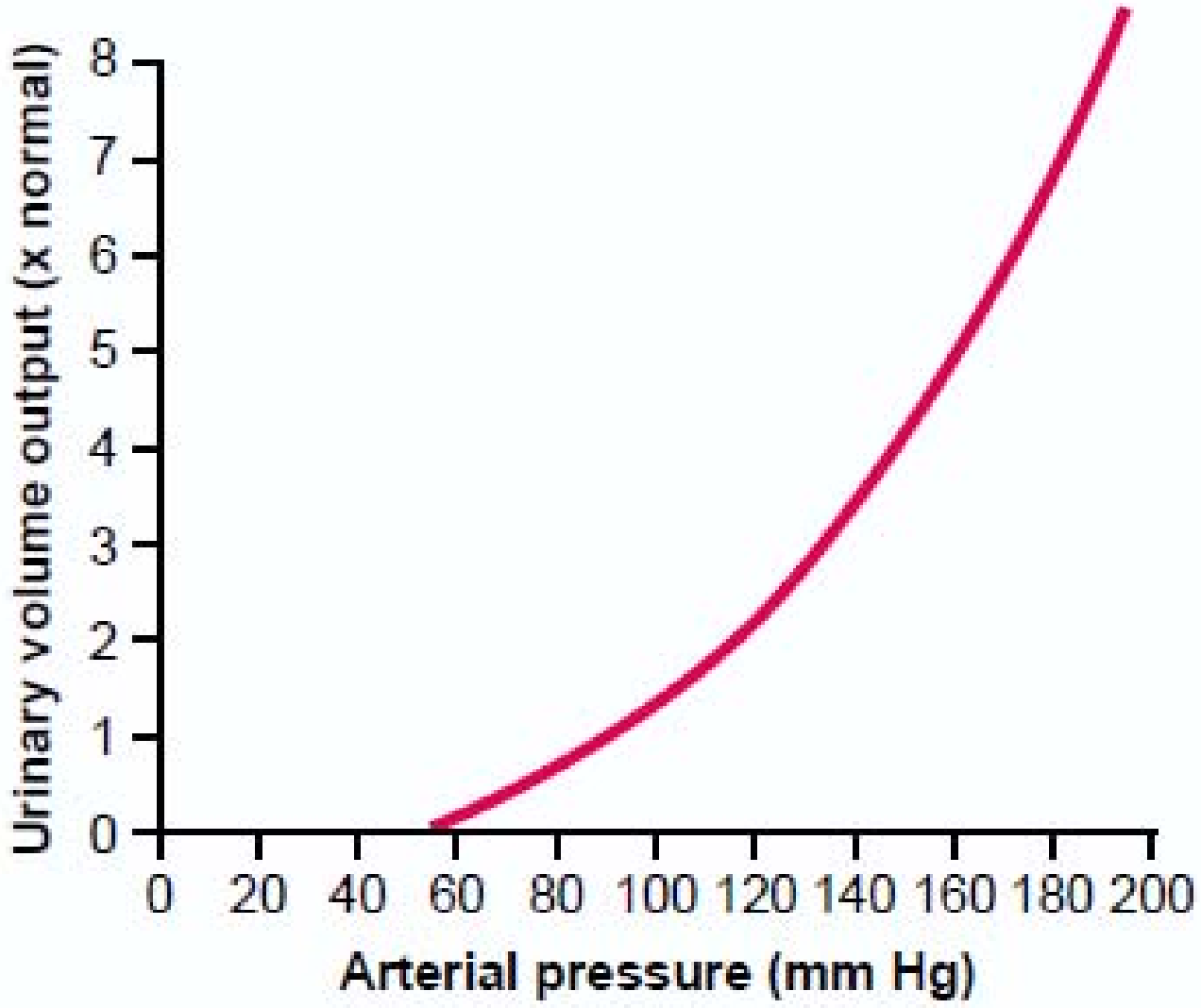
Due to resistance and compliance of blood vessel

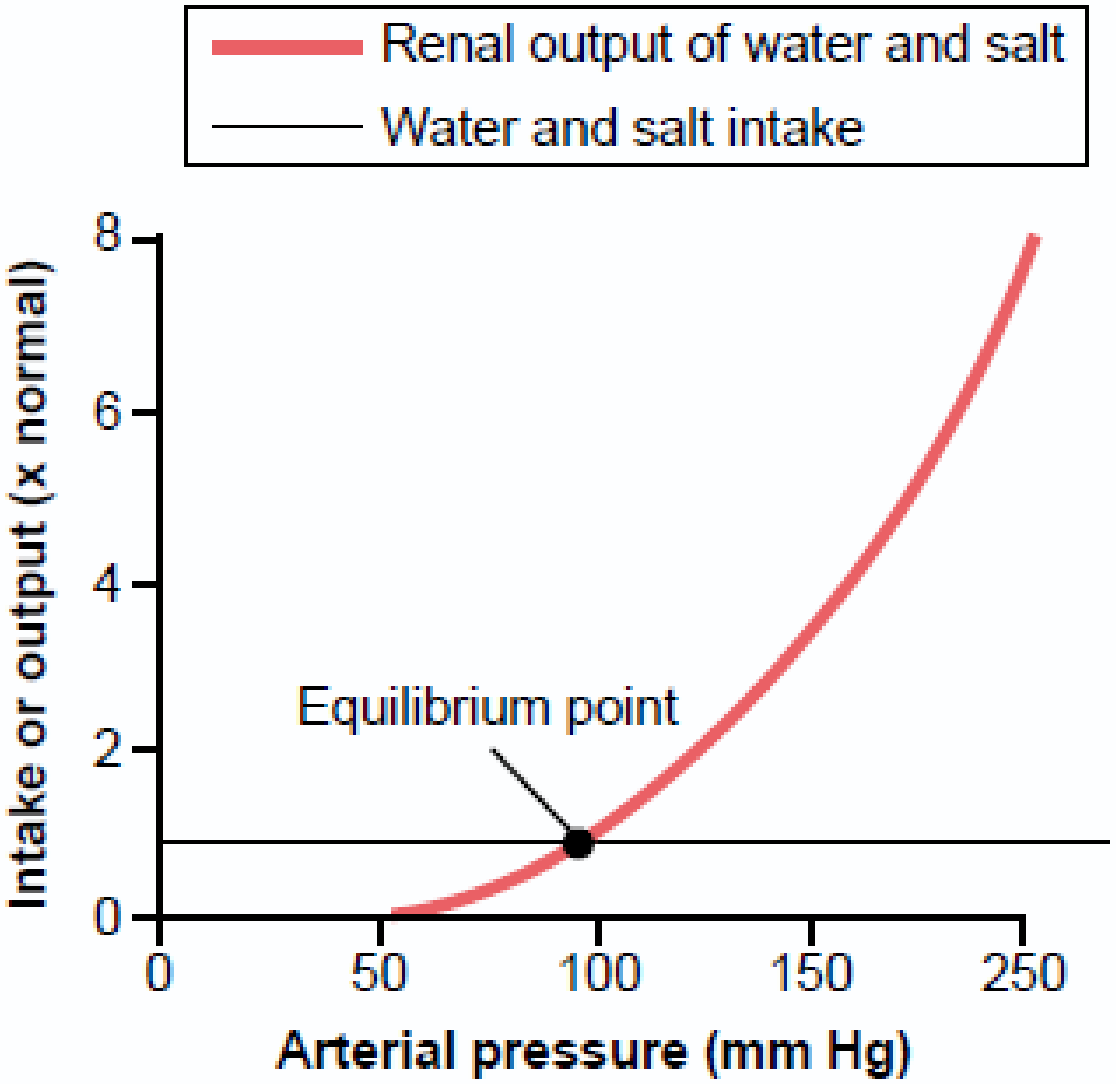


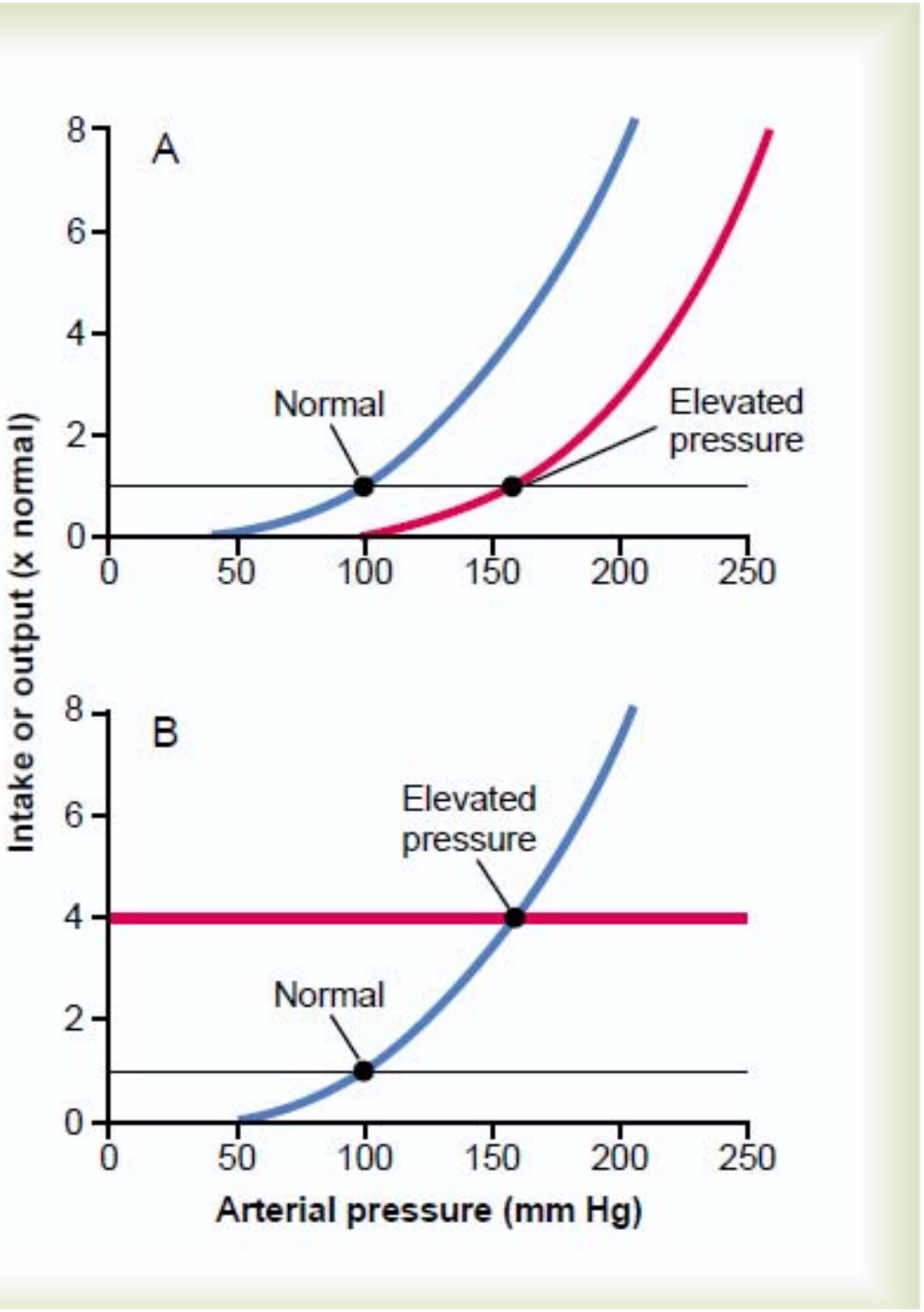

Glossopharyngeal ner
Hering's nerve
Carotid body
Carotid sinus
Vagus nerve
Aortic baroreceptors

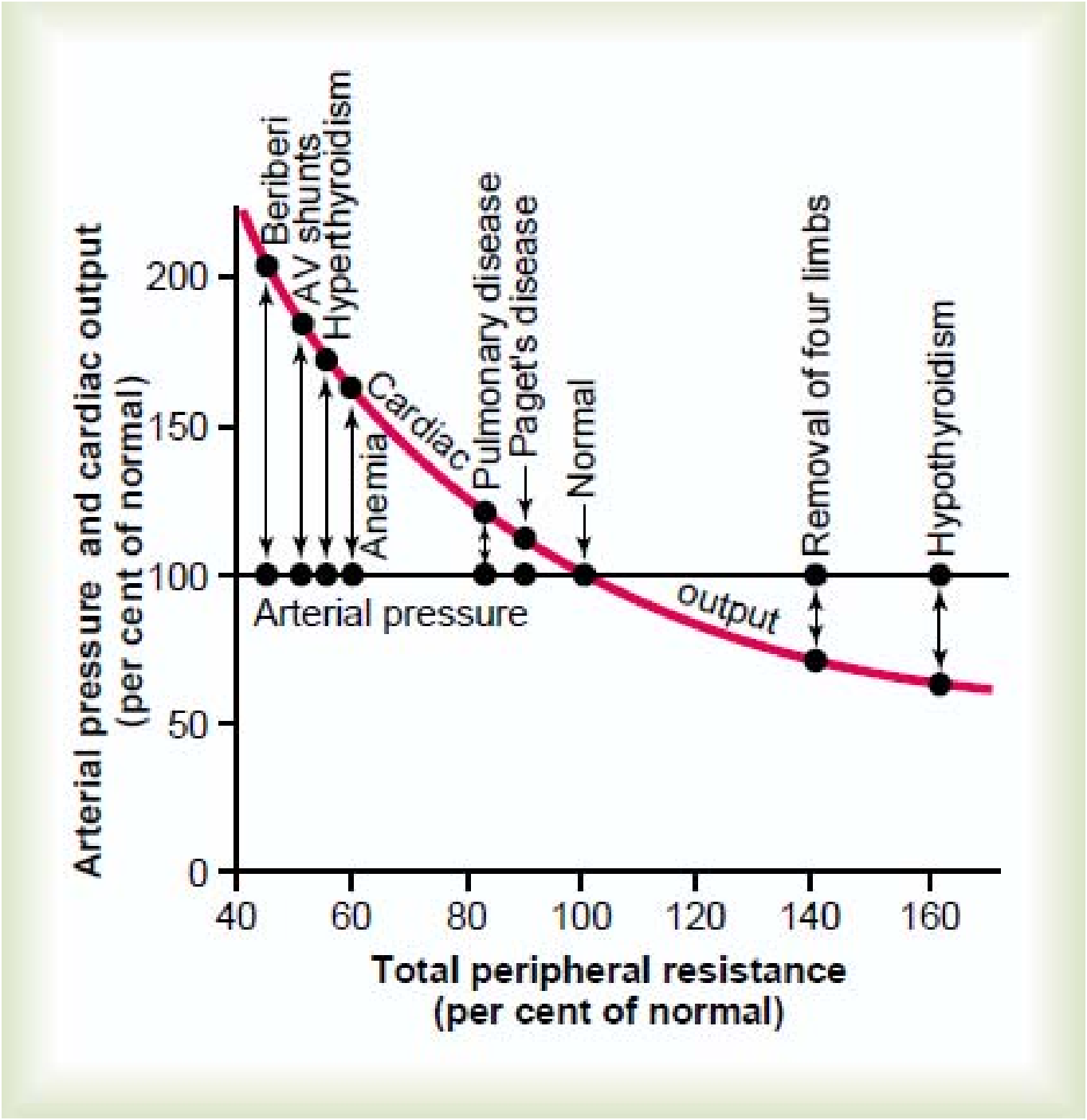

Number of impulses from carotid sinus nerves per second
ΔI/ΔP = maximum
0
80
160
244
Arterial blood pressure (mm Hg)


Arterial pressure (mm Hg)
150
125
100
75
50
25
0
Total spinal anesthesia
Injection of norepinephrine
0
5
10
15
20
25
Seconds

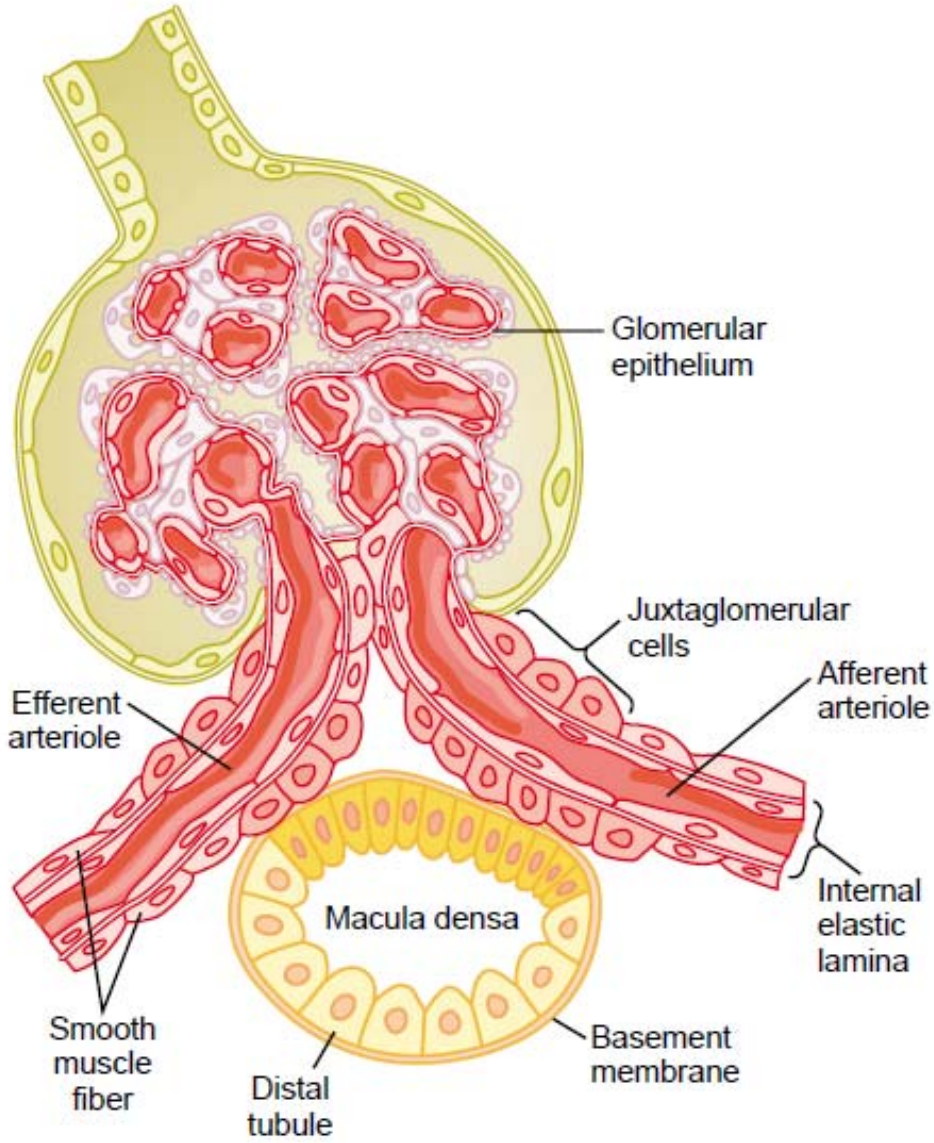

Urinary volume output (x normal)
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
120
140
160
180
200
Arterial pressure (mm Hg)

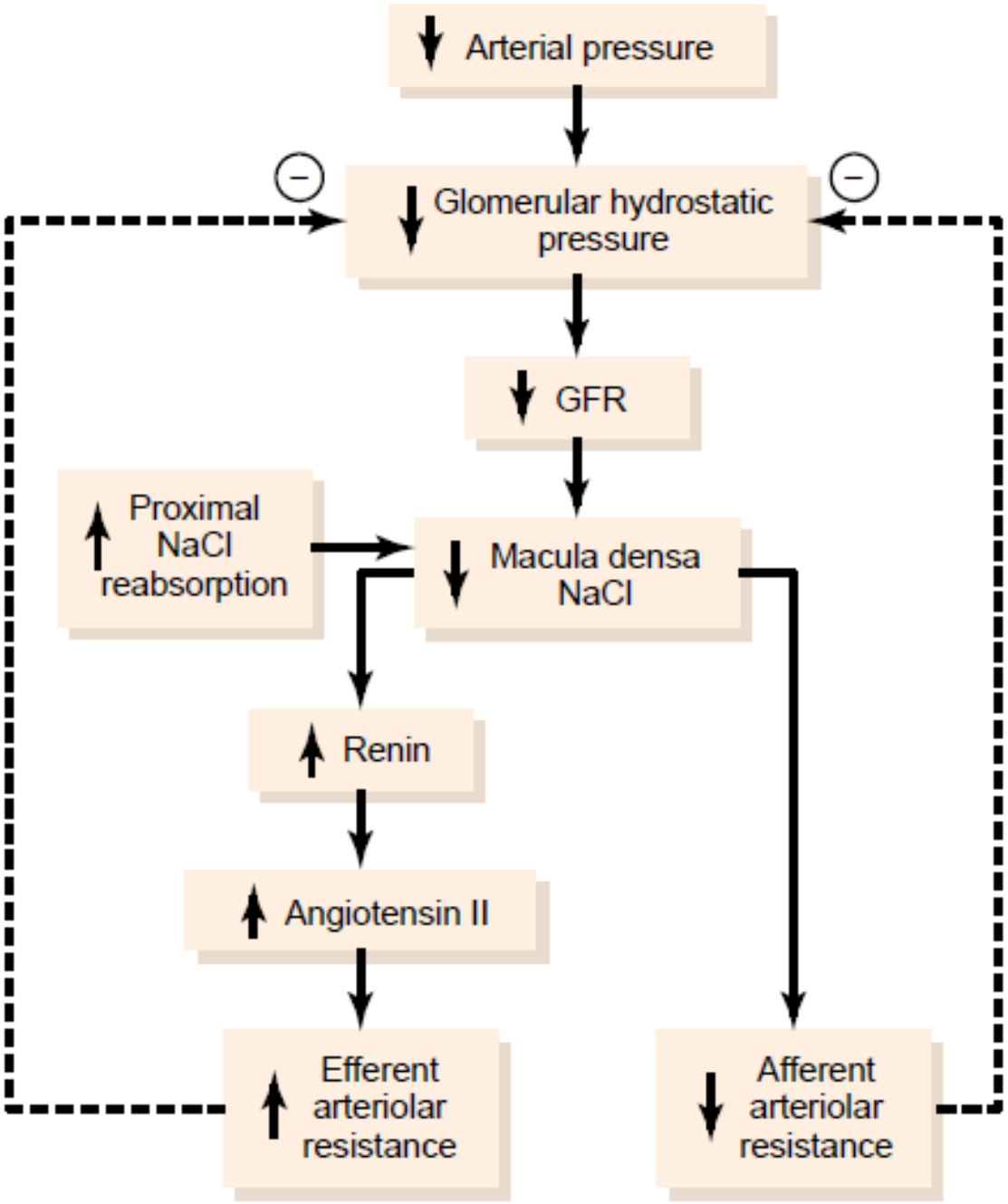

Renal output of water and salt
Water and salt intake
Intake or output (x normal)
8
6
4
2
0
Equilibrium point
0
50
100
150
250
Arterial pressure (mm Hg)

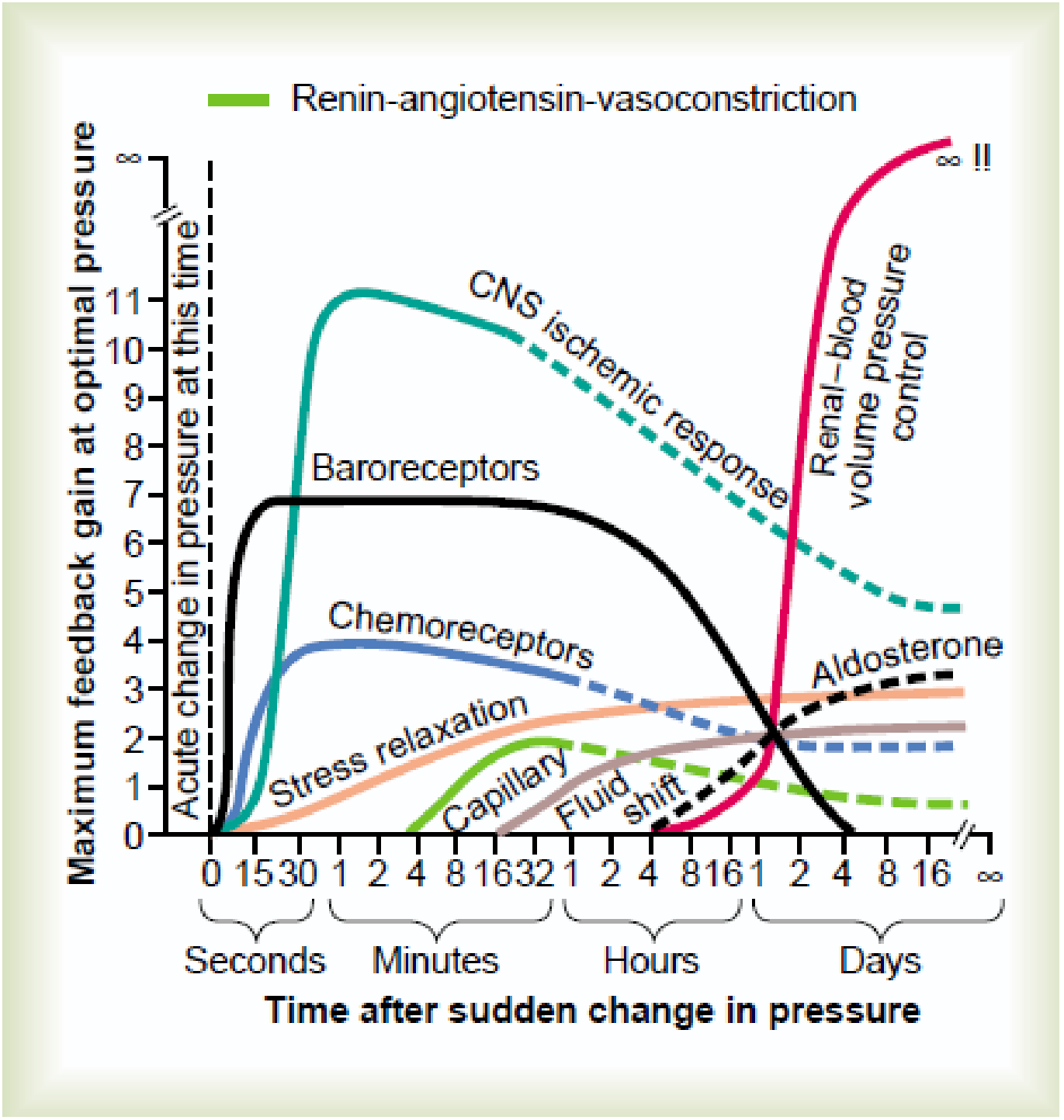

A
8
6
4
2
0
Normal
Elevated
pressure
0
50
100
150
200
250
B
Elevated
pressure
Normal
Intake or output (x normal)
Arterial pressure (mm Hg)

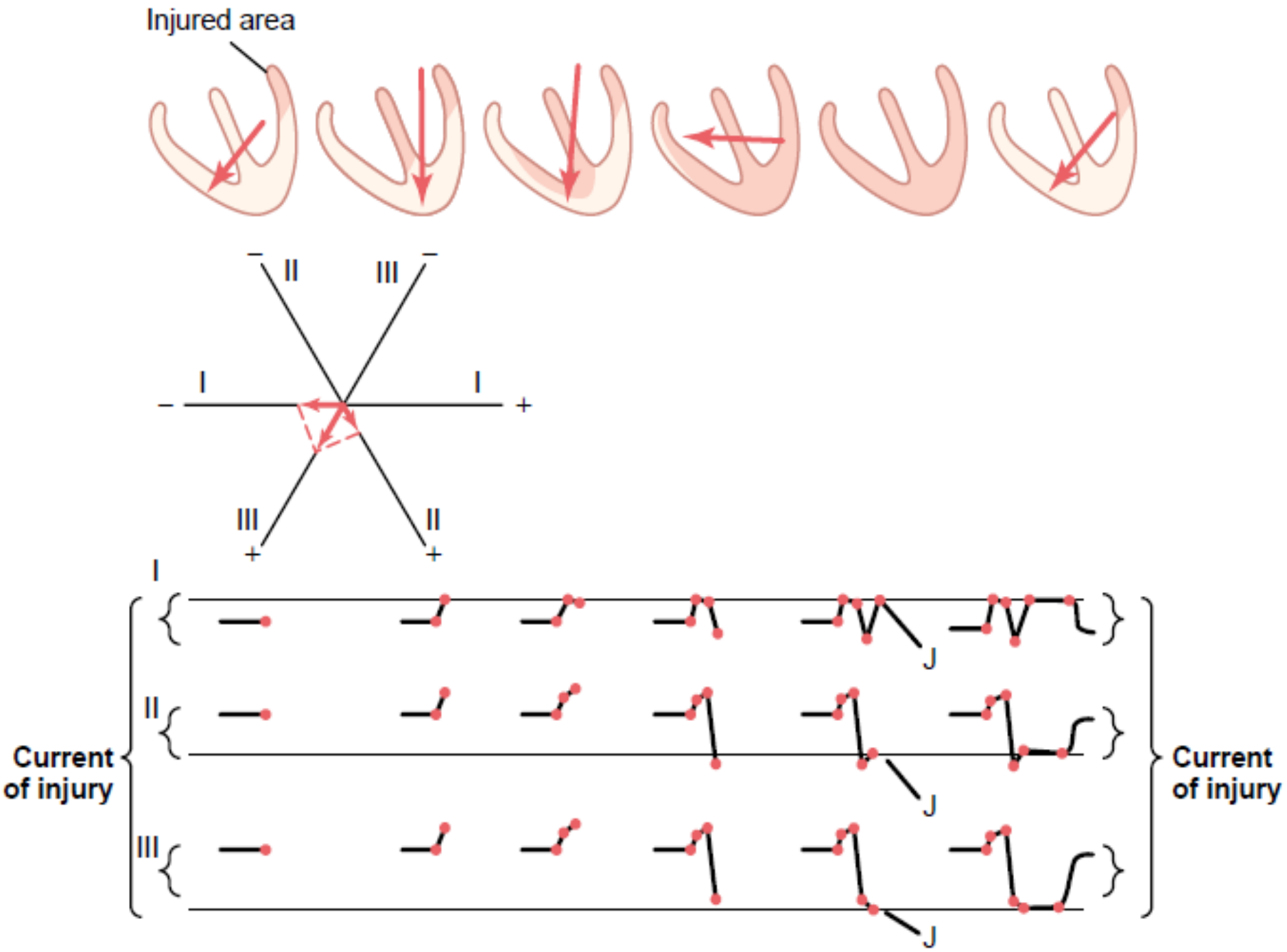

Arterial pressure and cardiac output
(per cent of normal)
200
150
100
50
0
40
60
80
100
120
140
160
Total peripheral resistance
(per cent of normal)
Beriberi
AV shunts
Hyperthyroidism
Anemia
Cardiac output
Pulmonary disease
Paget's disease
Normal
Removal of four limbs
Hypothyroidism
Arterial pressure

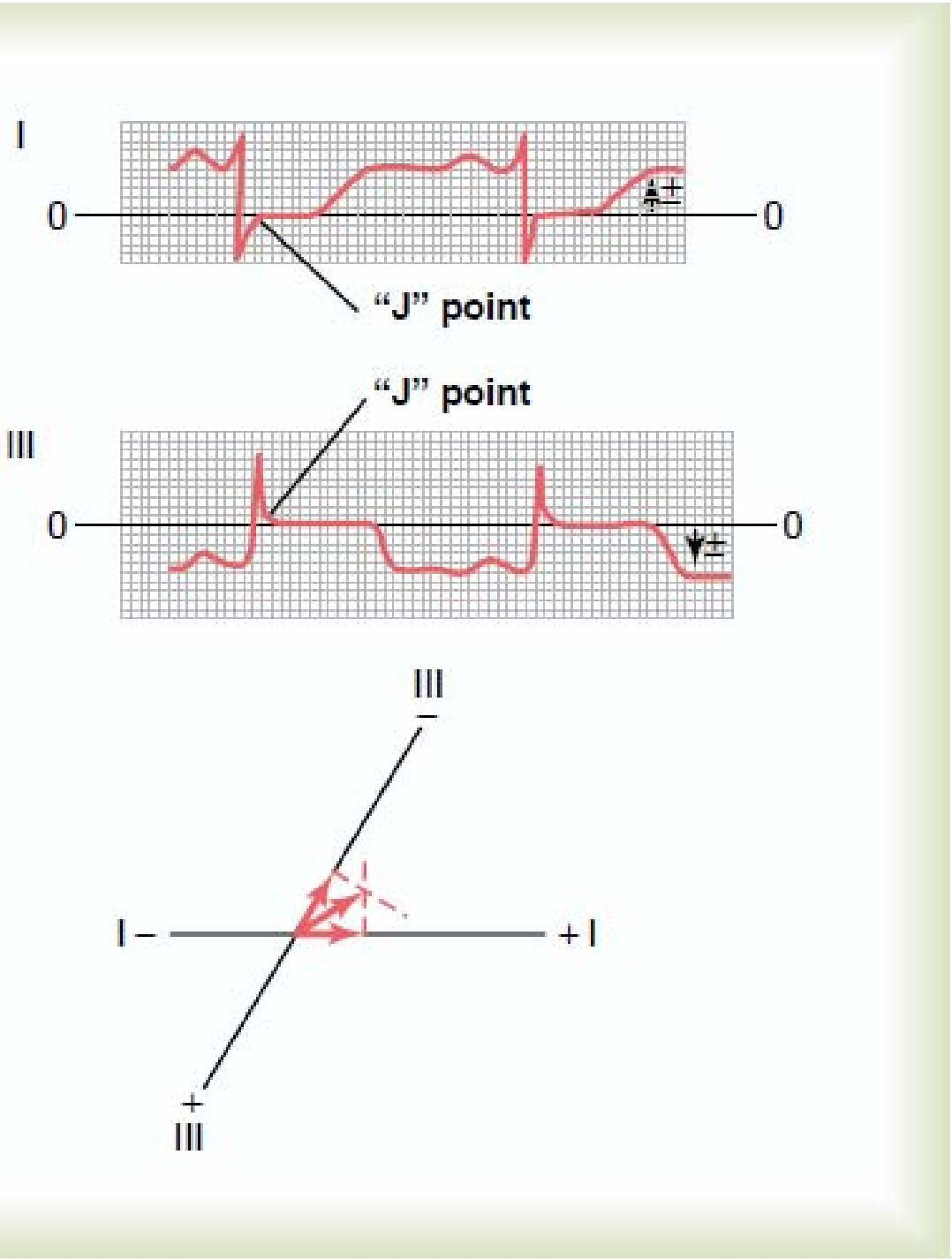
Renin- angiotensin System

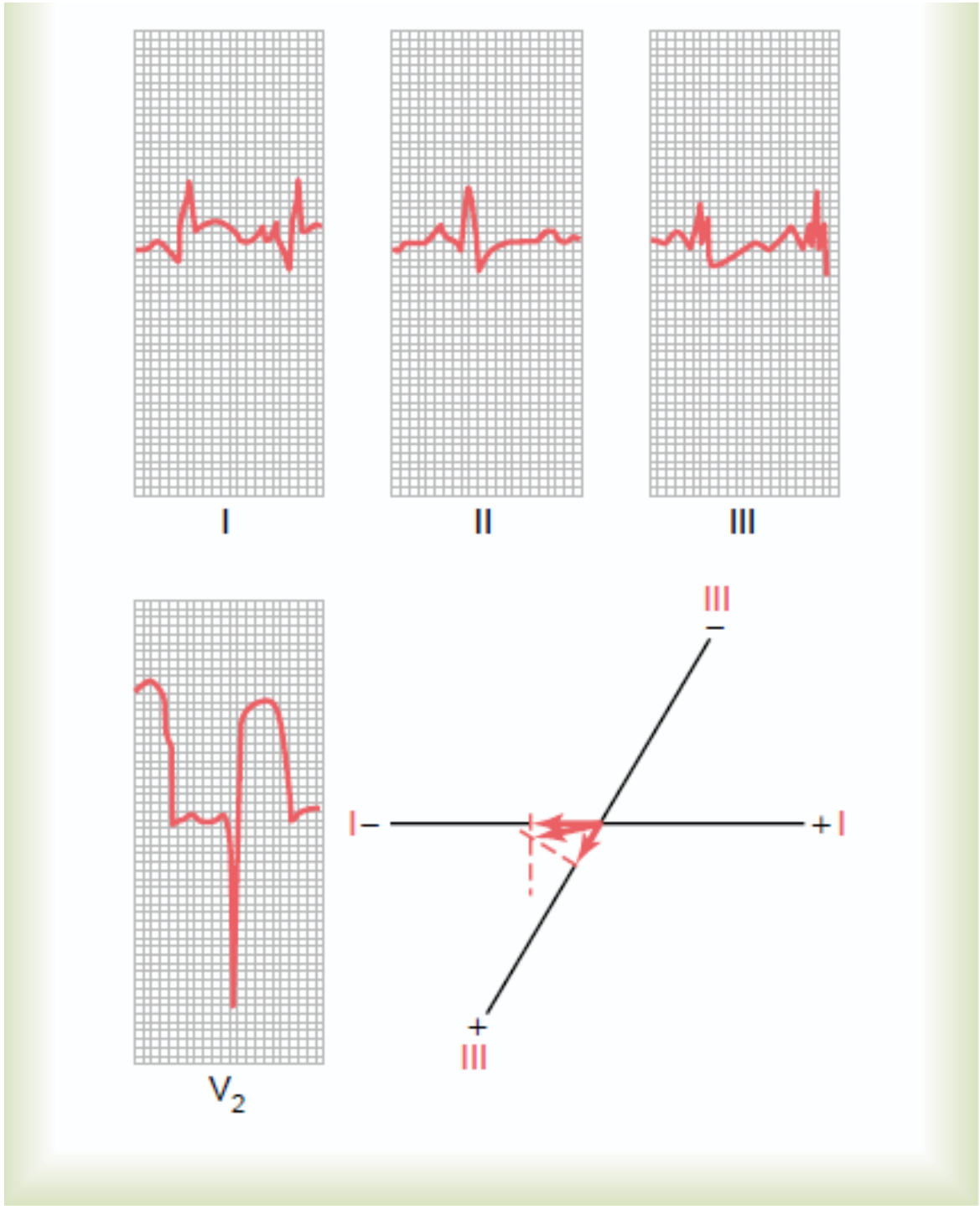



Arterial pressure
Glomerular hydrostatic pressure
GFR
Proximal NaCl reabsorption
Macula densa NaCl
Renin
Angiotensin II
Efferent arteriolar resistance
Afferent arteriolar resistance

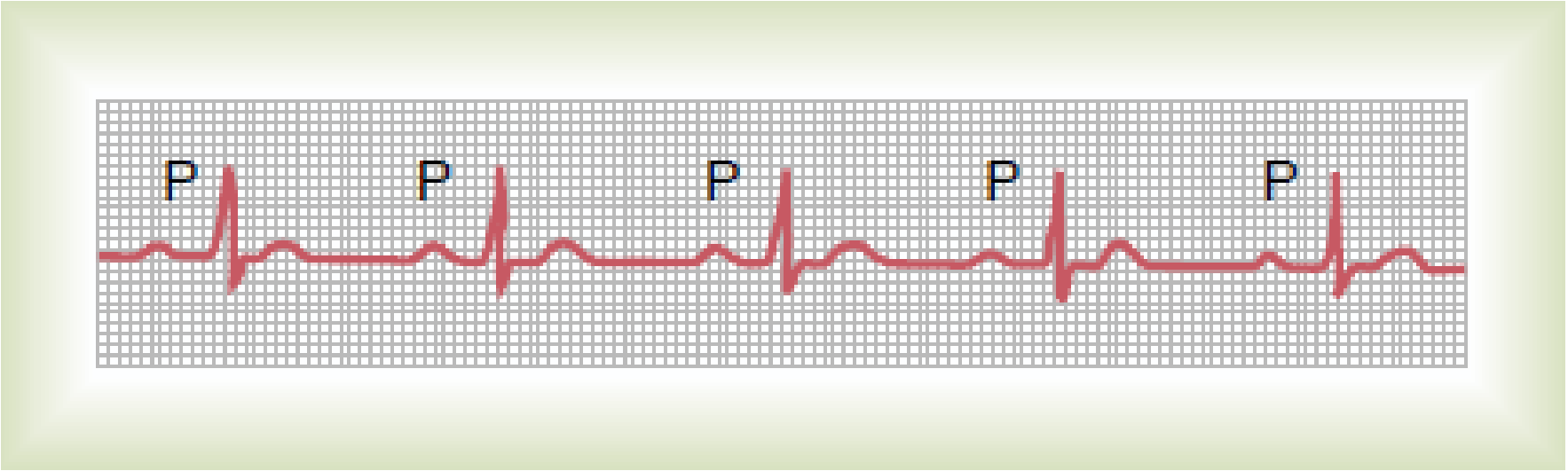

Renin-angiotensin-vasoconstriction
Maximum feedback gain at optimal pressure
Acute change in pressure at this time
∞
11
10
9
8
7
6
5
4
3
2
1
0
CNS ischemic response
Baroreceptors
Chemoreceptors
Stress relaxation
Capillary
Fluid shift
Aldosterone
Renal–blood volume pressure control
∞ II
0 15 30 1 2 4 8 16 32 1 2 4 8 16 1 2 4 8 16 ∞
Seconds
Minutes
Hours
Days
Time after sudden change in pressure


Injured area
−
II
III
−
I
I
−
+
III
II
+
+
I
II
III
J
J
J
Current of injury
Current of injury

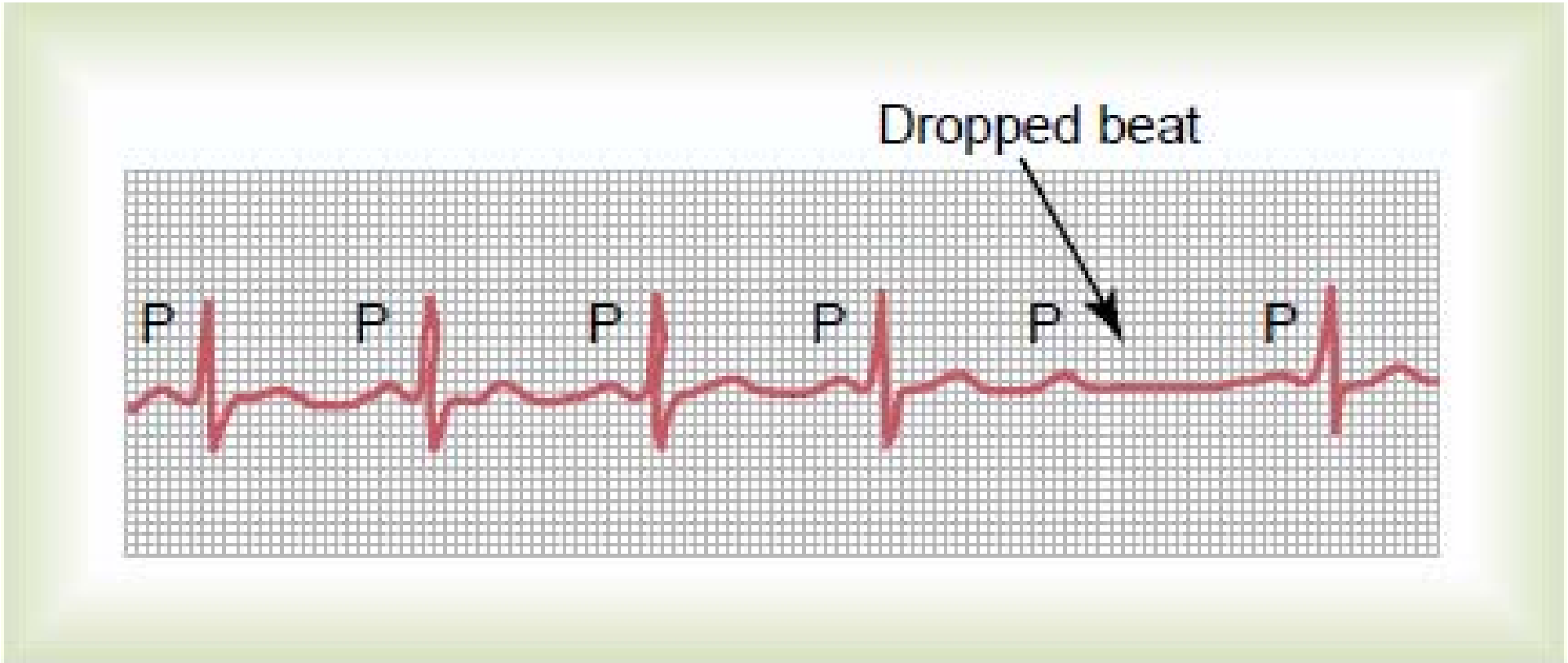

I
0
0
"J" point
III
"J" point
0
0
III
–
I –
+ I
+
III


I
II
III
V2
III
–
I –
+ I
+
III

1st degree heart block



2nd degree heart block



Complete heart block