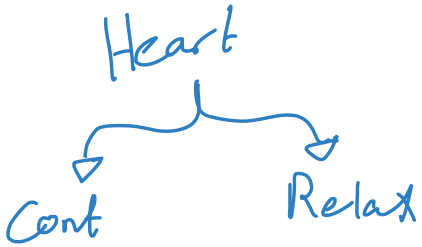
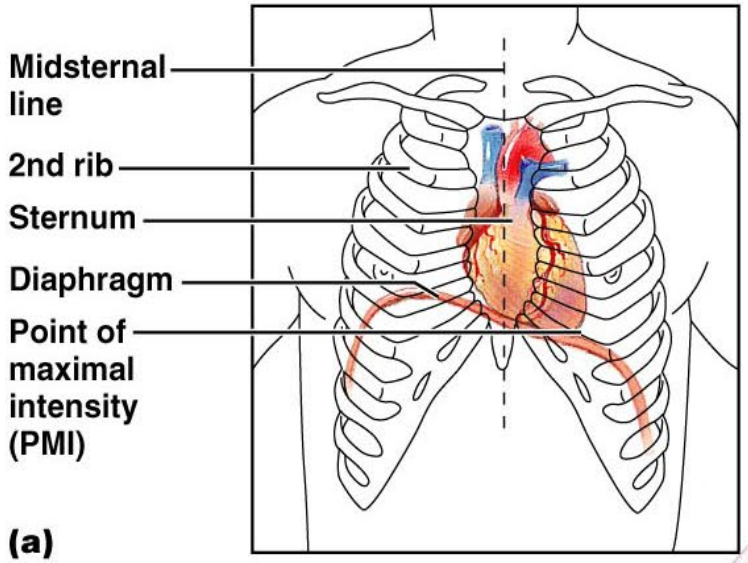
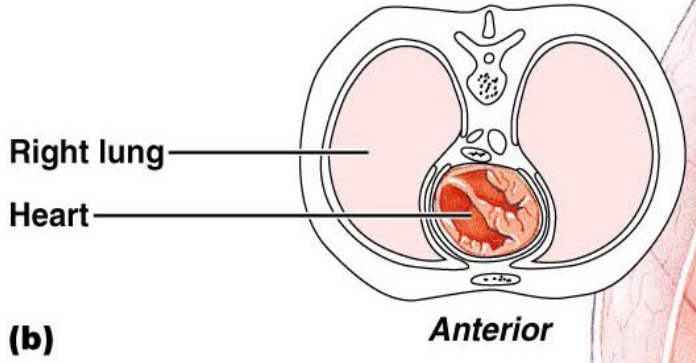
Cardiovascular system

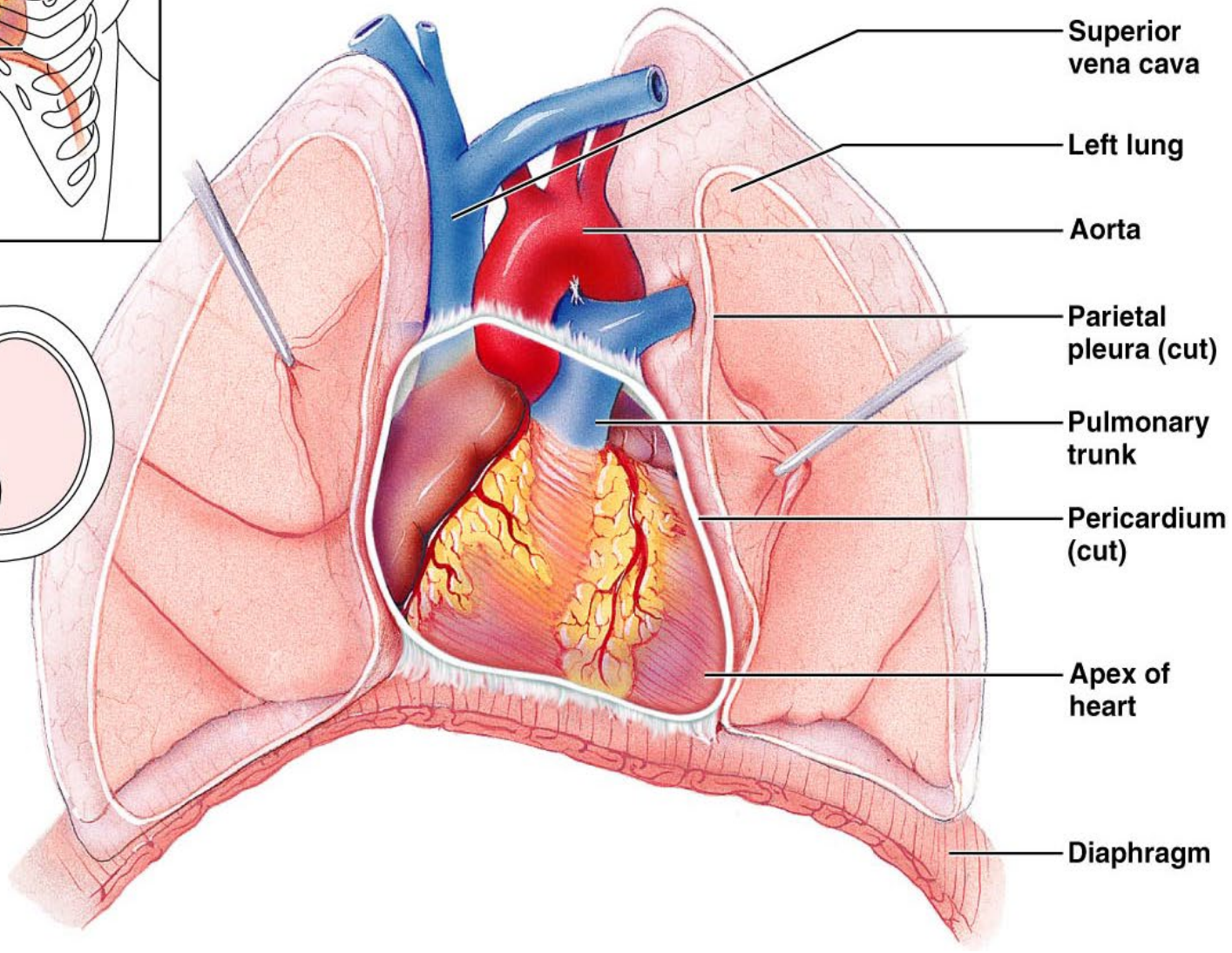


Dr Safa Abdul Ghani

Heart Anatomy





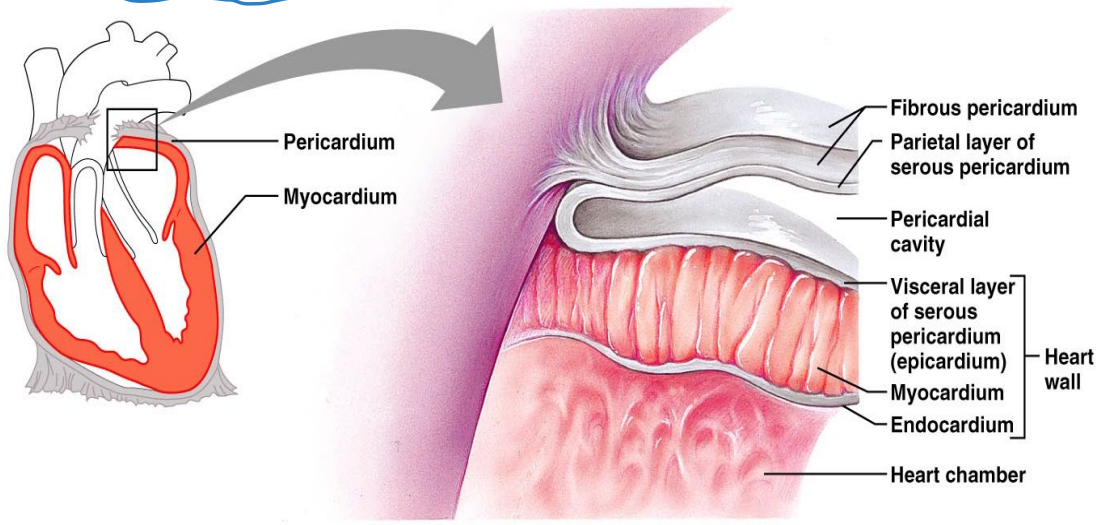


Superior surface of diaphragm

- Left of the midline
- Anterior to the vertebral column, posterior to the sternum

Coverings of the Heart: Anatomy

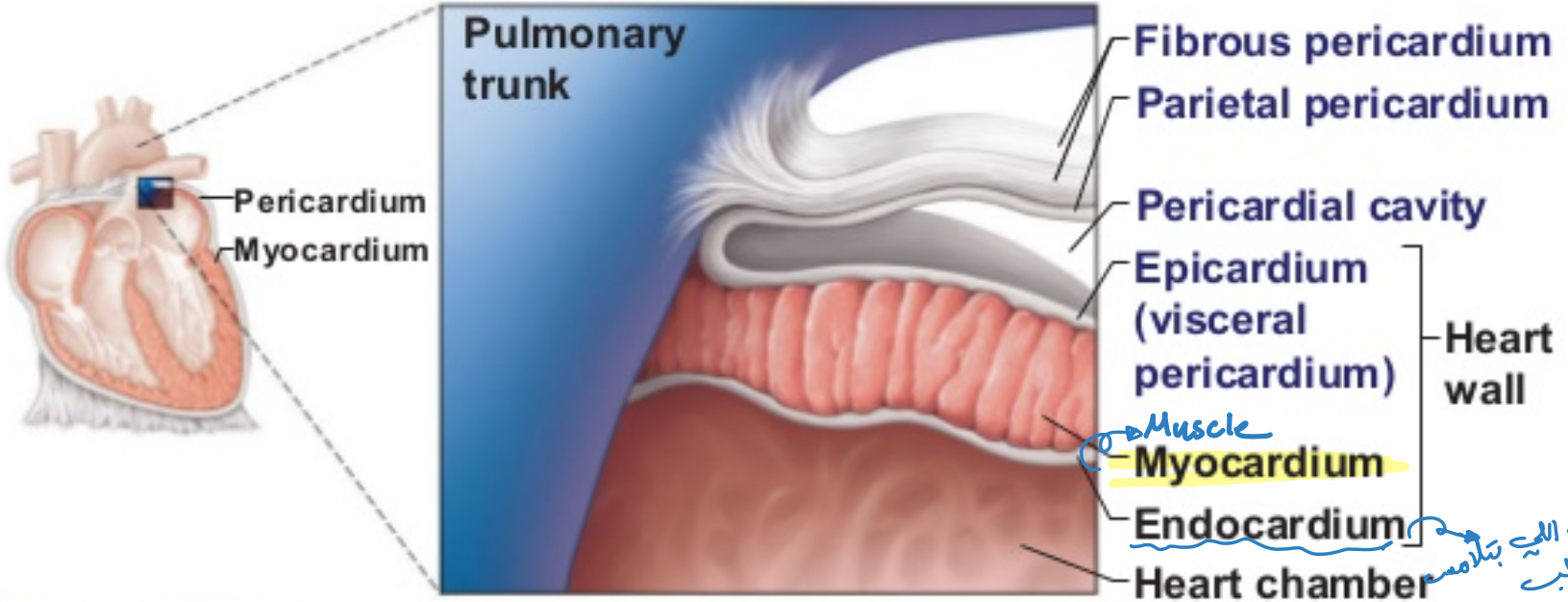
- **Pericardium** – a double-walled sac around the heart composed of:
  - A superficial fibrous pericardium **(Outer pericardium)**
  - A deep two-layer pericardium **(Inner pericardium)**
    - The parietal layer lines the internal surface of the fibrous pericardium
    - The visceral layer or epicardium lines the surface of the heart
  - ➢ They are separated by the fluid-filled **pericardial cavity**



- The pericardium:
  - Protects and anchors the heart
  - Prevents overfilling of the heart with blood
  - Allows for the heart to work in a relatively friction-free environment

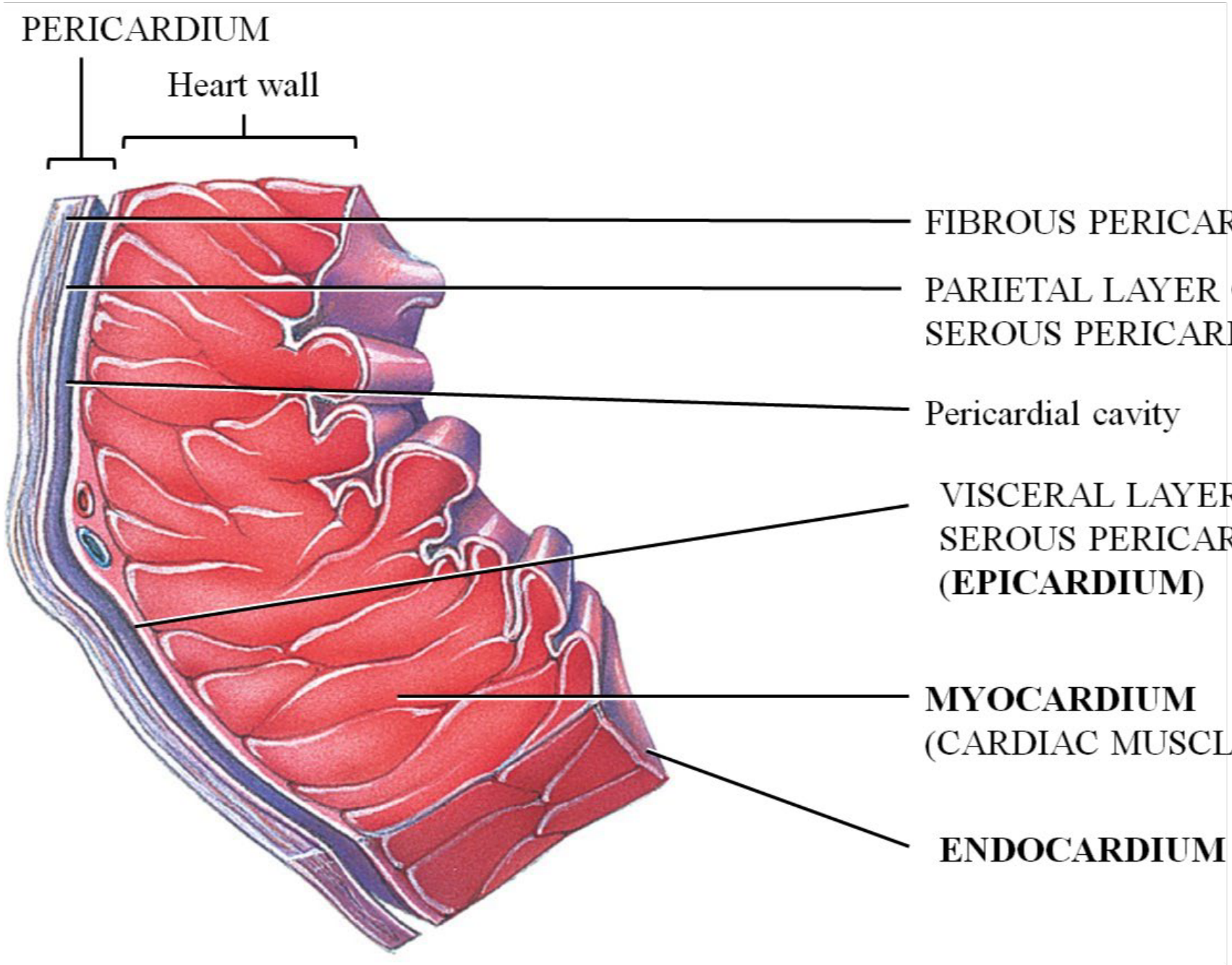
Layers of the Heart Wall

1. **Epicardium** — inner pericardium layer
2. **Myocardium -** cardiac muscle layer
3. **Endocardium -** inner layer of heart

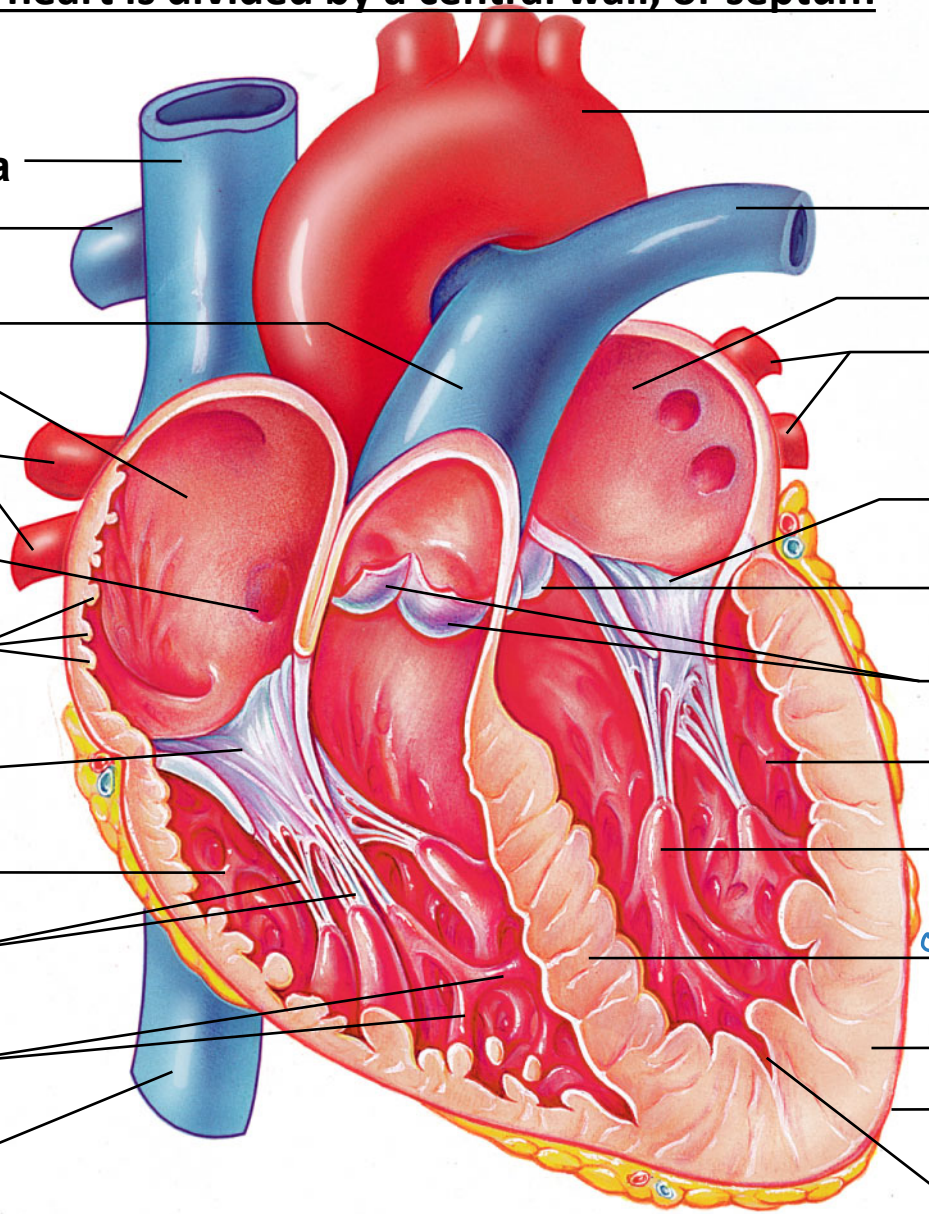


Heart Wall

- Epicardium – Fused with the visceral layer of the serous pericardium
- Myocardium – cardiac muscle layer forming the bulk of the heart (Middle/thick portion)
- Endocardium – endothelial layer of the inner myocardial surface (direct contact with blood inside our chambers)


PERICARDIUM
Heart wall
FIBROUS PERICARDIUM
PARIETAL LAYER OF SEROUS PERICARDIUM
Pericardial cavity
VISCERAL LAYER OF SEROUS PERICARDIUM (EPICARDIUM)
MYOCARDIUM (CARDIAC MUSCLE)
ENDOCARDIUM
Outer Pericardiuom
Inner Pericardiuom (Serous Layer)
Heart wall

The heart is divided by a central wall, or septum



Superior vena cava
Right pulmonary artery
Pulmonary trunk
Right atrium
Right pulmonary veins
Fossa ovalis
Pectinate muscles
Tricuspid valve
Right ventricle
Chordae tendineae
Trabeculae carneae
Inferior vena cava
(e)

Aorta
Left pulmonary artery
Left atrium
Left pulmonary veins
Mitral (AV) valve
(bicuspid) valve
Aortic valve
Pulmonary valve
Left ventricle
Papillary muscle
Interventricular septum
Myocardium
Visceral pericardium
Endocardium

Figure 18.4e

Atria of the Heart

- Atria are the receiving chambers of the heart
- Each atrium has a protruding auricle
- Pectinate muscles mark atrial walls
- Blood enters right atria from superior and inferior venae cavae and coronary sinus
- Blood enters left atria from pulmonary veins

Ventricles of the Heart

- Ventricles are the discharging chambers of the heart
- Papillary muscles and trabeculae carneae muscles mark ventricular walls
- Right ventricle pumps blood into the pulmonary trunk
- Left ventricle pumps blood into the aorta

Right and Left Ventricles

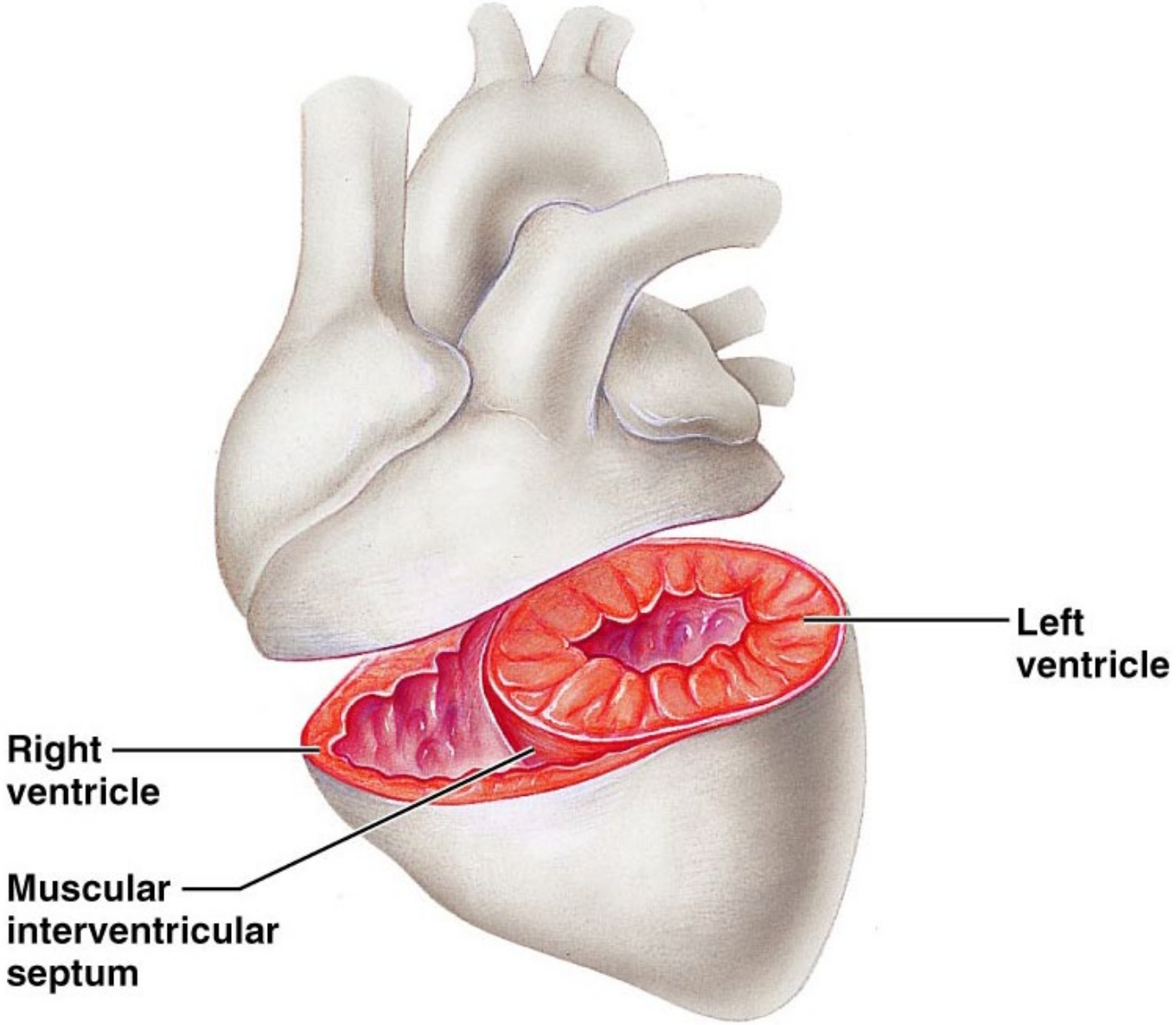


Figure 18.6

FUNCTION OF THE CARDIOVASCULAR SYSTEM:

* يتحرك الدم عبر الأوعية الدموية
عن طريق فرق الضغط "Hydrostatic pressure"
* وكلما زاد فرق الضغط تزيد سرعة حركة الدم

200 A 99
10 B 5
A > B

- The major functions of the cardiovascular system are:

1. <u>Transports Materials Throughout the Body:</u>

(1) nutrients, water, and gases that enter the body from the external environment

(2) materials that move from cell to cell within the body

(3) wastes that the cells eliminate

2. <u>Create hydrostatic pressure</u> to transport nutrients, gases and waste products around the body through blood vessels

3. <u>To maintain homeostasis</u>

- To help maintain fluid balance within the body
- To help the body maintain a constant body temperature ('thermoregulation')
- To protect the body from infection (WBC) and blood loss(Platelets)

"تخثر"

Cardiovascular system is closed system (closed circuit)

- The cardiovascular systems of humans are closed, meaning that the **blood never leaves the network of blood vessels**. In contrast, oxygen and nutrients diffuse across the blood vessel layers and enter interstitial fluid, which carries oxygen and nutrients to the target cells, and CO_2 and wastes in the opposite direction

➢Closed circuit can be divided: * كمية الدم اللي طلعت = اللي دخلت
ال Contents هي اللي بتغير

1- Systemic Circulation: (Carry oxygenated blood from heart → tissue

Then deoxygenated blood from tissue → heart)

2- Pulmonary Circulation:(Carry deoxy blood from heart → Lung then carry oxygenated blood from Lung → heart)

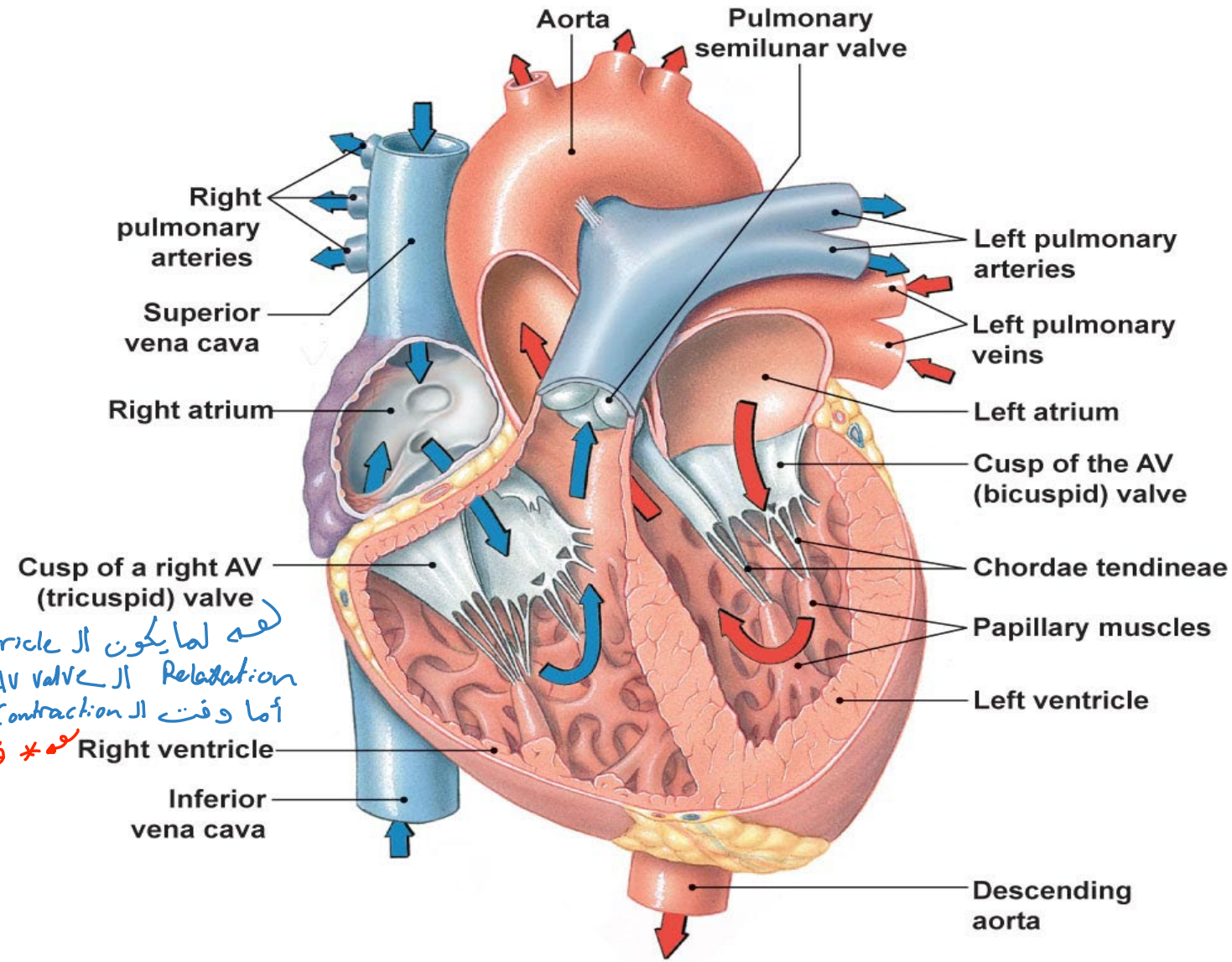
Types of blood vessels: Major Vessels of the Heart (Anterior View)

- Vessels returning blood to the heart include: **(Veins)**
  - Superior and inferior venae cavae
  - Right and left pulmonary veins
- Vessels carrying blood away from the heart: **(Artery)**
  - Pulmonary trunk, which splits into right and left pulmonary arteries
  - Ascending aorta (three branches) – brachiocephalic, left common carotid, and subclavian arteries

Functional Anatomy of the Heart

Chambers

- 4 chambers
  - 2 Atria
  - 2 Ventricles
- 2 systems
  - Pulmonary
  - Systemic



لهذا لما يكون ال Ventricle بتكون ال AV valve فاتحة Relaxation
أما وقت ال Contraction بتكون مسكرة ال AV valve
* فرق ال pressure هو اللي بتحكم فيهم

Pathway of Blood Through the Heart and Lungs

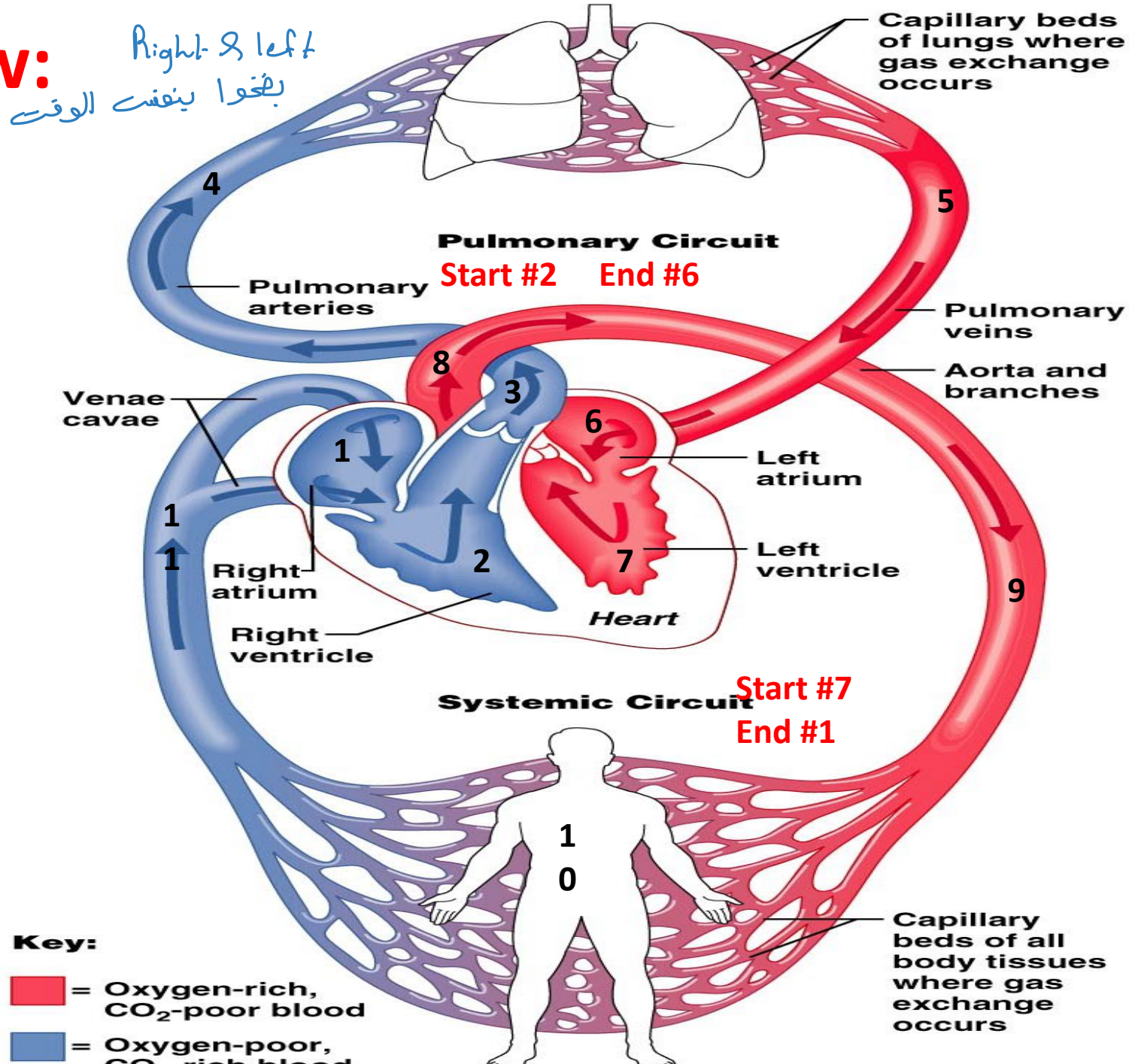
- Right atrium → tricuspid valve → right ventricle
- Right ventricle → pulmonary semilunar valve → pulmonary arteries → lungs
- Lungs → pulmonary veins → left atrium
- Left atrium → bicuspid valve → left ventricle
- Left ventricle → aortic semilunar valve → aorta
- Aorta → systemic circulation

Pathway of Blood Flow:

Right & left بضخوا بنفس الوقت

1. Deoxygenated blood return to Right Atrium
2. Move into Right ventricle
3. R ventricle pump deoxygenated blood to pulmonary artery
4. Blood in pulmonary artery moves into arterioles then capillary (exchange)
5. Oxygenated blood in pulmonary veins
6. Moves into Left atrium
7. Moves into L ventricle
8. Left ventricle pump oxygenated blood into Aorta
9. Moves into descending ascending aorta
10. Oxygenated blood carried into organs
11. Deoxygenated blood return through vena cava back to the right atrium (#1)

➢ (Unidirectional flow)



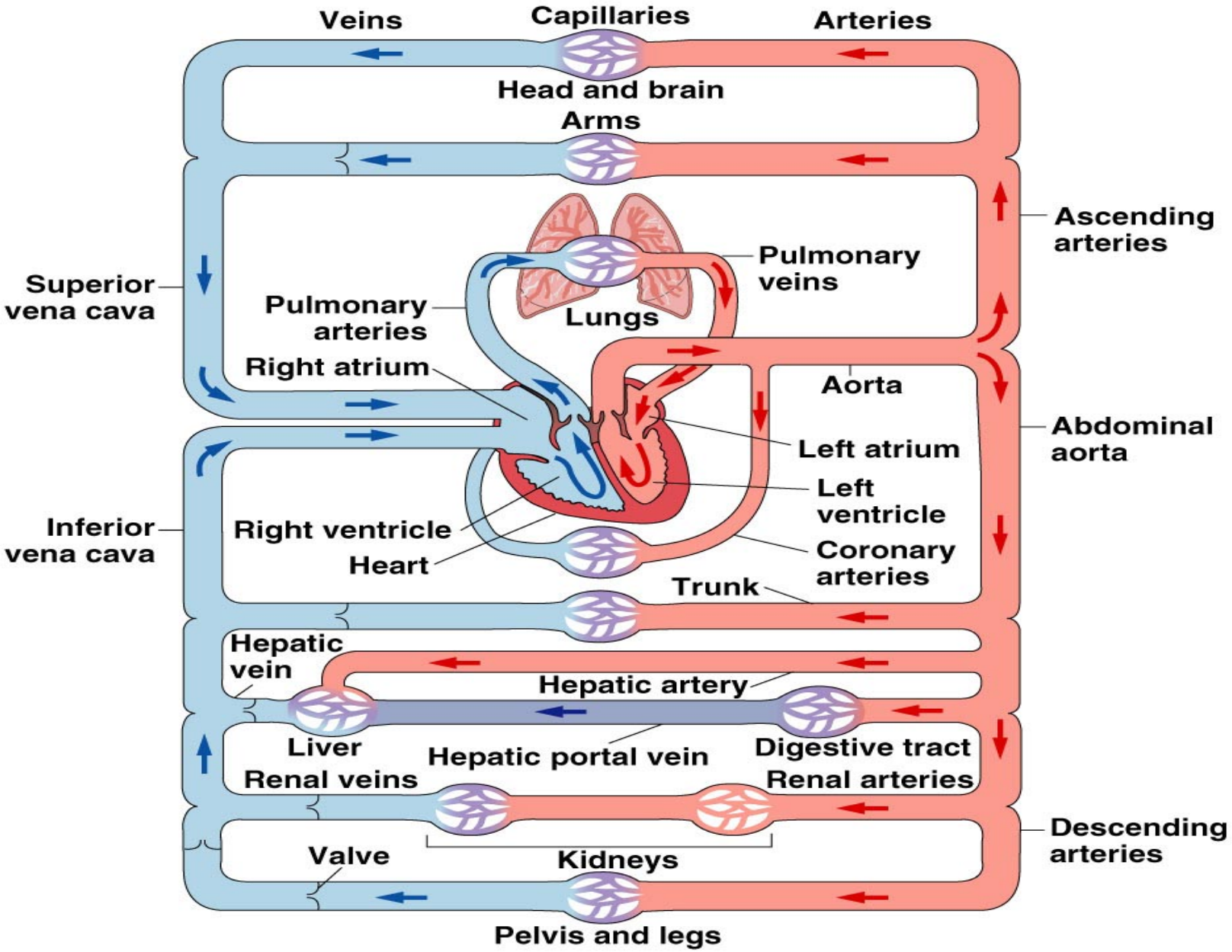
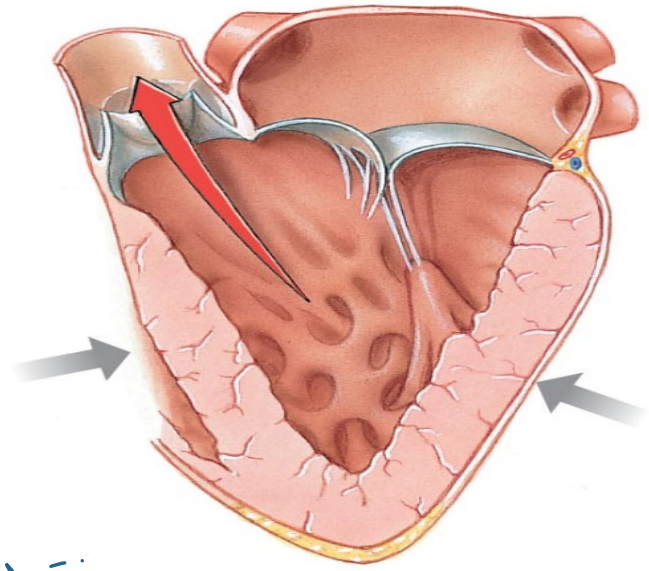


Figure 14-1

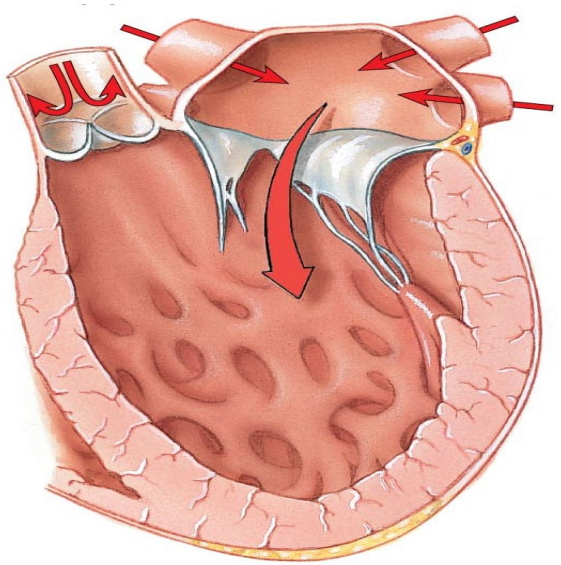
Functional Anatomy of the Heart

Valves (One way flow)



- **Function is to prevent backflow**
  - Atrioventricular Valves
    - Prevent backflow to the atria
    - Prolapse is prevented by the chordae tendinae
      - Tensioned by the papillary muscles
  - Semilunar Valves
    - Prevent backflow into ventricles

فقصد ال AV valve اللي عندهم ال papillary muscle عشان تتعيب فتح ال valve من قوة ال pressure



Fibrous connective tissue acts as an electrical insulator, blocking most transmission of electrical signals between the atria and the ventricles.

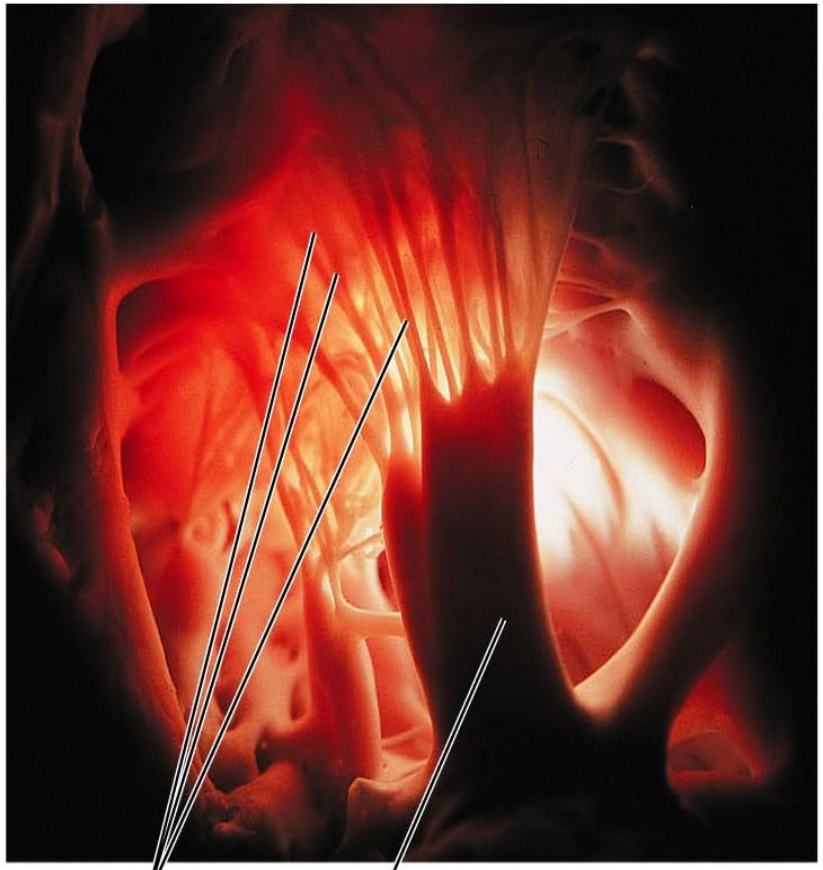
عشان صيك بتتجمع الكهرباء بـ AV node

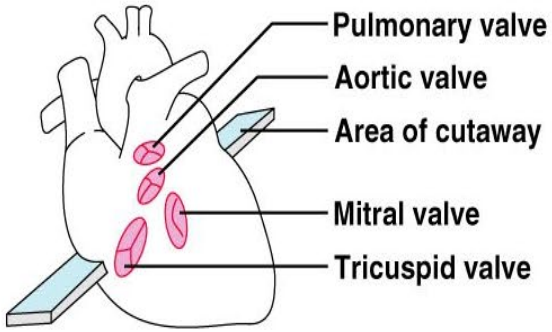
Heart Valves

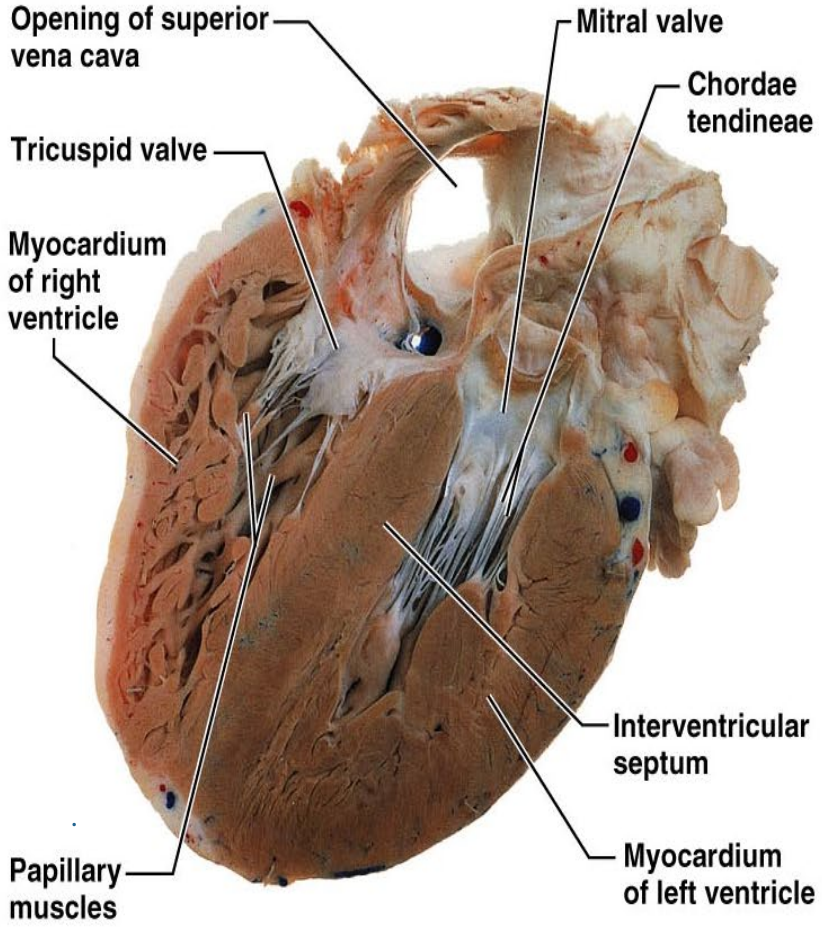
Heart valves ensure unidirectional blood flow through the heart

Atrioventricular (AV) valves lie between the atria and the ventricles

AV valves prevent backflow into the atria when ventricles contract
Chordae tendineae anchor AV valves to papillary muscles







* AV valve
pointed down
pressure بفتحو ويسكروا على حسب الـ
مين اعلى فوق أم تحت

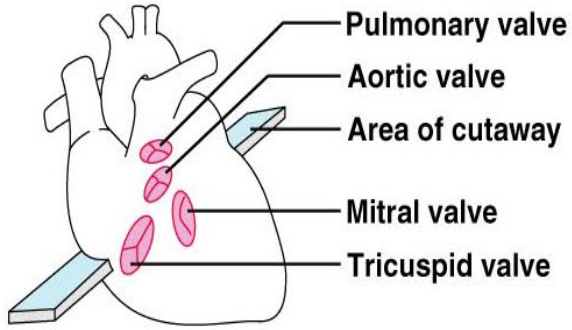
* semilunar valve
pointed up
ولازم يكون الـ pressure تحت بالـ Ventricle أعلى عشان تفتح الـ Valve

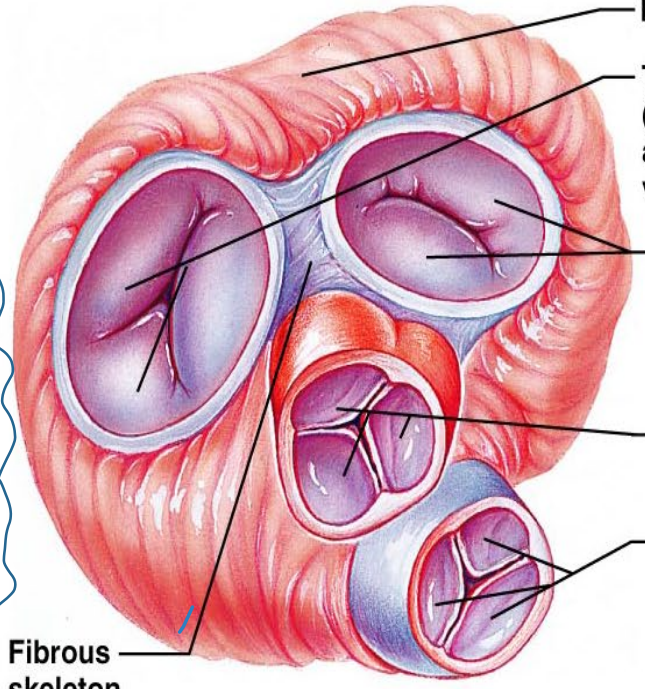
Figure 18.8c, d

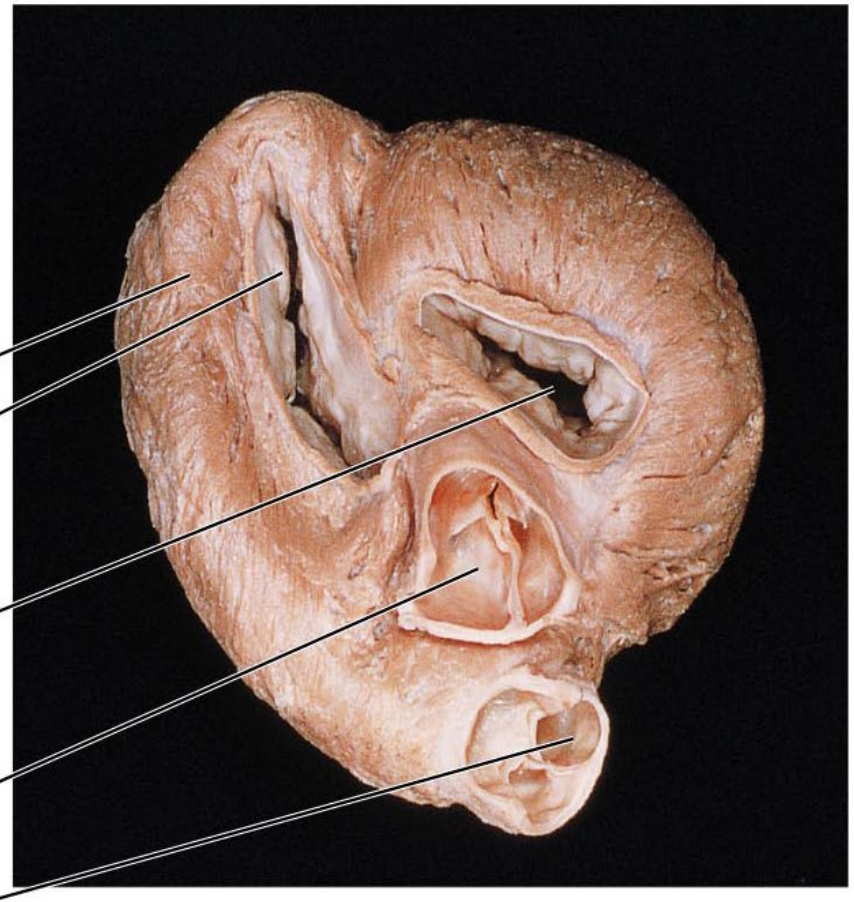
Heart Valves

Right AV valve
(Tricuspid valve)

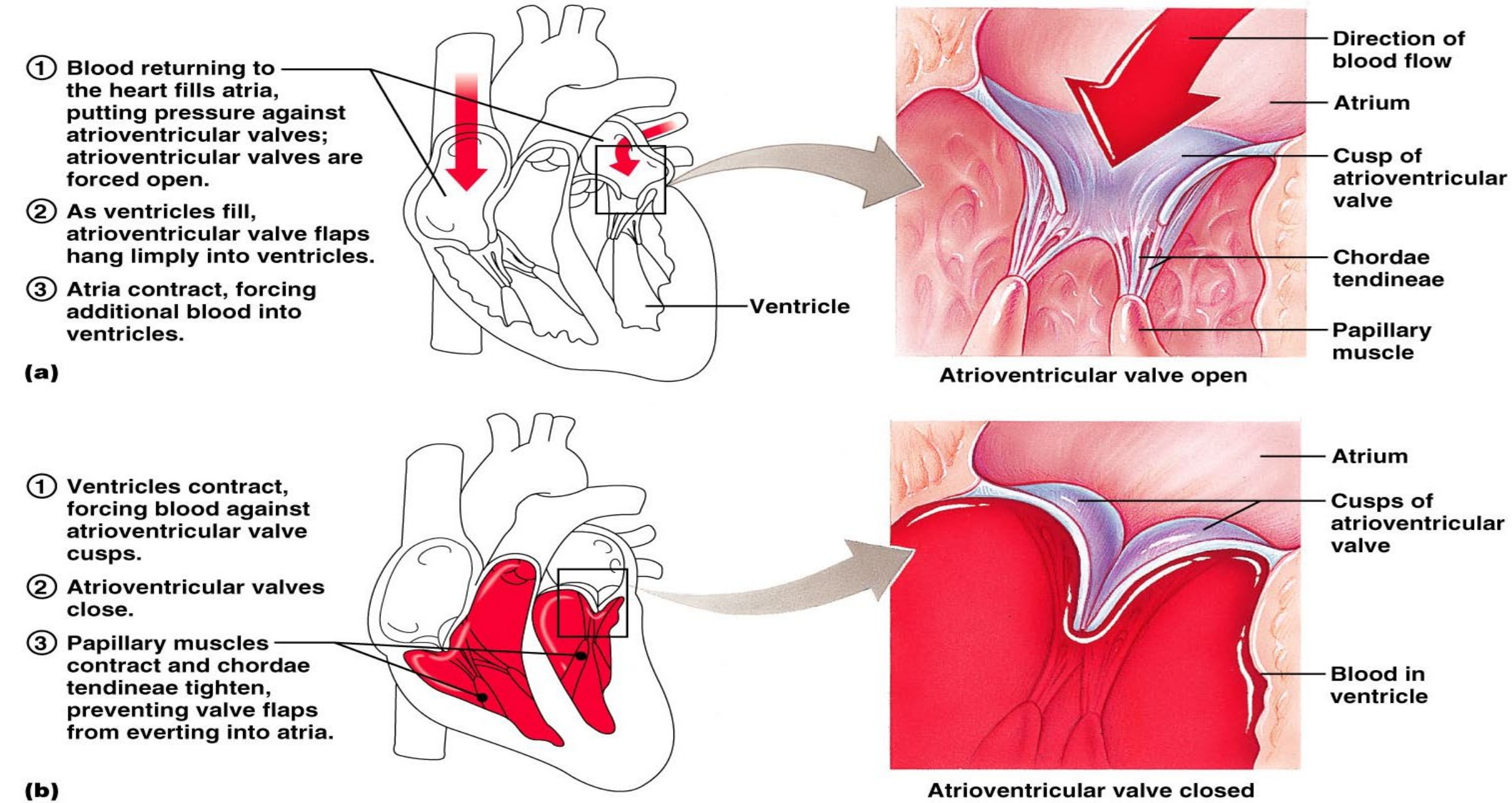
Left AV valve
(Bicuspid valve)
also called Mitral







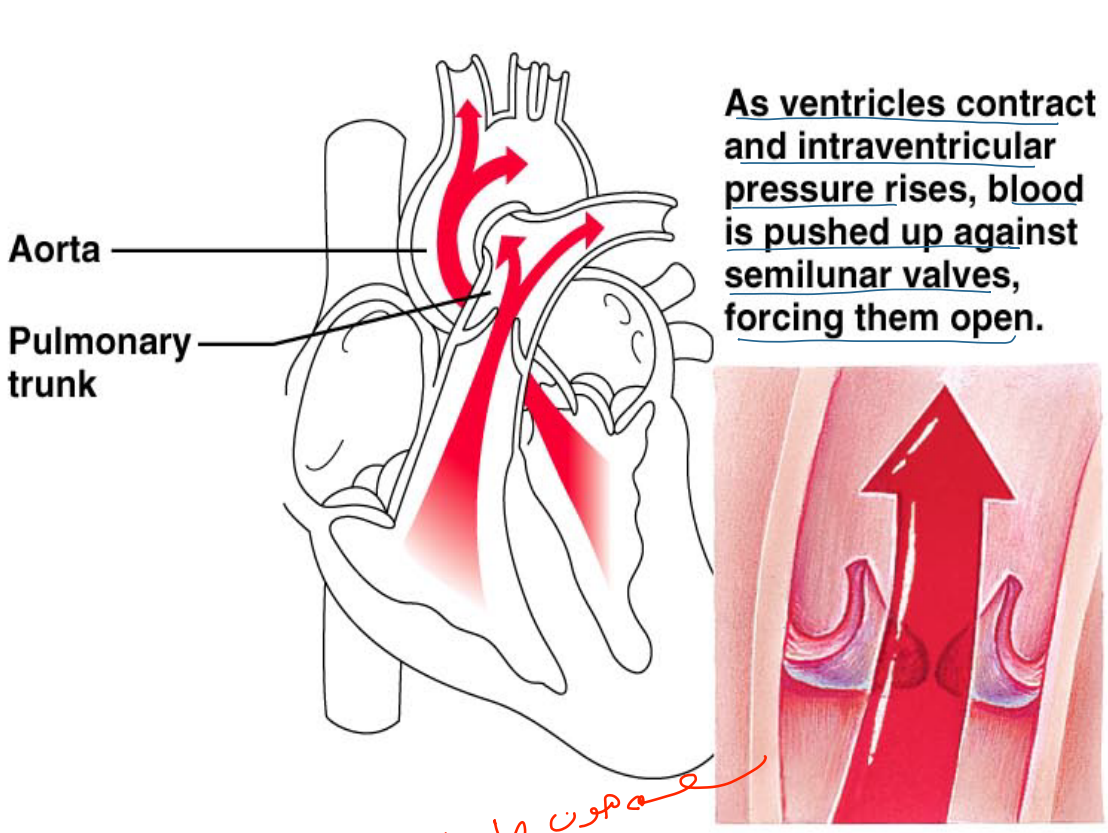
Atrioventricular Valve Function



* كلما زاد الـ Volume يقل الـ pressure

V↑ P↓ V↓ P↑

Semilunar Valve Function



عشان يصير الـ pressure بالـ Ventricle أعلى

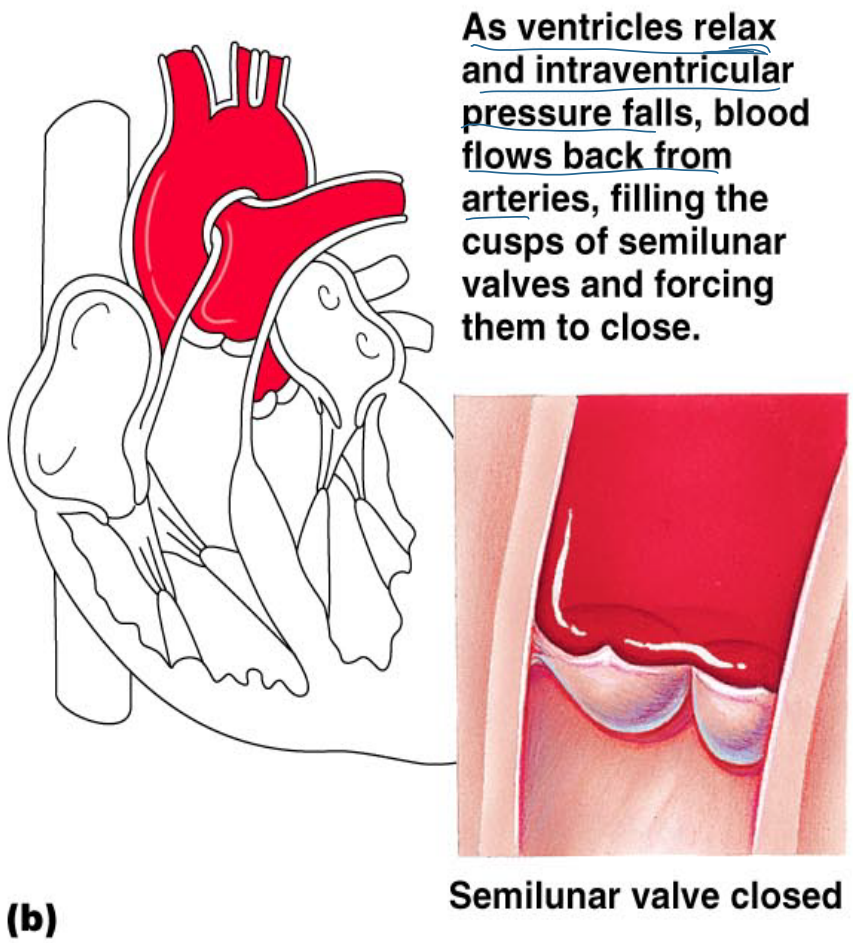


Figure 18.10

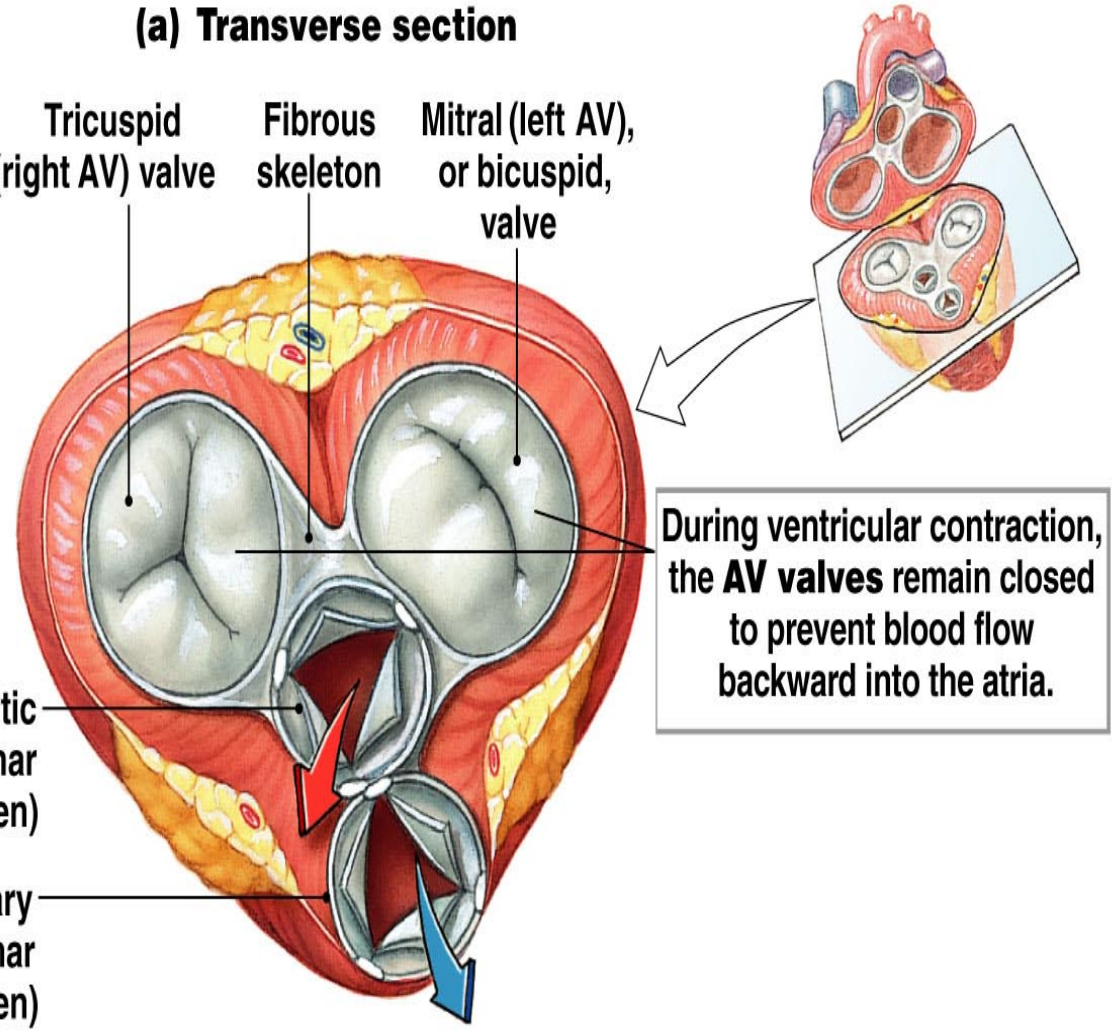
Heart Valves

- During Relaxation: AV valves open & Semilunar close
- During Contraction: Semilunar valves open & AV close

* مستحيل يكون الـ AV valve & Semilunar فاتحين مع بعض غير الأطراف
* لكن بتظير انو الـ AV & Semilunar مع بعض مسكرين

VENTRICULAR CONTRACTION

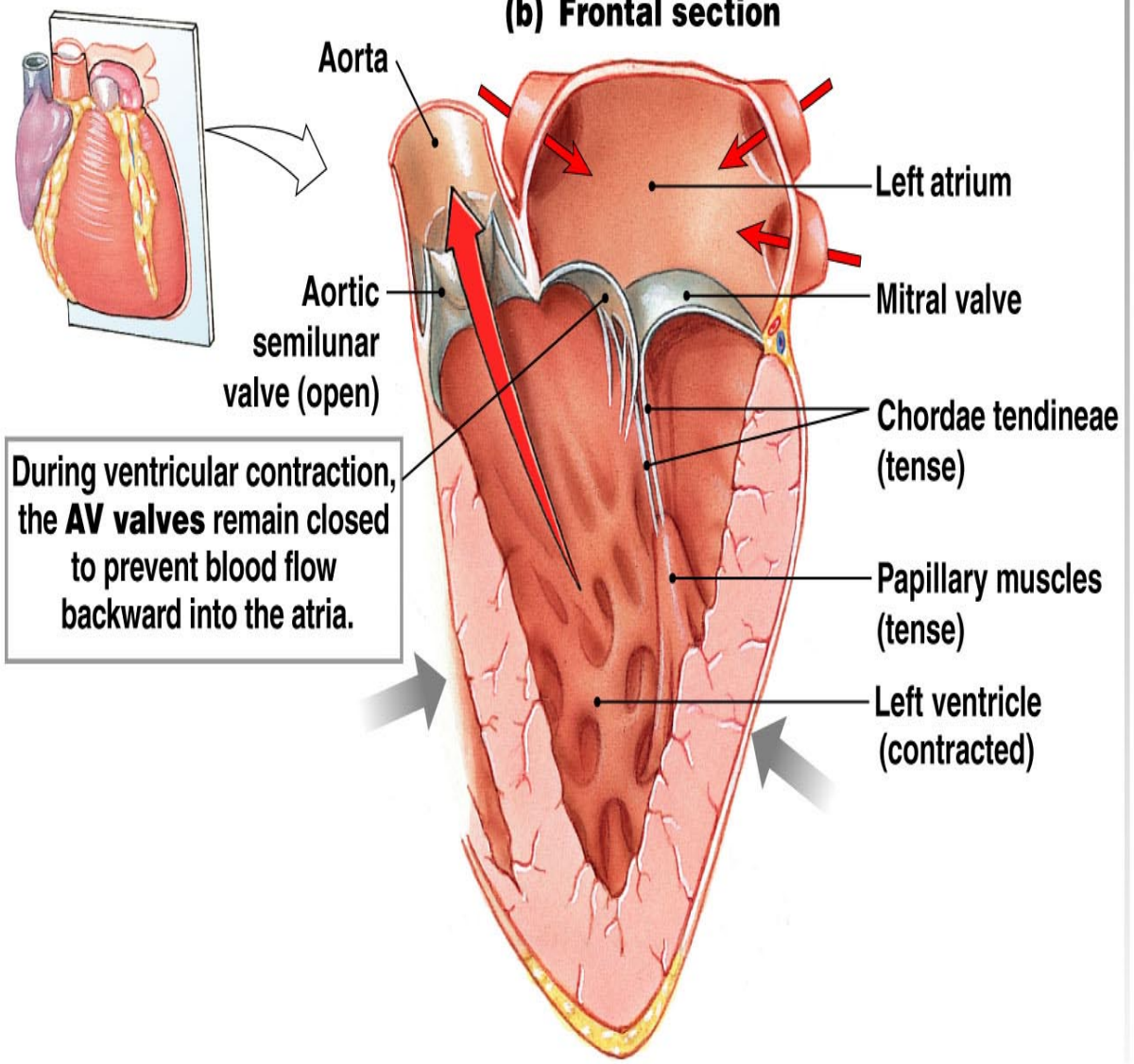
(a) Transverse section



During ventricular contraction, the **AV valves** remain closed to prevent blood flow backward into the atria.

VENTRICULAR CONTRACTION

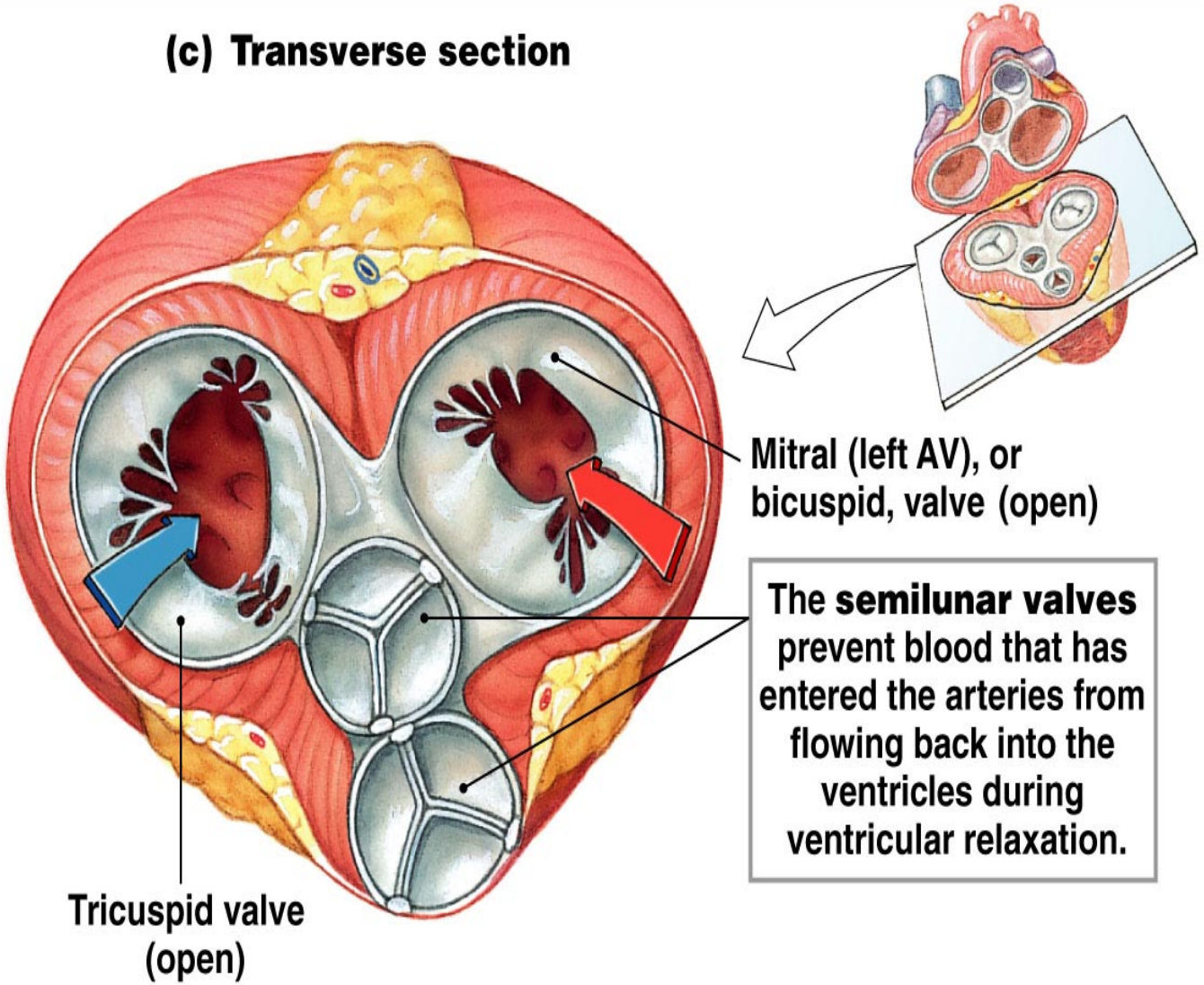
(b) Frontal section



During ventricular contraction, the **AV valves** remain closed to prevent blood flow backward into the atria.

VENTRICULAR RELAXATION

(c) Transverse section



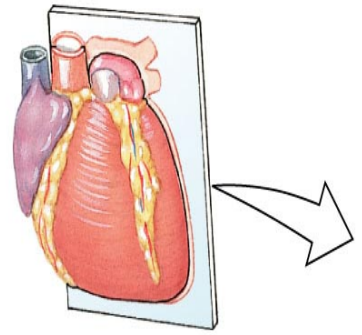
Mitral (left AV), or bicuspid, valve (open)

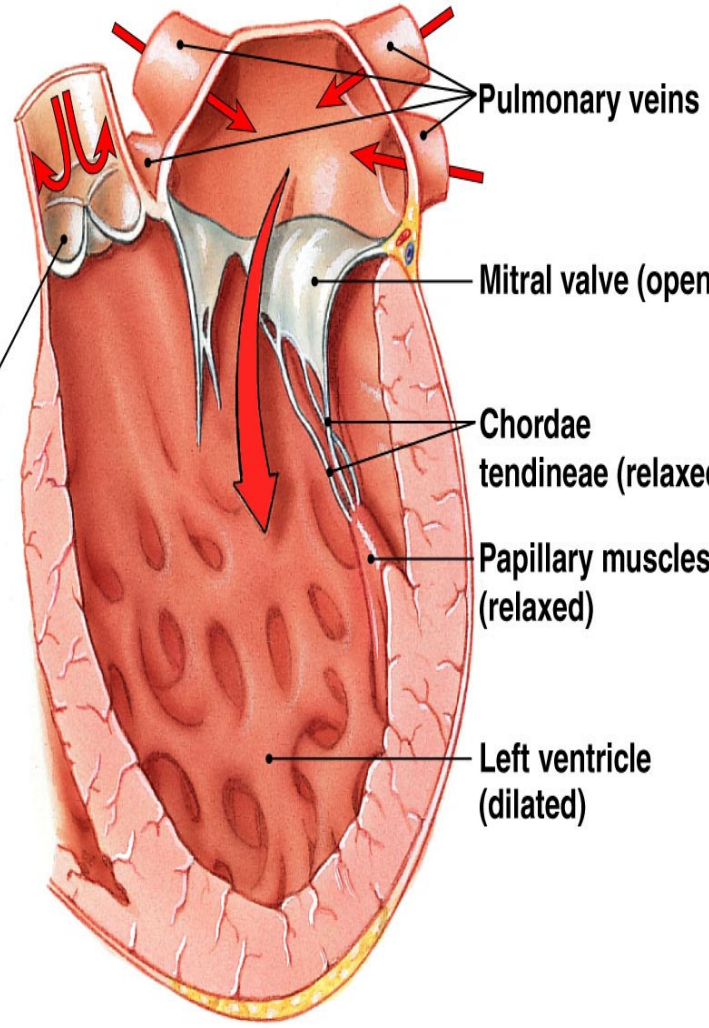
The **semilunar valves** prevent blood that has entered the arteries from flowing back into the ventricles during ventricular relaxation.

Tricuspid valve (open)

VENTRICULAR RELAXATION

(d) Frontal section





Pulmonary veins

Mitral valve (open

Chordae tendineae (relaxe

Papillary muscles (relaxed)

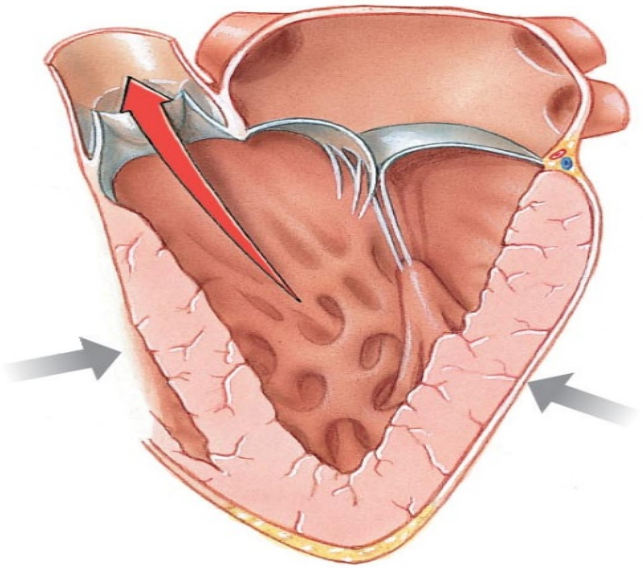
Left ventricle (dilated)

The **semilunar valves** prevent blood that has entered the arteries from flowing back into the ventricles during ventricular relaxation.

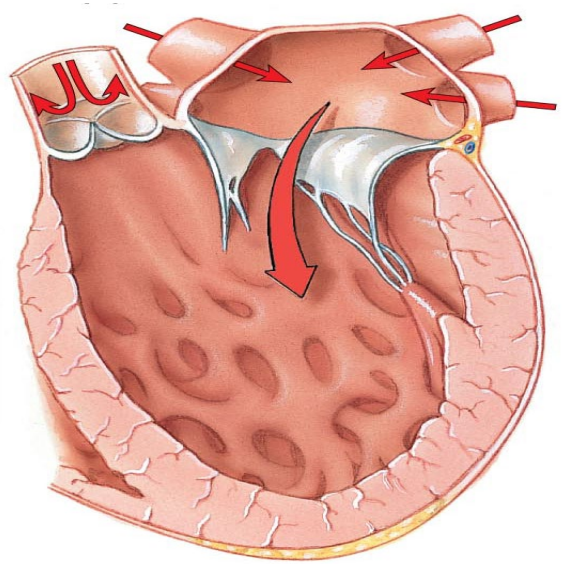
Figure 14-9c

Functional Anatomy of the Heart

Valves (One way flow)



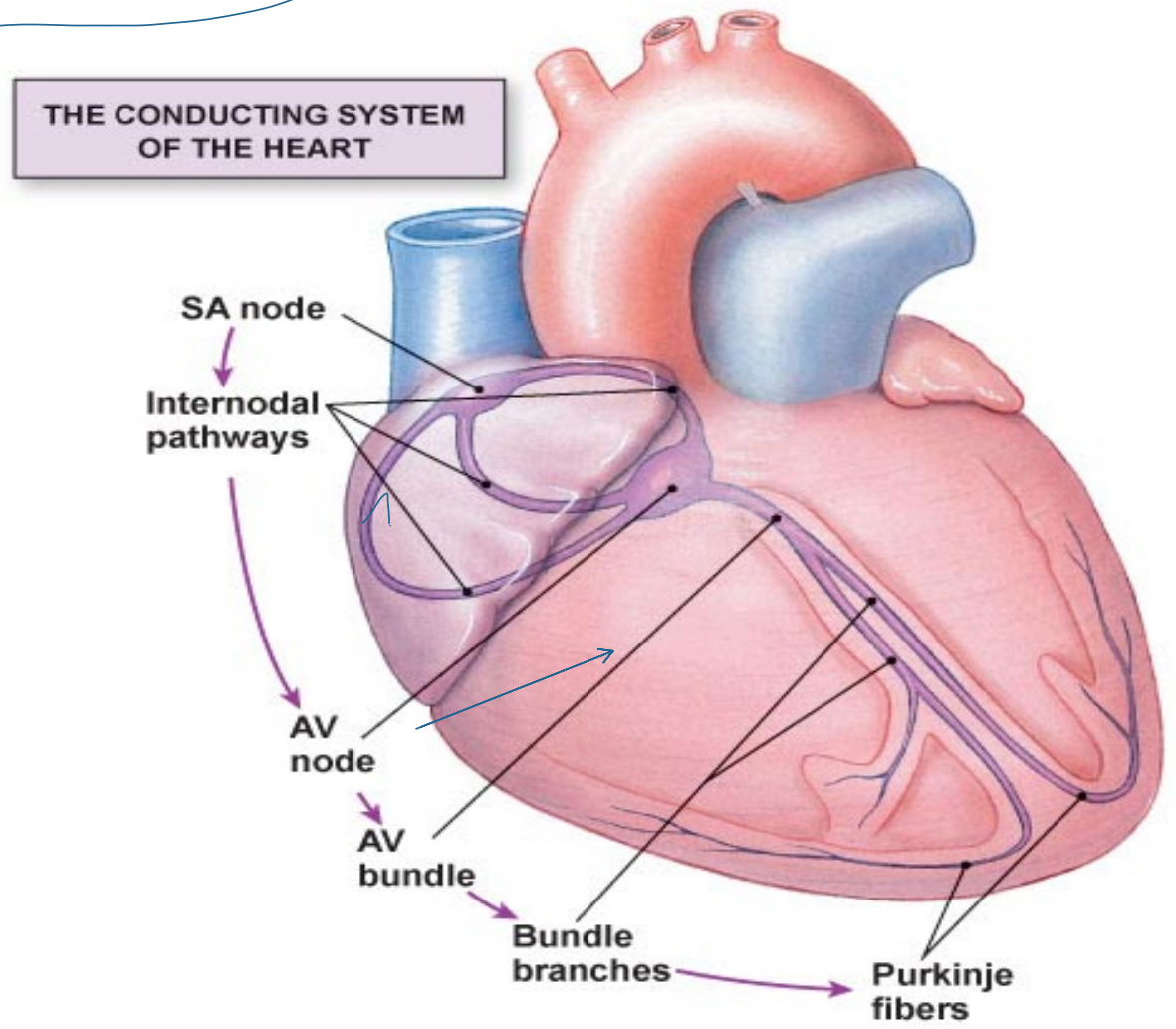
Fibrous connective tissue acts as an electrical insulator, blocking most transmission of electrical signals between the atria and the ventricles.



Functional Anatomy of the Heart

Intrinsic Conduction System

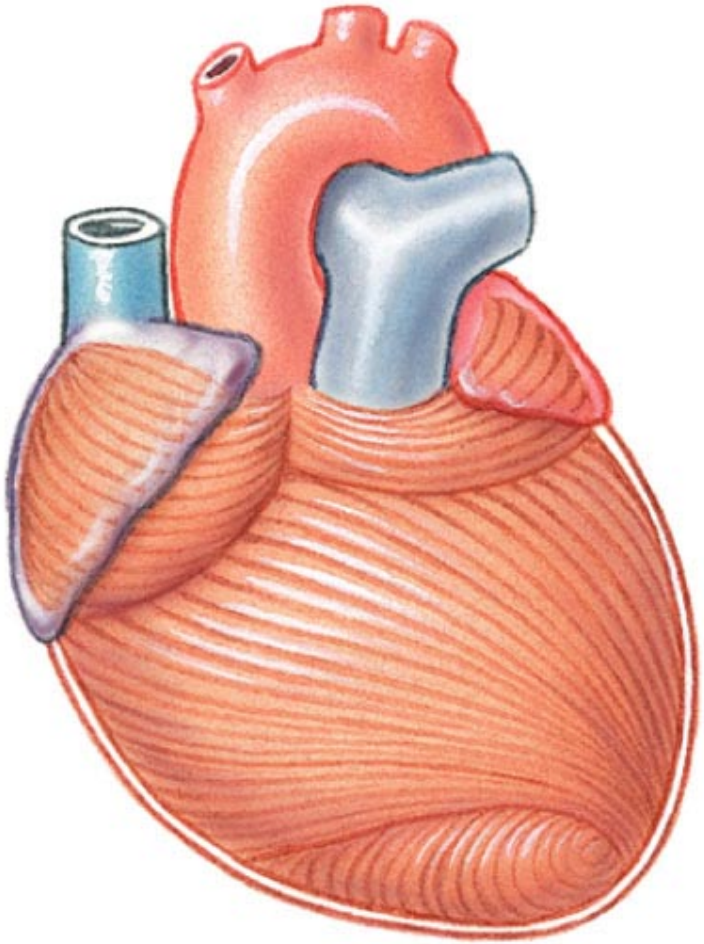
- Consists of "pacemaker" cells and conduction pathways
  - Coordinate the contraction of the atria and ventricles

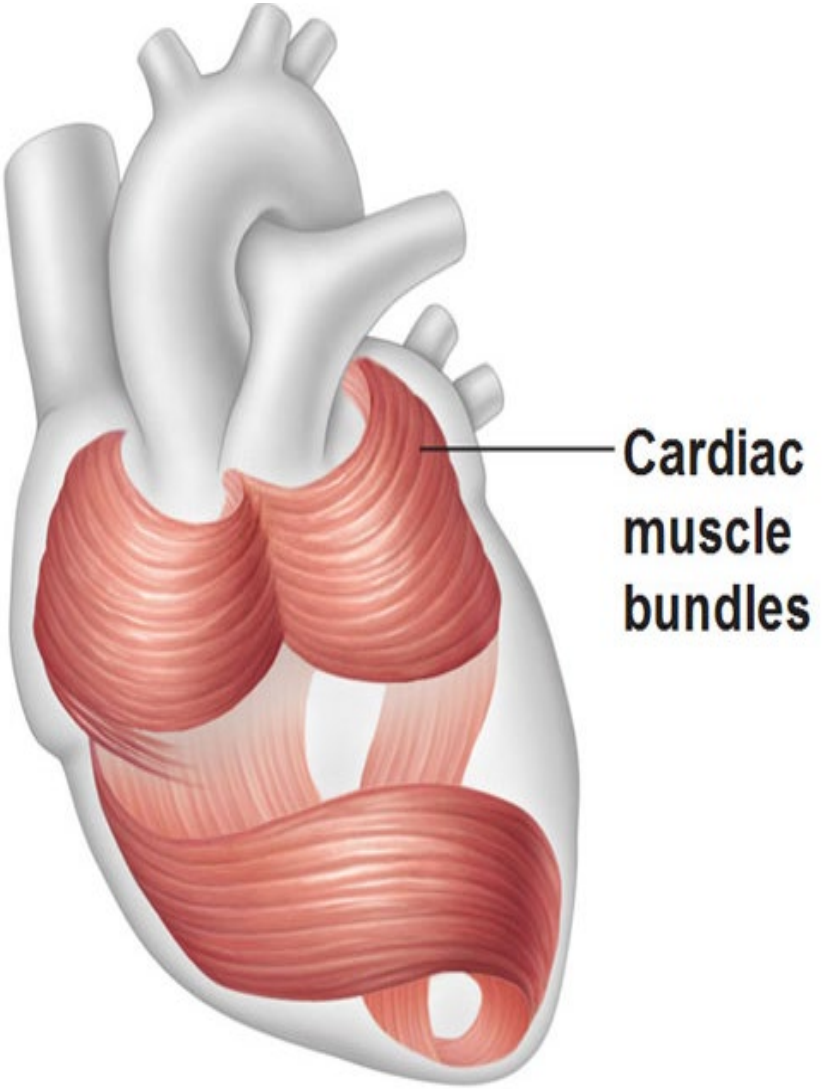


(a) The spiral arrangement of ventricular muscle allows ventricular contraction to squeeze the blood upward from the apex of the heart.

"spiral shape"

* شكلوا بساعدها بضخ الدم من
From Apex to the base



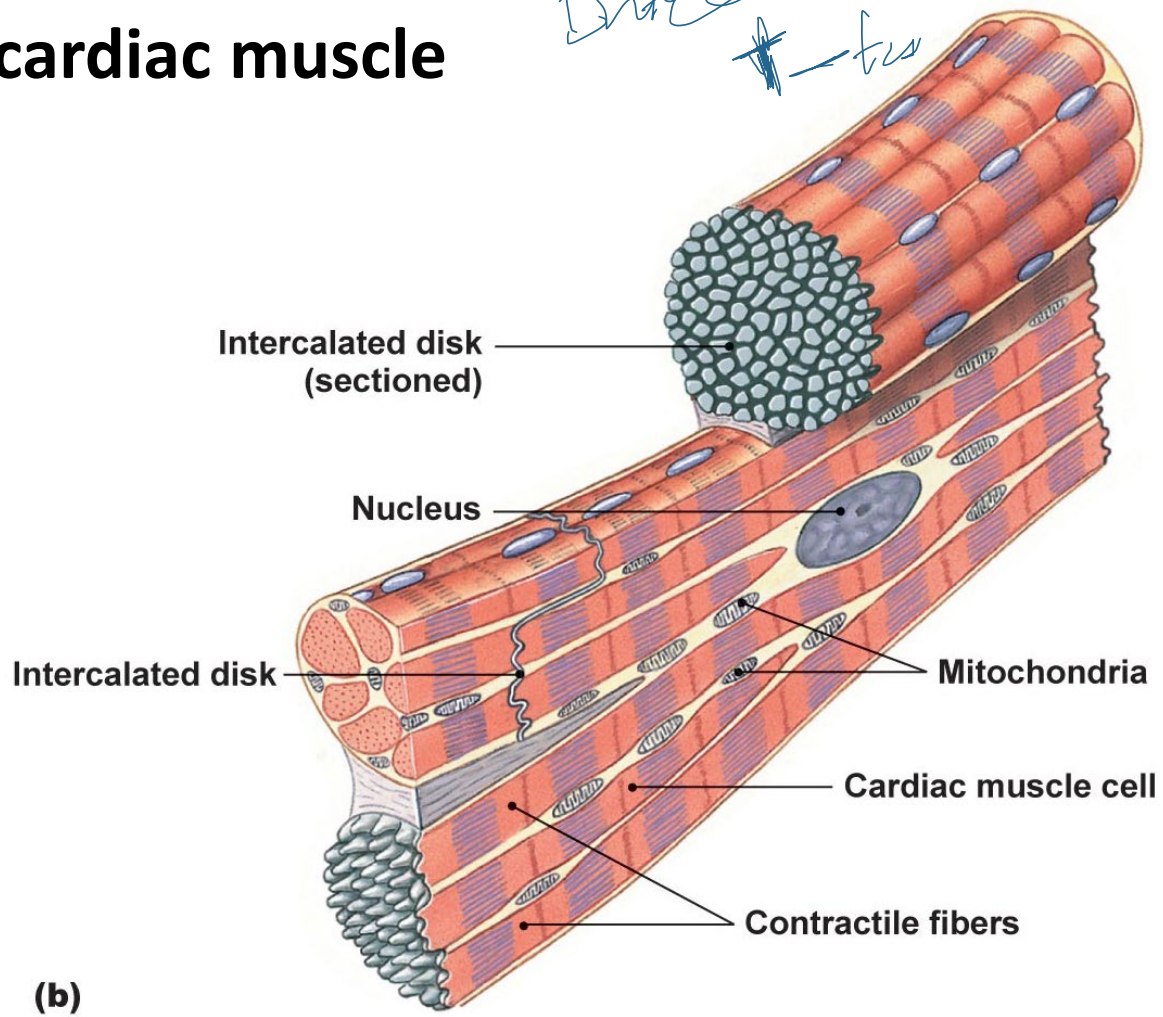


Functional Anatomy of the Heart

Cardiac Muscle

The heart itself is composed mostly of cardiac muscle (myocardium)

- **Characteristics**
  - Striated
  - Short branched cells
  - Uninucleate
  - Intercalated discs
  - T-tubules larger and over z-discs



(b)

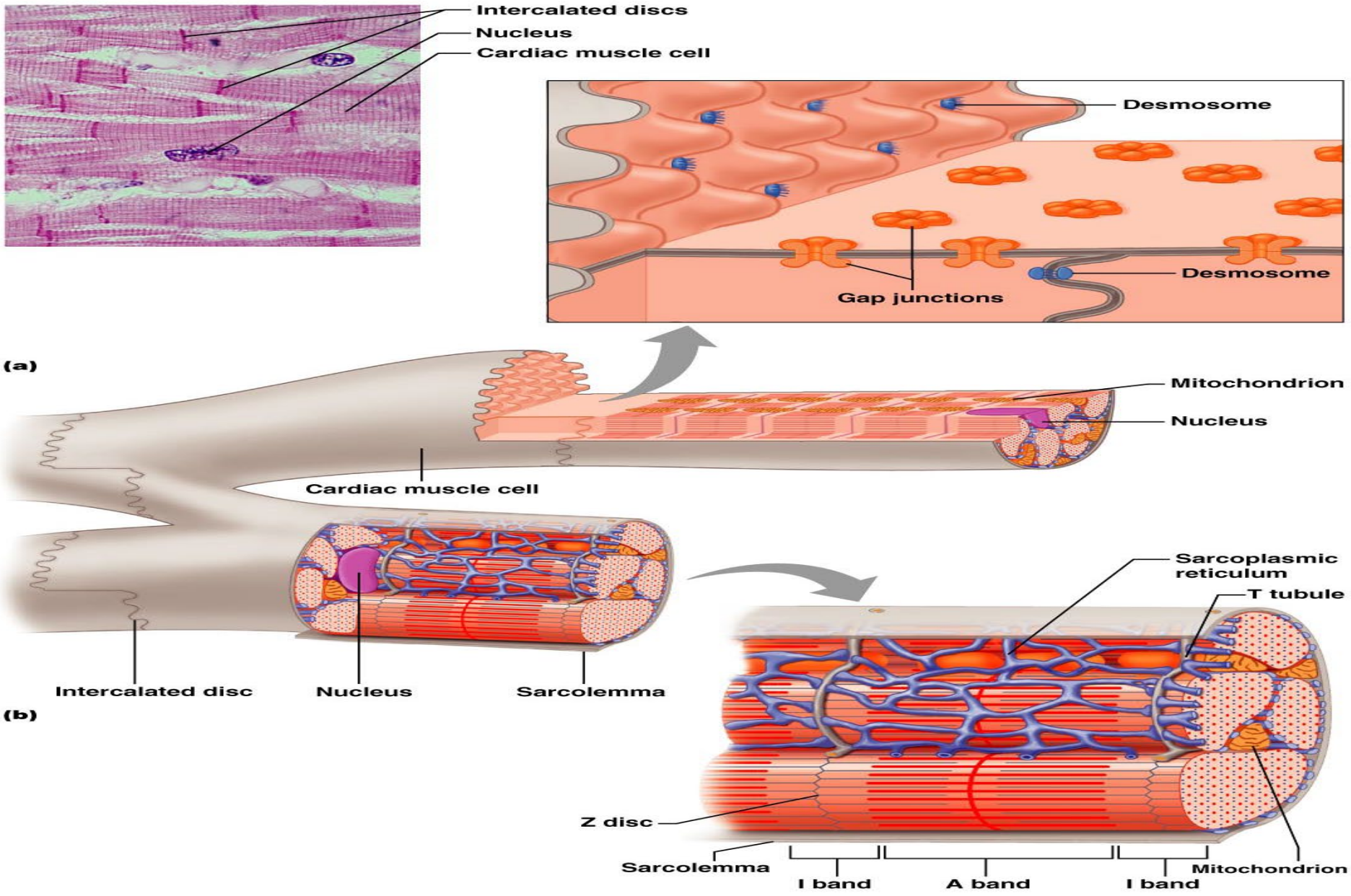
Microscopic Anatomy of Heart Muscle

- Cardiac muscle is striated (Sarcomere) , short, fat, branched, and interconnected
- Intercalated discs anchor cardiac cells together and allow free passage of ions (Gap junction, Desmosome)

(gap junctions) permit the conduction of impulses from one cell to the next

- Cardiac muscle can produce impulses (Myogenic) and contract spontaneously (unlike skeletal muscle need nervous stimulation to contract)

Microscopic Anatomy of Cardiac Muscle



Cardiomayocyte

Non-viable

Rod viable

Round

Fat, short & branched

(Mechanical activity)

Cardiac Muscle Contraction

- Heart muscle:
  - Is stimulated by nerves and is self-excitable (automaticity)
  - Contracts as a unit
  - Has a long (250 ms) absolute refractory period
- Cardiac muscle contraction is similar to skeletal muscle contraction

What cause the heart to contract??

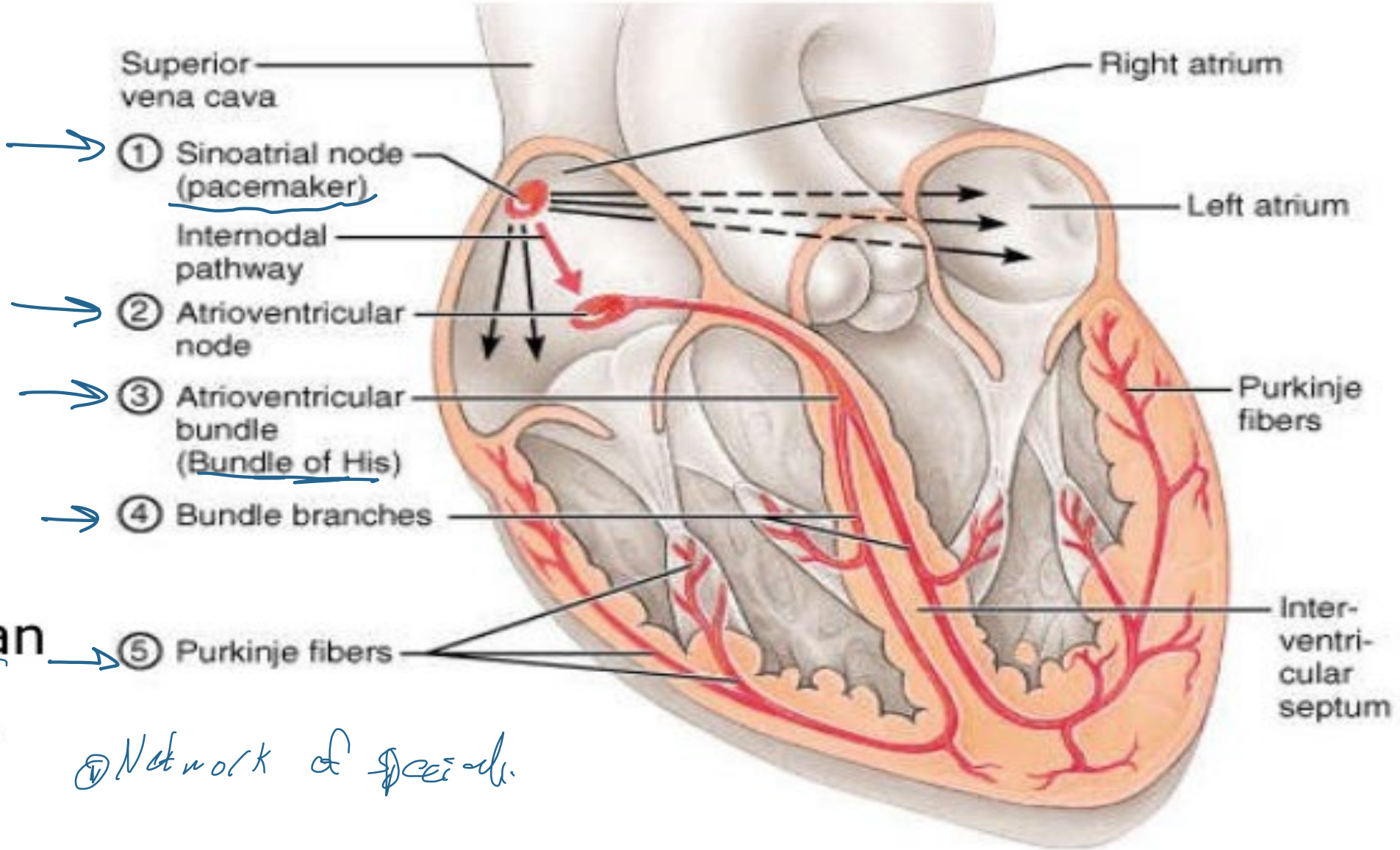
- Heart **generate electrical signal** → cause the heart to **contract**
- ANS regulate the beats of the heart but does not initiate the beats.
- **Myogenic activity**: myocardial tissue are able to generate electrical signal
- The right atrium (upper wall) contain a **bundle of specialized cells** known as Sinoatrial node (SA)
- Cells in SA node are responsible for initiating action potential by depolarizing the atrium → cause the atrium to contract

Electrical activity:
Intrinsic Conduction System

- Autorhythmic cells:
  - Initiate action potentials
  - Have unstable resting potentials called pacemaker potentials (SA)
  - Use calcium influx (rather than sodium) for rising phase of the action potential

Conducting System

- Network of specialized tissue that stimulates contraction
- Modified cardiac myocytes
- The heart can contract without any innervation



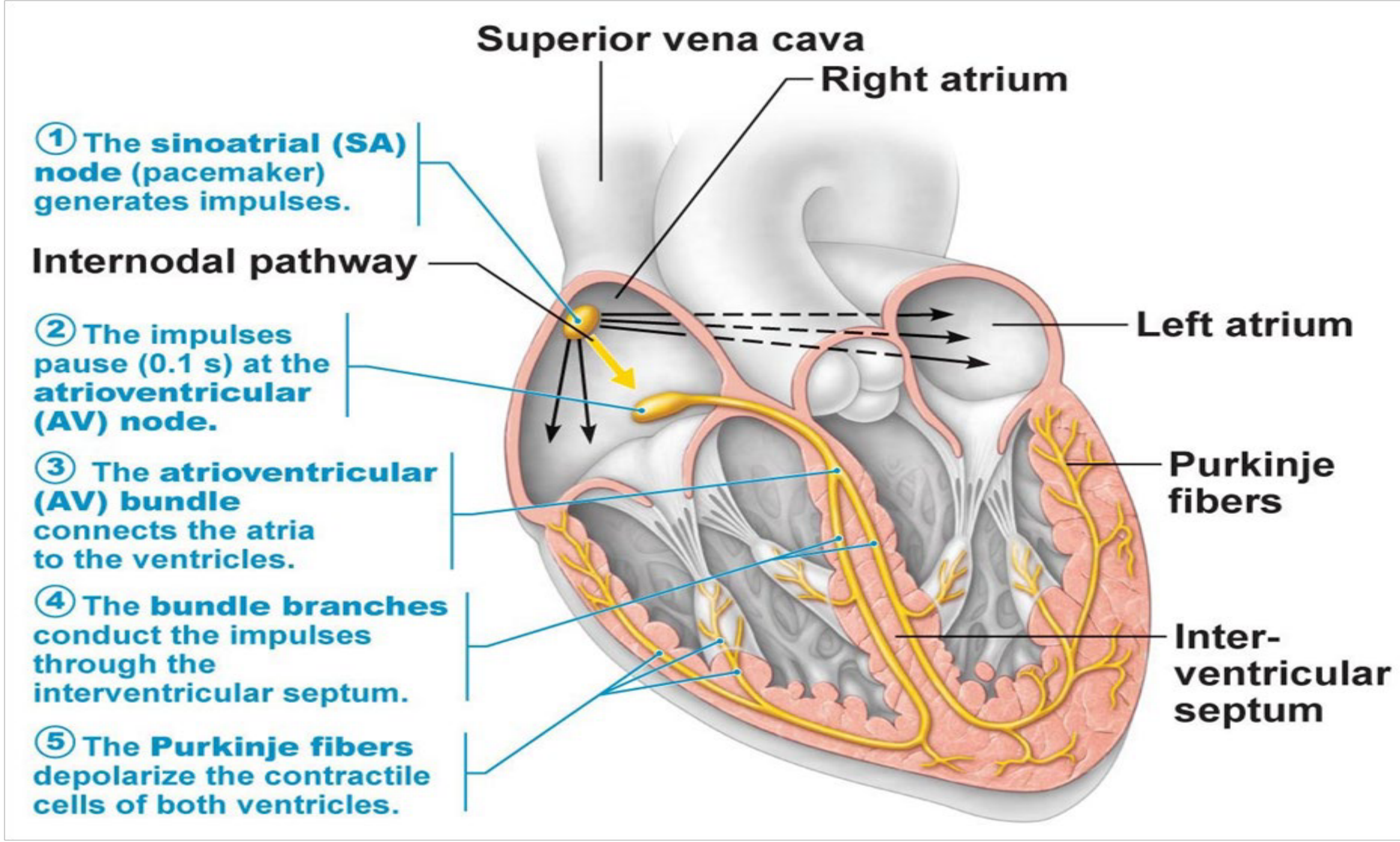
① Network of fibers.

Heart Physiology: Sequence of Excitation

- Sinoatrial (SA) node generates impulses about 75 times/minute
- Atrioventricular (AV) node delays the impulse approximately 0.12 second
- Impulse passes from atria to ventricles via the atrioventricular bundle (bundle of His)

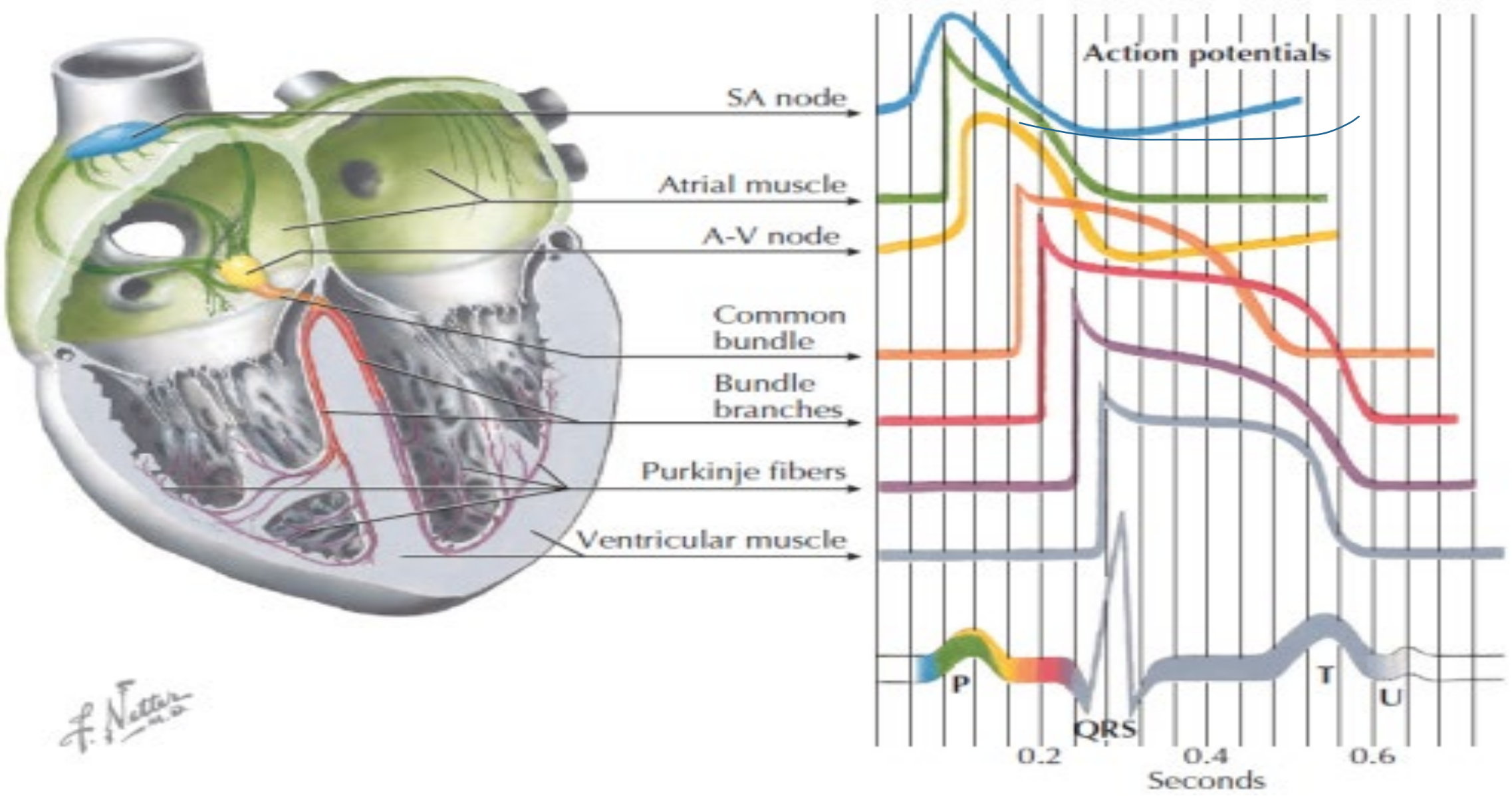
Heart Physiology: Sequence of Excitation

- AV bundle splits into two pathways in the interventricular septum (bundle branches)
  - Bundle branches carry the impulse toward the apex of the heart
  - Purkinje fibers carry the impulse to the heart apex and ventricular walls

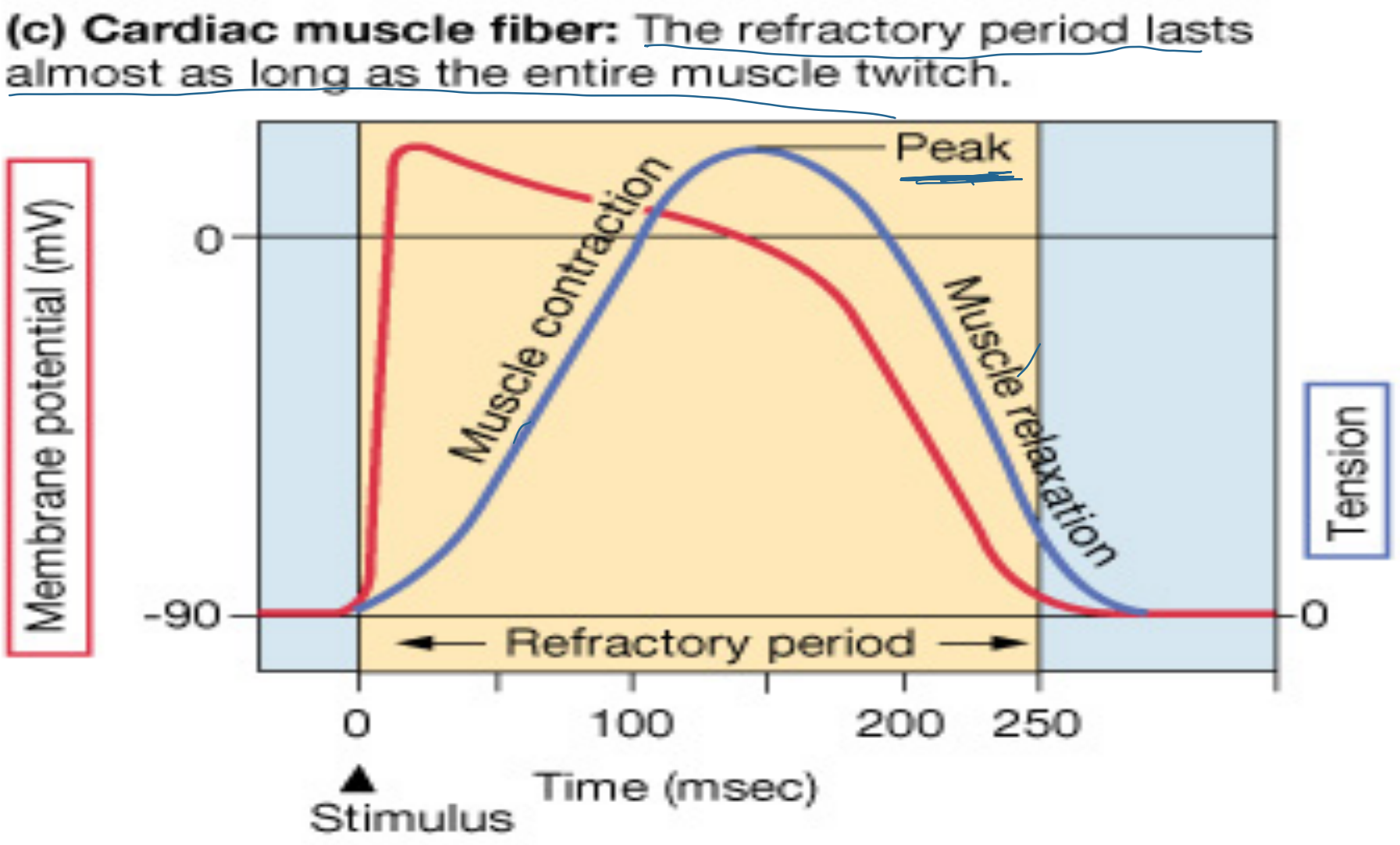

Superior vena cava
Right atrium
① The sinoatrial (SA) node (pacemaker) generates impulses.
Internodal pathway
② The impulses pause (0.1 s) at the atrioventricular (AV) node.
③ The atrioventricular (AV) bundle connects the atria to the ventricles.
④ The bundle branches conduct the impulses through the interventricular septum.
⑤ The Purkinje fibers depolarize the contractile cells of both ventricles.
Left atrium
Purkinje fibers
Inter-ventricular septum

More Characteristics of Cardiac Muscle Contraction

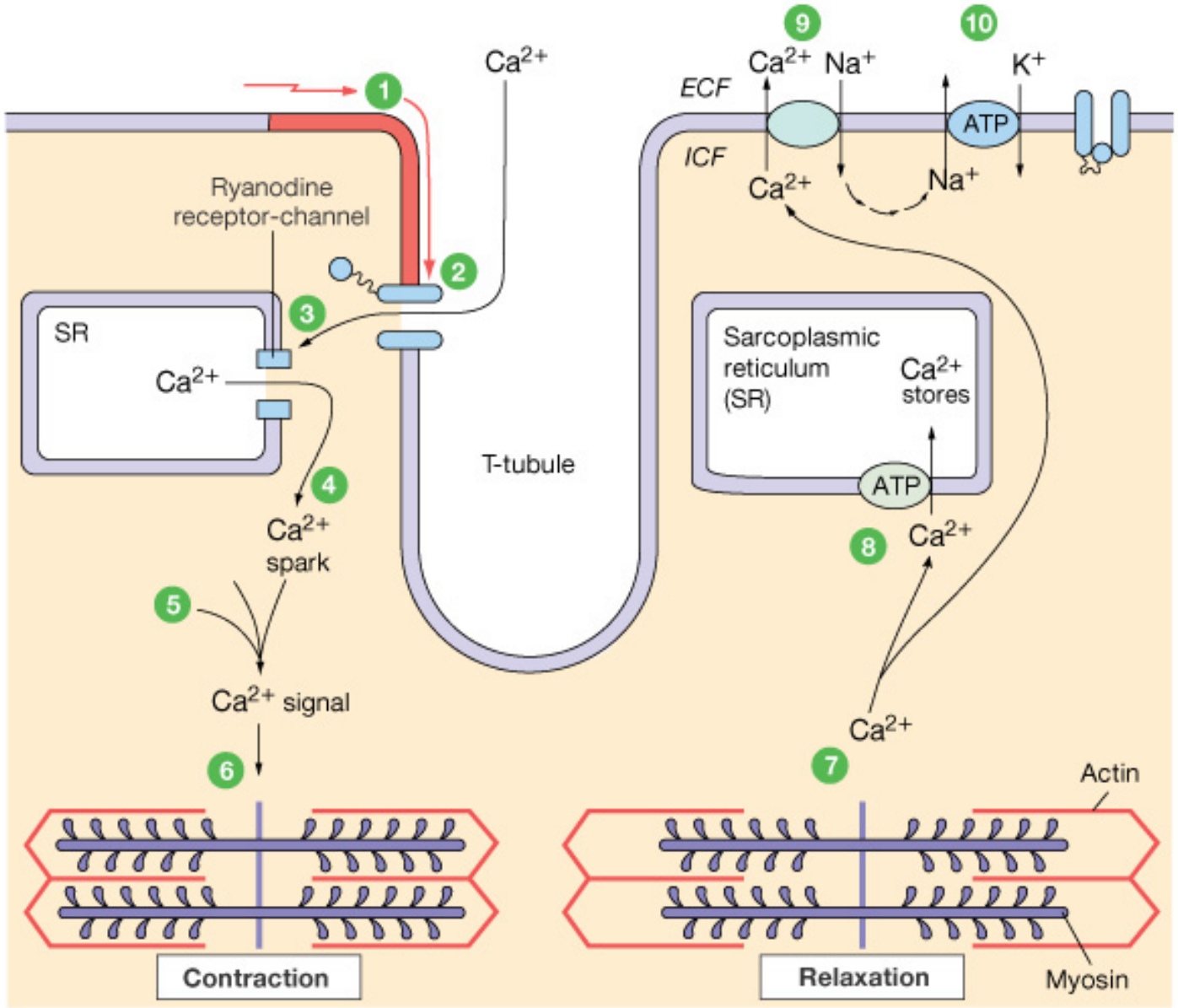
- Stretch-length relationship
  - ↑ Ca++ entering
  - ↑ contraction force
- Long action potential
- Long refractory period


SA node
Atrial muscle
A-V node
Common bundle
Bundle branches
Purkinje fibers
Ventricular muscle
Action potentials
P
QRS
T
U
0.2
0.4
0.6
Seconds

More Characteristics of Cardiac Muscle Contraction



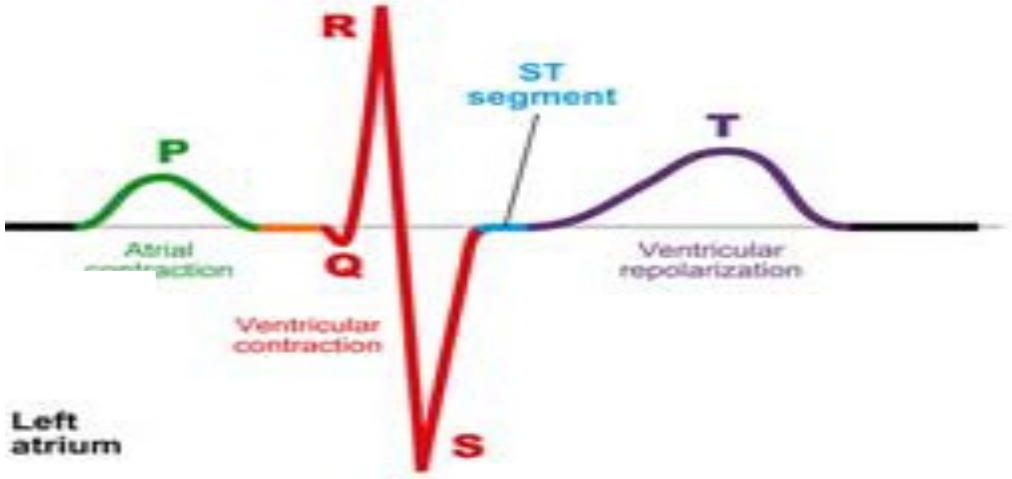
Mechanism of Cardiac Muscle Excitation, Contraction & Relaxation



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^{+}.
10. Na^{+} gradient is maintained by the Na^{+}-K^{+}-ATPase.

The electrical conduction of the heart can be monitored using Electrocardiograph ECG

Electrocardiography



- Electrical activity is recorded by electrocardiogram (ECG) using electrodes
- P wave corresponds to depolarization of SA node
- QRS complex corresponds to ventricular depolarization
- T wave corresponds to ventricular repolarization
- Atrial repolarization record is masked by the larger QRS complex

Heart Excitation Related to ECG

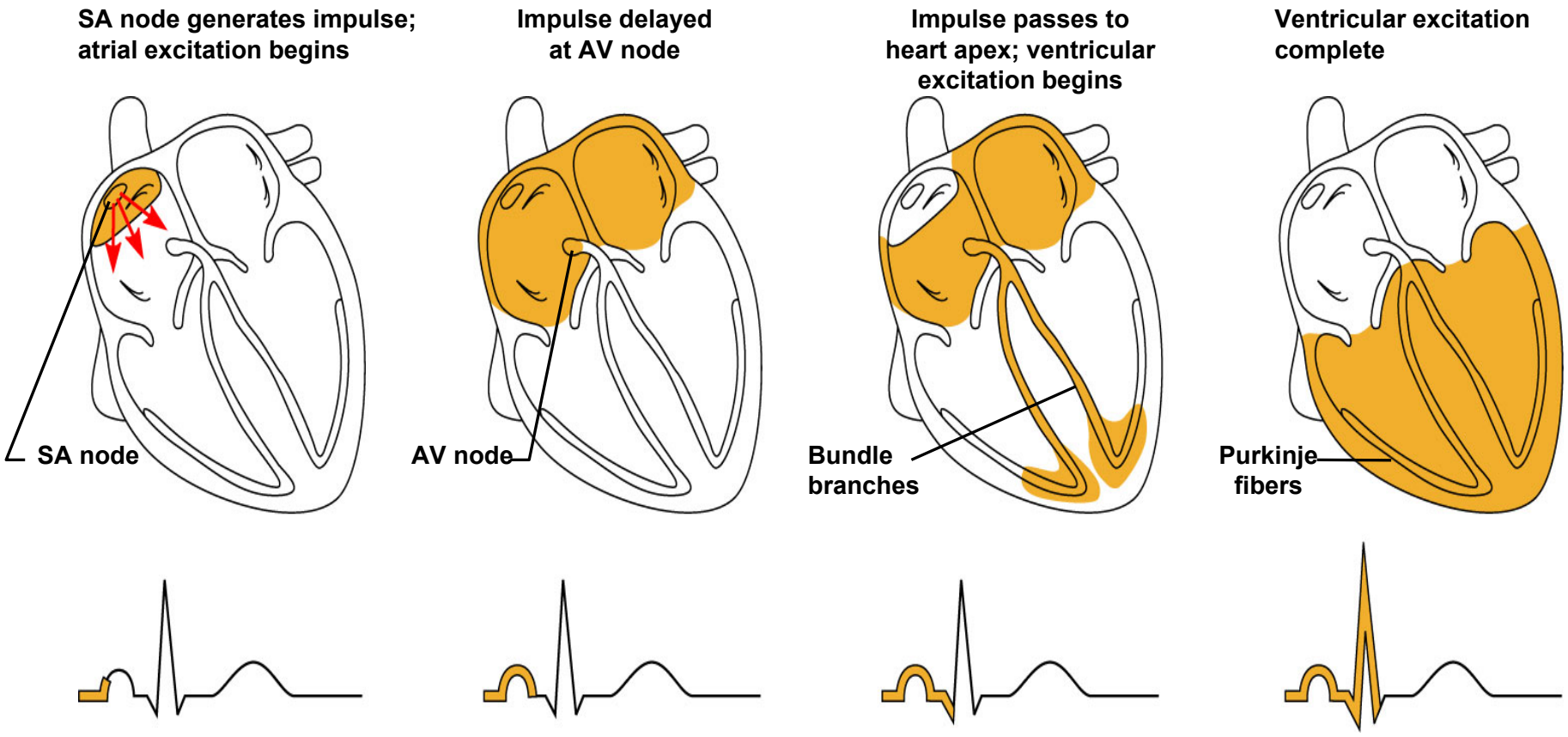
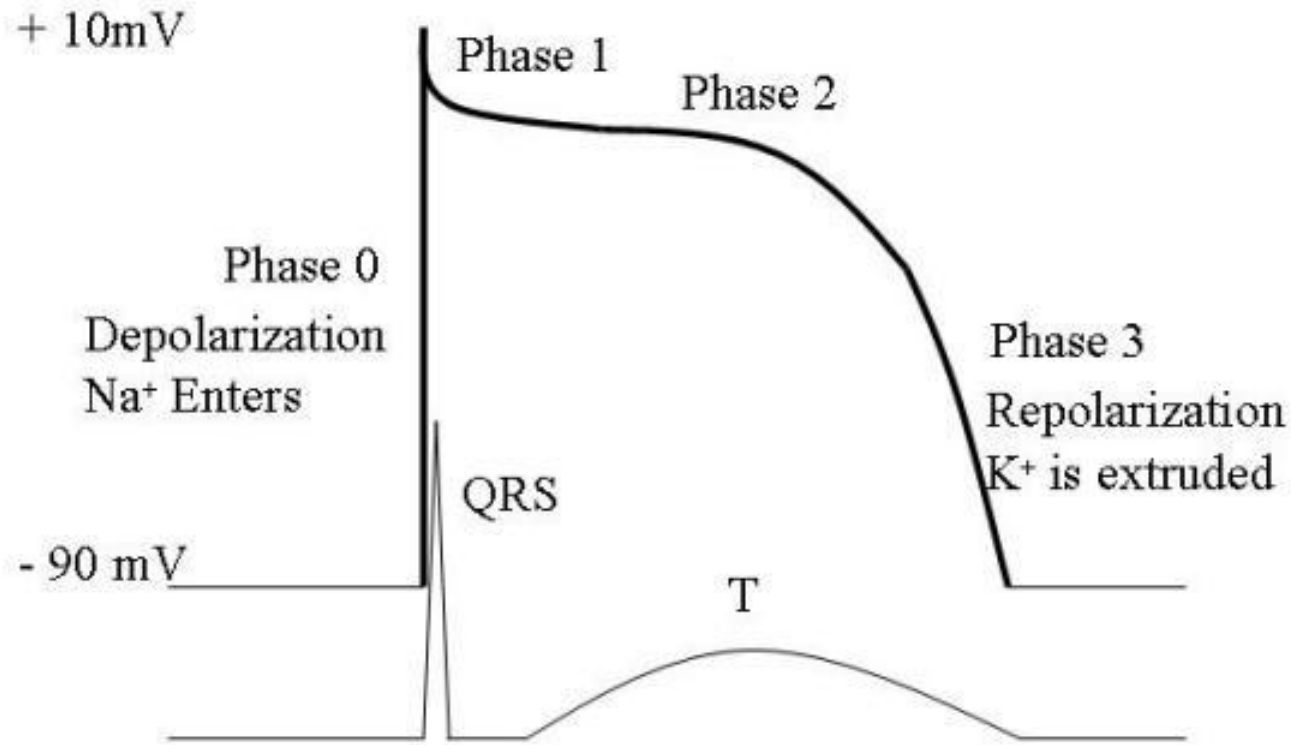
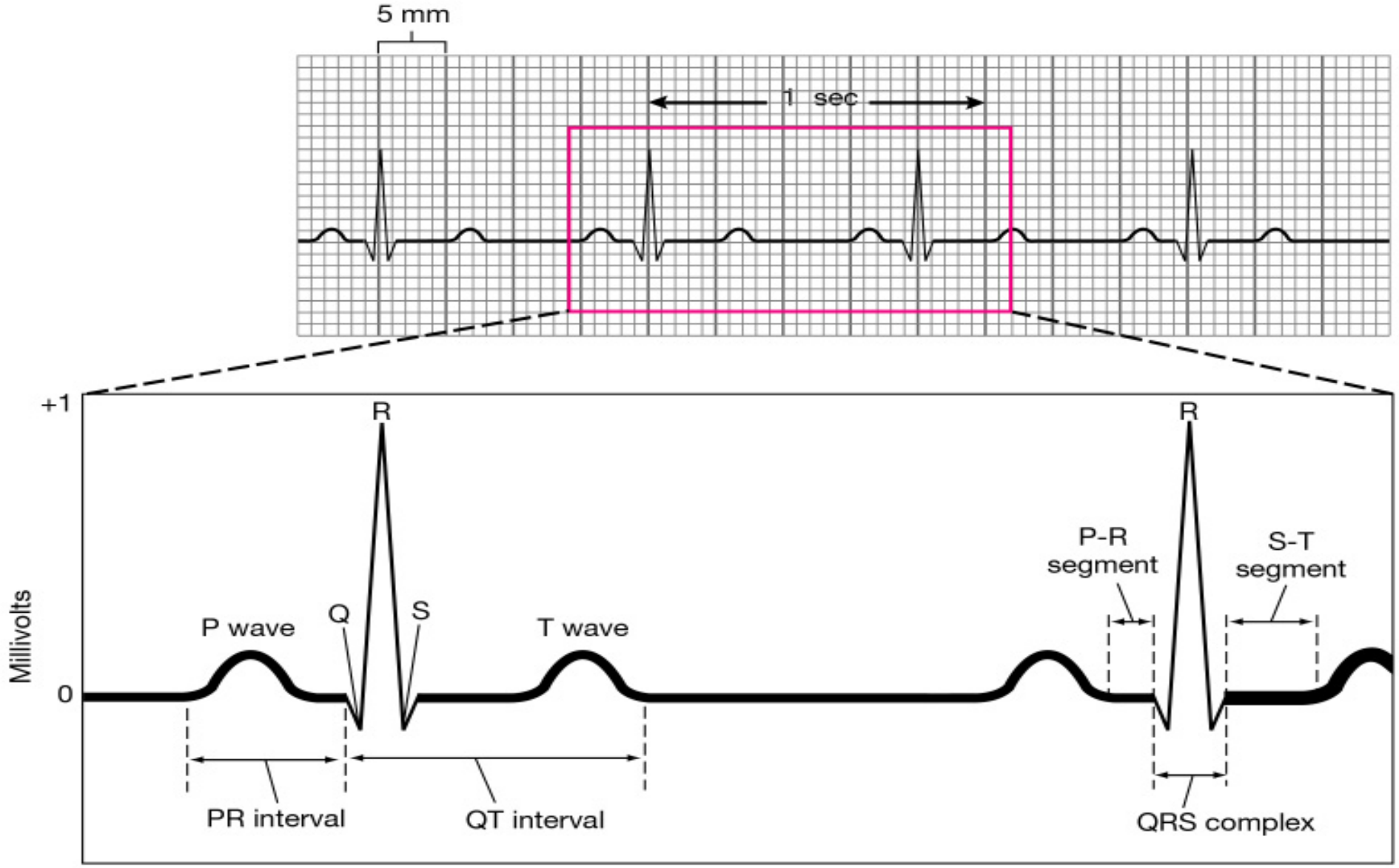


Figure 18.17

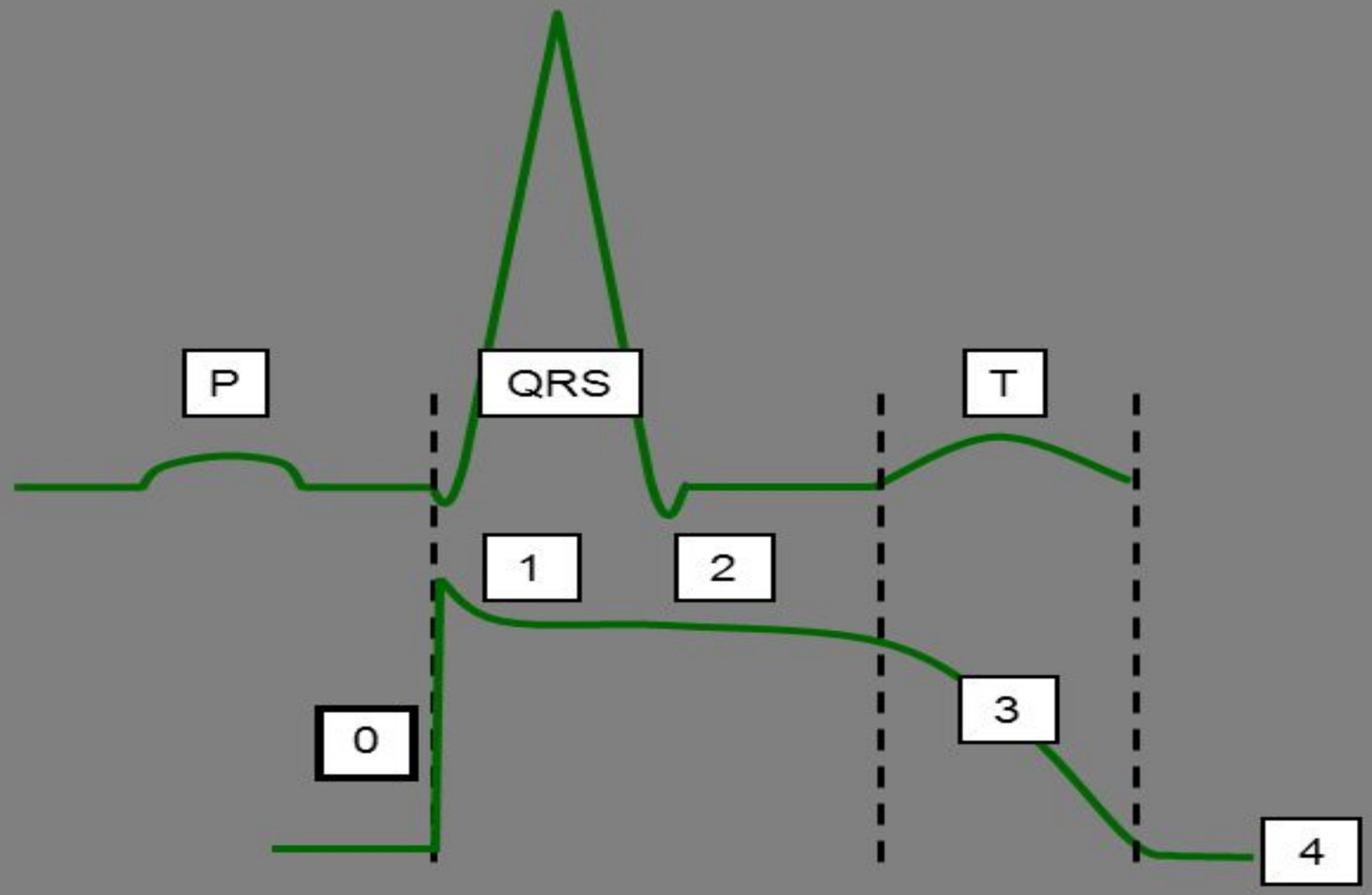
Monophasic Action Potential (Cardiac Muscle Cell)



Electrocardiogram (ECG): Electrical Activity of the Heart



Correspondence between a ventricular action potential & the ECG

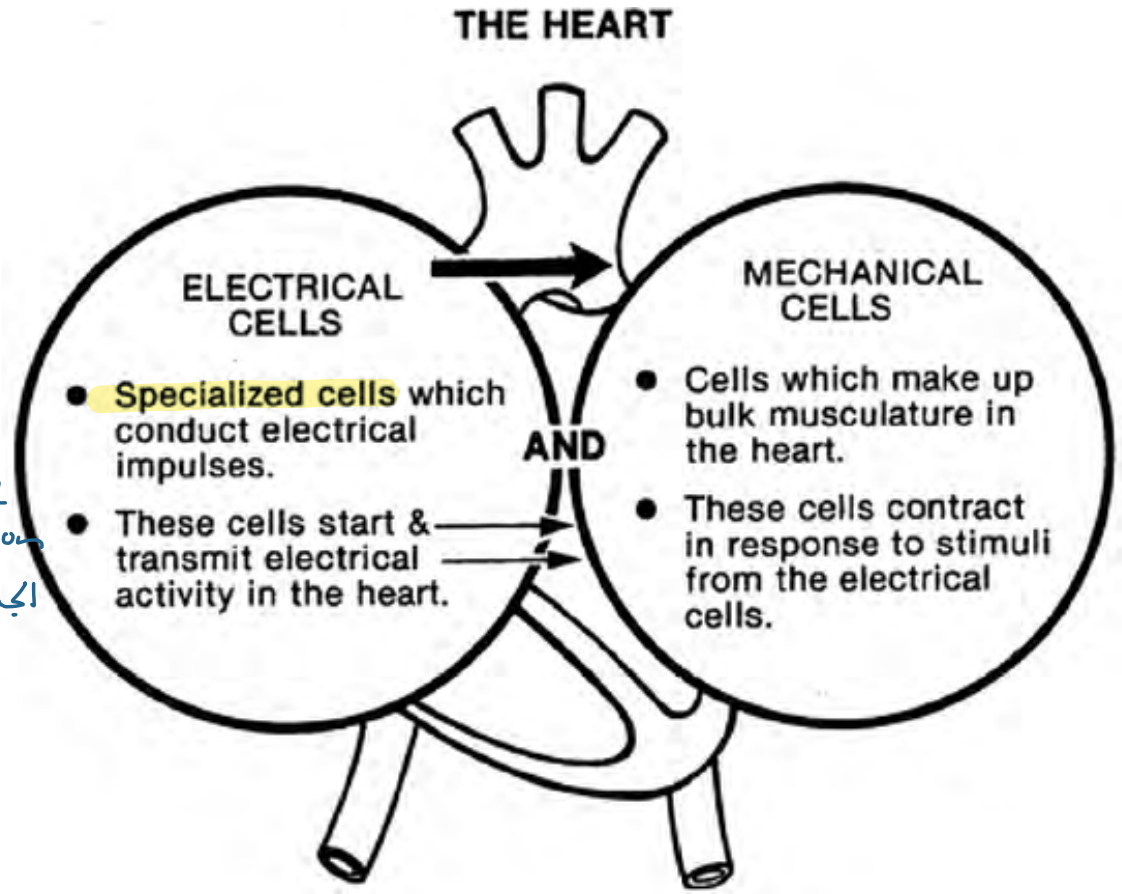


The QRS complex is produced by the summed upstrokes (phase 0) of the ventricular myocyte action potentials.
The S-T segment corresponds to the plateaus of the action potentials.
The T wave is produced by ventricular repolarization.

Electrical Activity of the heart

Dr Safa Abdul Ghani

Intrinsic Conduction System



- **Heart Cells**

Two types of cells are found in the heart :

1. Mechanical cells (contractile) → يعني يصير الها Contraction & Relaxation
2. Electrical cells (Autorhythmic) → الجدار معضلي Contractile Cell

نسبتهم قليلة هما موجودين بمناطق معينة

بوزعو كهرباء هما وبجلو Contraction & Relaxation

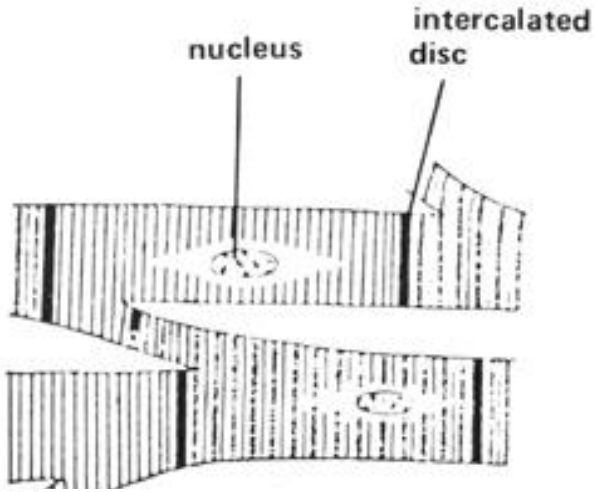
Autorhythmic cells:

- Initiate action potentials
- Have unstable resting potentials called pacemaker potentials (SA)
- Use calcium influx (rather than sodium) for rising phase of the action potential

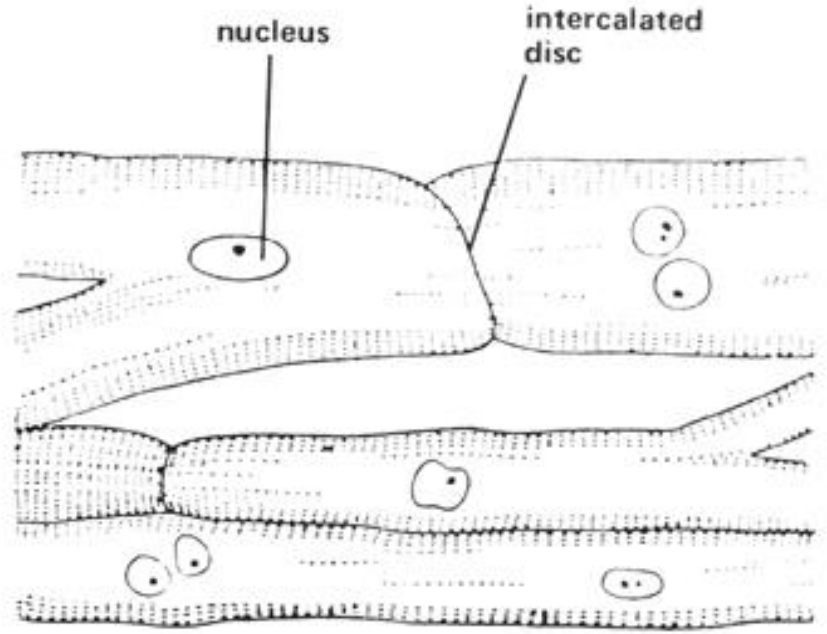
Myocardial Physiology

Autorhythmic Cells (Pacemaker Cells)

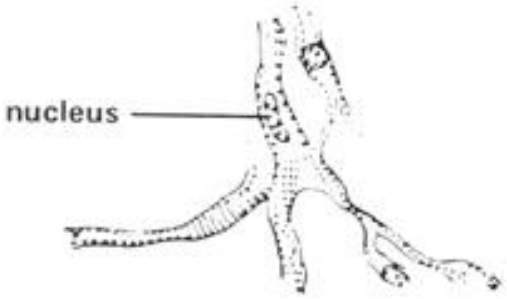
- Characteristics of Pacemaker Cells
  - Smaller than contractile cells
  - Don't contain many myofibrils
  - No organized sarcomere structure
    - do not contribute to the contractile force of the heart



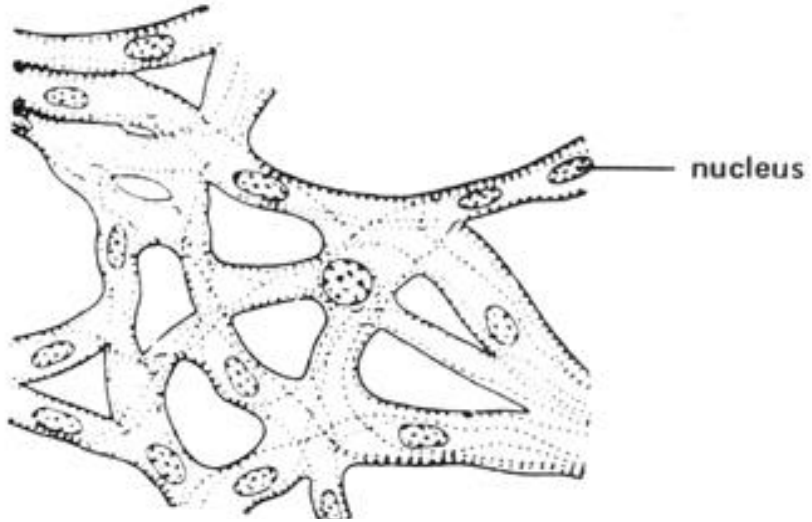
normal contractile myocardial cell



conduction myofibers B

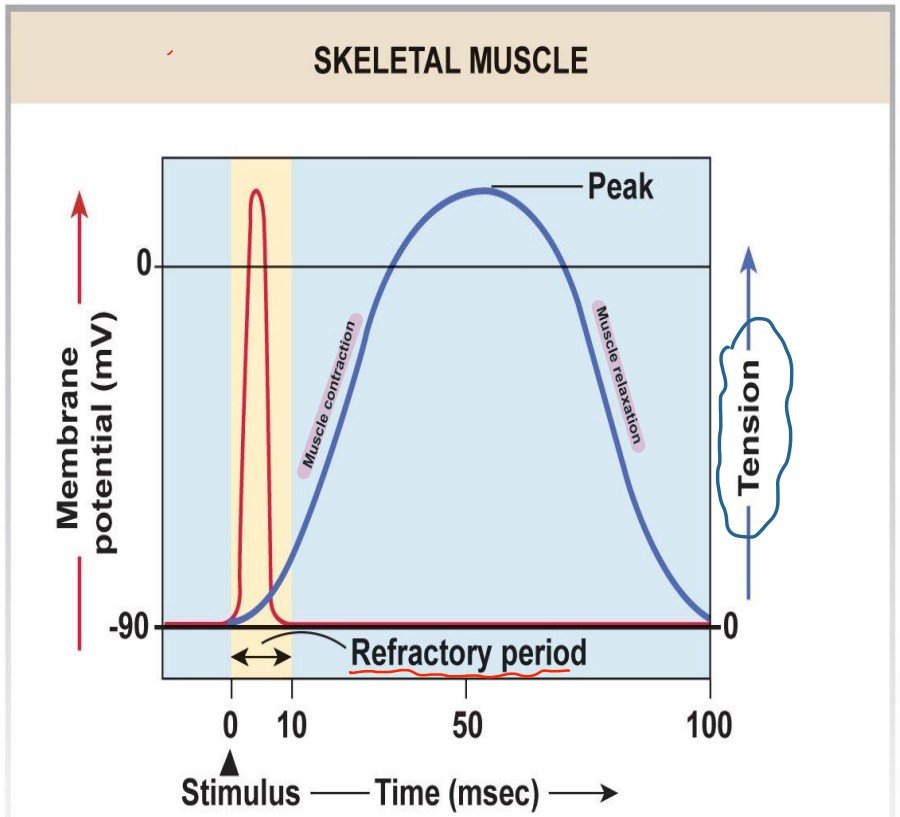


SA node cell

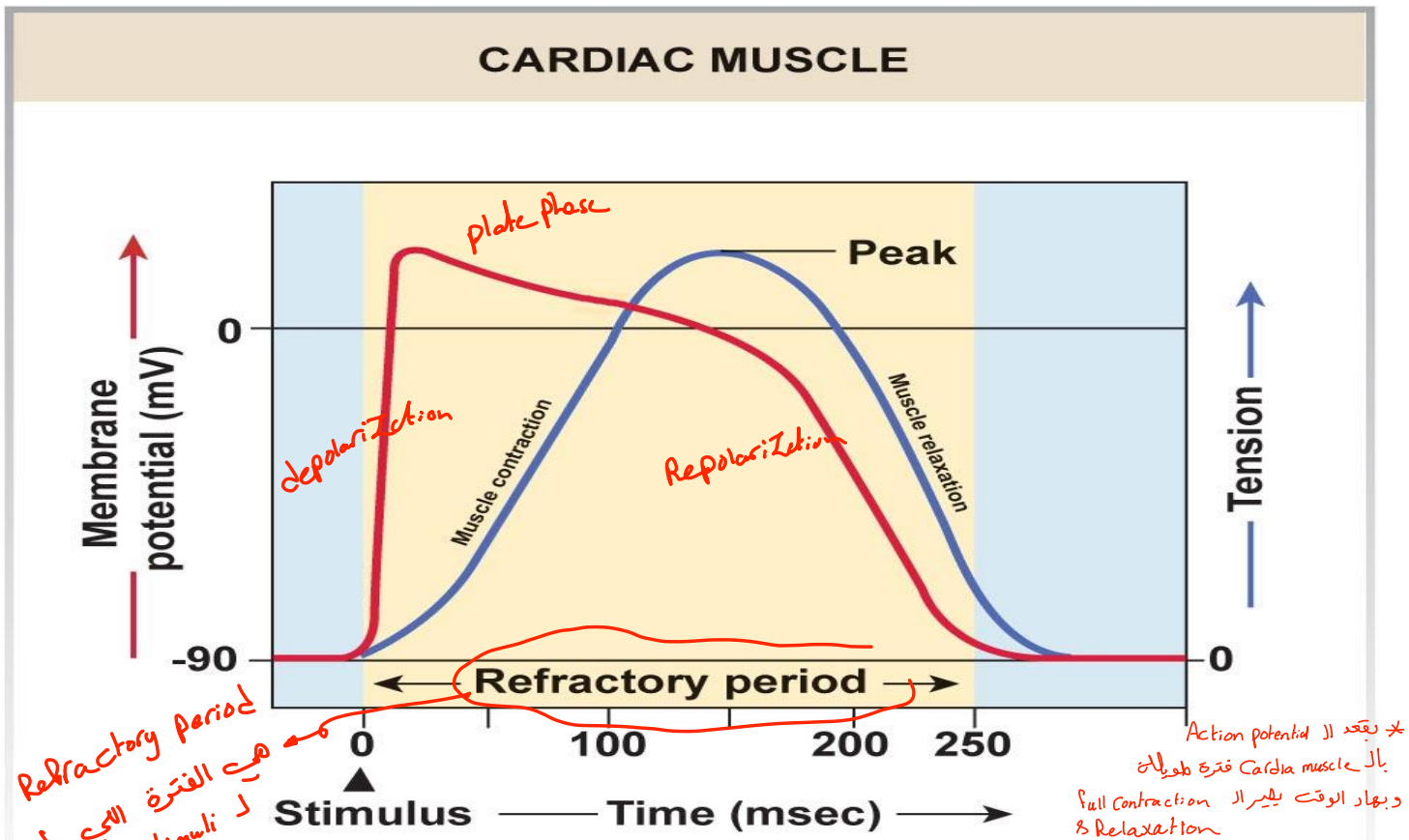


AV node cells

- Skeletal Action Potential vs Contractile Myocardial Action Potential



(a) **Skeletal muscle fast-twitch fiber:** The refractory period (yellow) is very short compared with the amount of time required for the development of tension.



(c) **Cardiac muscle fiber:** The refractory period lasts almost as long as the entire muscle twitch.

Myocardial Physiology

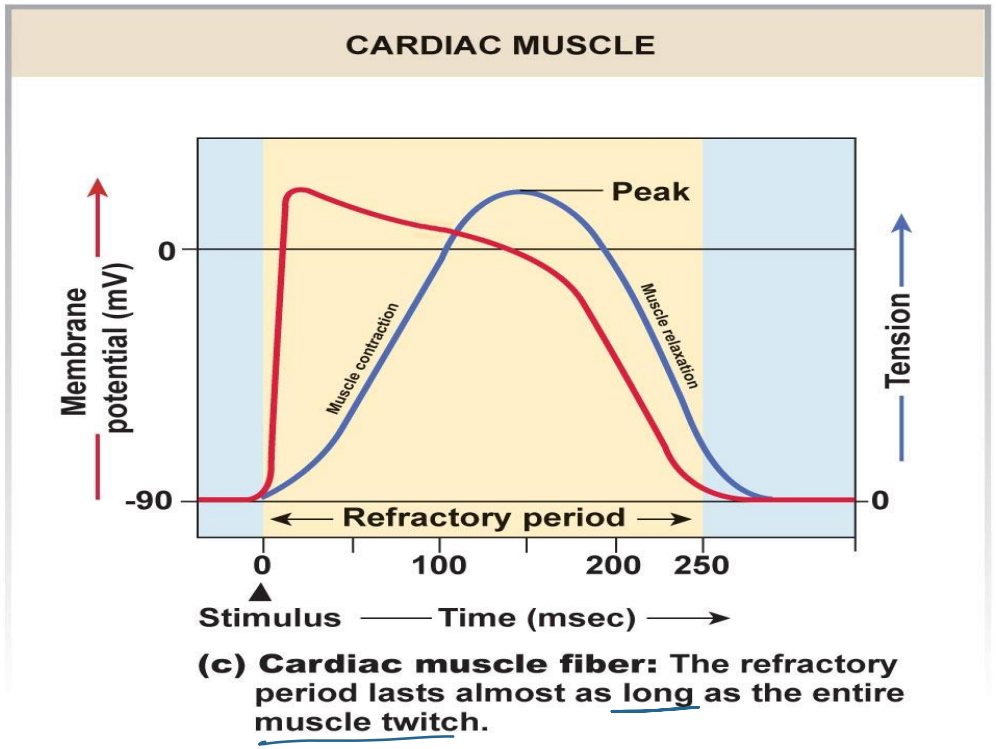
Contractile Cells

In sympathatic
↳ 60- ما تكون فبدل ما يدخل Cataion على الخلية
بخليها 50 - يعني بخليها تقرب على ال Threshold
فبزيد ال Heart rate

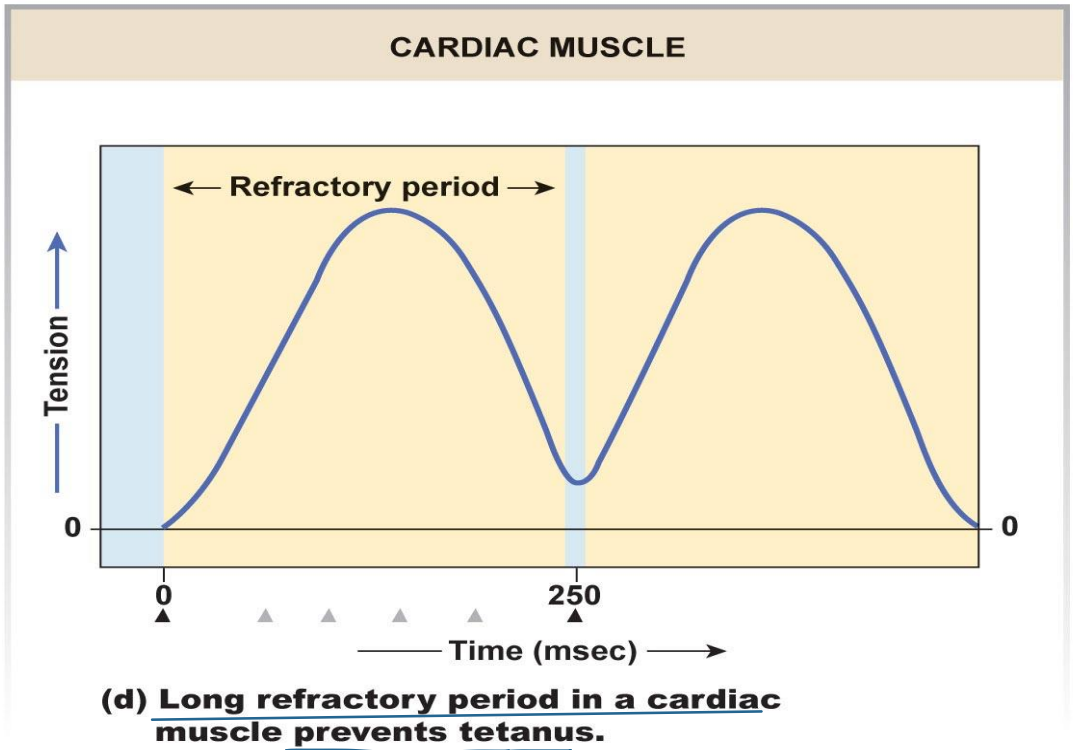
ها بينفرز الادرنالين

In parasympathatic
↳ Acetycholine ال Anaion يدخل على الخلية فبدل ما تكون 60- بتصير 70- فبتقل ال Heart rate

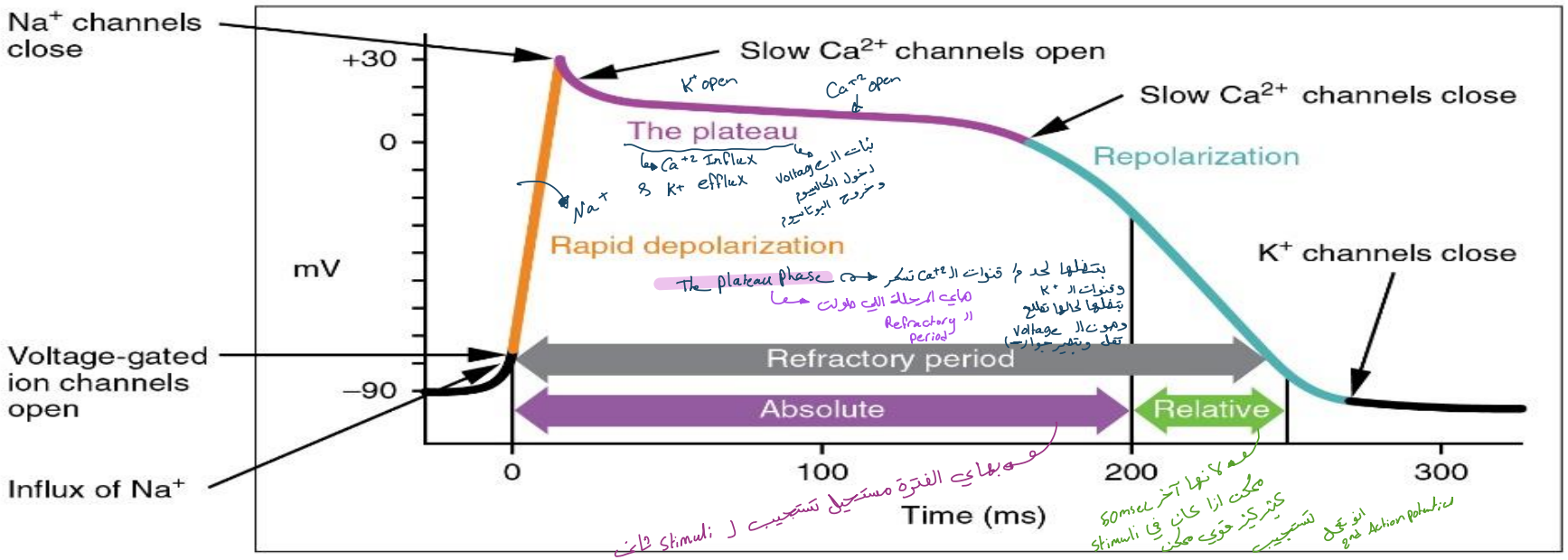
- Plateau phase prevents summation due to the elongated refractory period
- No summation capacity = no tetanus
  - Which would be fatal



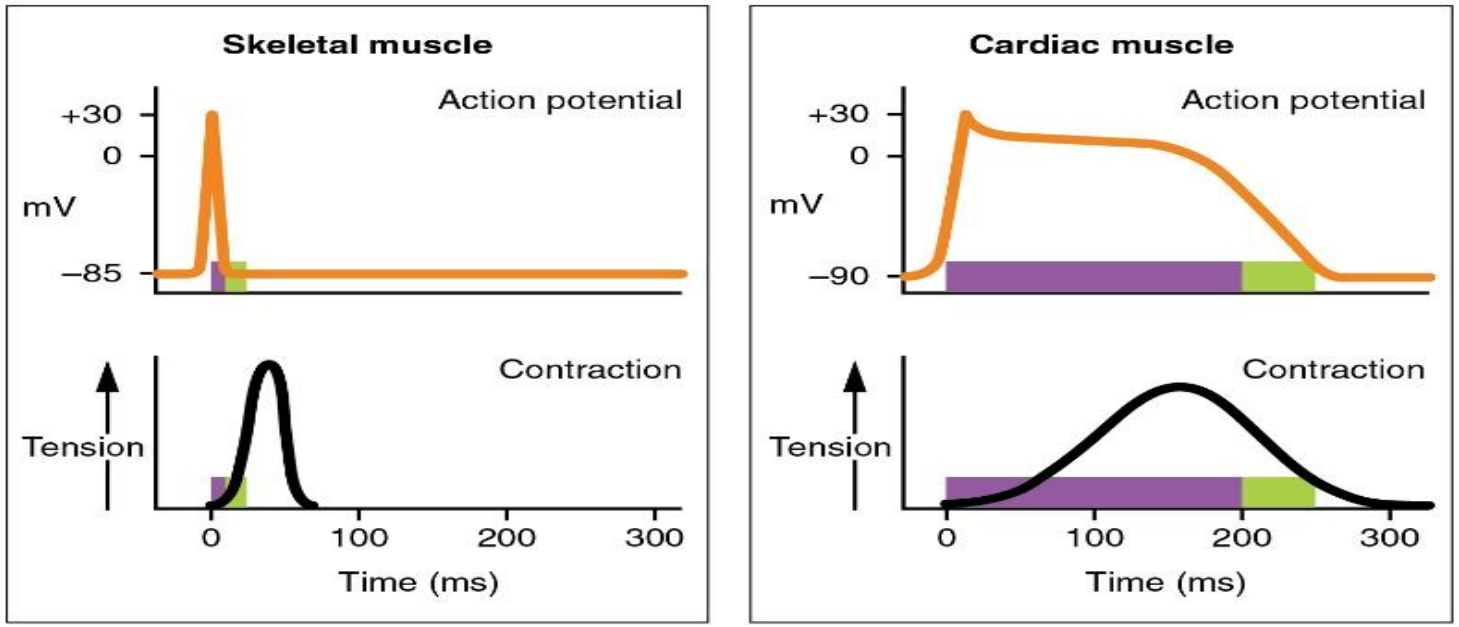
(c) **Cardiac muscle fiber:** The refractory period lasts almost as long as the entire muscle twitch.



(d) **Long refractory period in a cardiac muscle prevents tetanus.**


Na+ channels close
Slow Ca2+ channels open
Slow Ca2+ channels close
The plateau
Repolarization
Rapid depolarization
K+ channels close
+30
0
mV
–90
Voltage-gated ion channels open
Refractory period
Absolute
Relative
Influx of Na+
0
100
200
300
Time (ms)

(a)


Skeletal muscle
Action potential
+30
0
mV
–85
Contraction
Tension
0
100
200
300
Time (ms)
Cardiac muscle
Action potential
+30
0
mV
–90
Contraction
Tension
0
100
200
300
Time (ms)

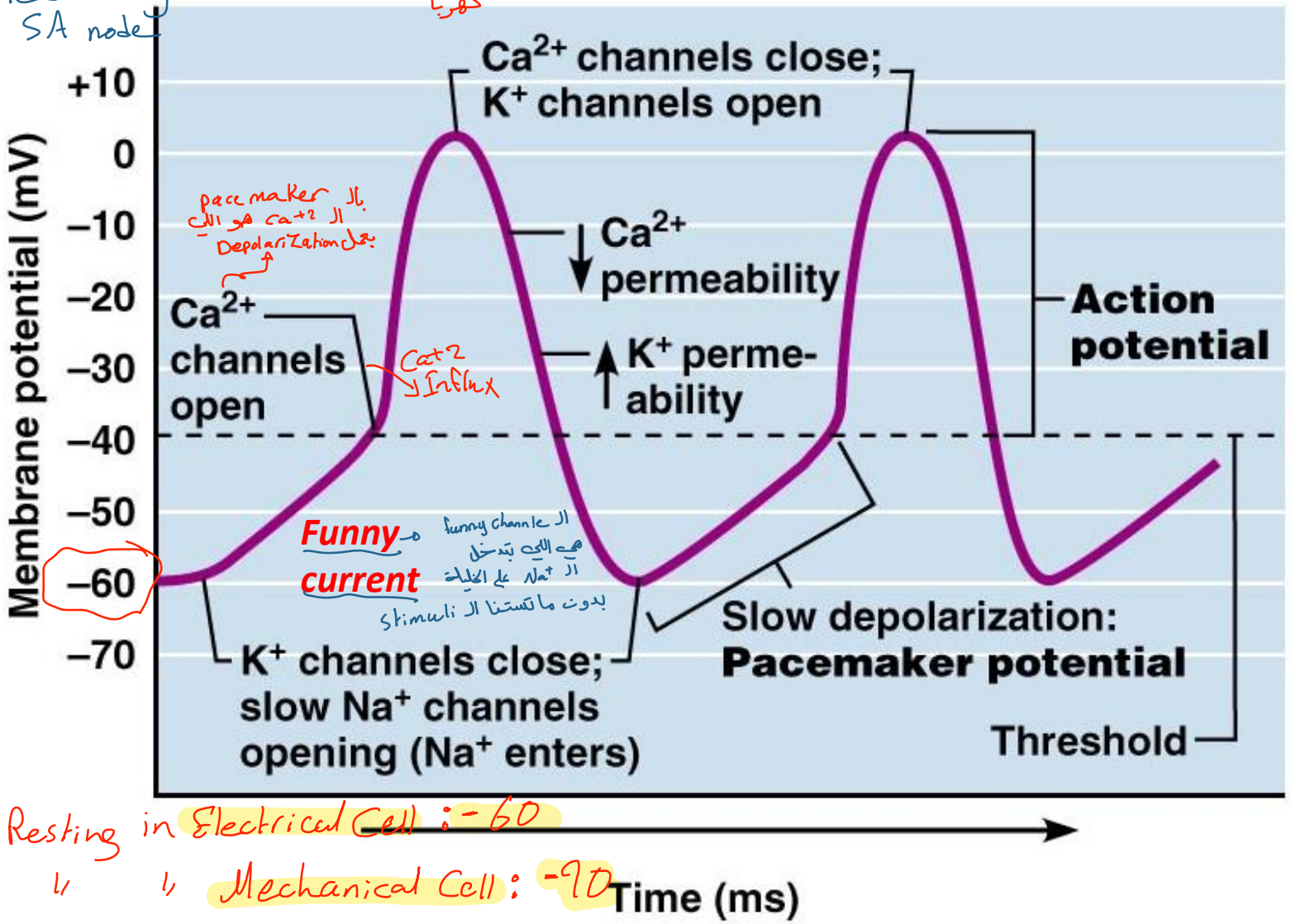
(b)

TABLE 14-3 Comparison of Action Potentials in Cardiac and Skeletal Muscle

	SKELETAL MUSCLE	CONTRACTILE MYOCARDIUM	AUTORHYTHMIC MYOCARDIUM
Membrane potential	Stable at −70 mV	Stable at −90 mV	Unstable pacemaker potential; usually starts at −60 mV
Events leading to threshold potential	Net Na^+ entry through ACh-operated channels	Depolarization enters via gap junctions	Net Na^+ entry through I_f channels; reinforced by Ca^{2+} entry
Rising phase of action potential	Na^+ entry	Na^+ entry	Ca^{2+} entry
Repolarization phase	Rapid; caused by K^+ efflux	Extended plateau caused by Ca^{2+} entry; rapid phase caused by K^+ efflux	Rapid; caused by K^+ efflux
Hyperpolarization	Due to excessive K^+ efflux at high K^+ permeability when K^+ channels close; leak of K^+ and Na^+ restores potential to resting state	None; resting potential is −90 mV, the equilibrium potential for K^+	Normally none; when repolarization hits −60 mV, the I_f channels open again. ACh can hyperpolarize the cell.
Duration of action potential	Short: 1–2 msec	Extended: 200+ msec	Variable; generally 150+ msec
Refractory period	Generally brief	Long because resetting of Na^+ channel gates delayed until end of action potential	None

- Characteristics of Pacemaker Cells
  - Unstable membrane potential
    - “bottoms out” at -60mV
    - “drifts upward” to -40mV, forming a pacemaker potential
  - Myogenic
    - The upward “drift” allows the membrane to **reach threshold potential (-40mV)** by itself
    - This is due to
      1. **slow depolarization**
         - Occurs through I_f channels (f=funny) that open at negative membrane potentials and start closing as membrane approaches threshold potential
      2. **Ca^{2+} channels opening** as membrane approaches threshold
         - At threshold additional Ca^{2+} ion channels open causing more rapid depolarization
         - These deactivate shortly after and
      3. **Slow K^+ channels** open as membrane depolarizes causing an efflux of K^+ and a repolarization of membrane

Pacemaker and Action Potentials of the Heart



spontaneous action potential

Cardiac conductive cells do not have a stable resting potential

-Decrease potassium permeability
-slow Na+ influx (Funny current)

The SA and AV node do not have fast Na+ channels like neurons

Depolarization is mainly caused by a slow influx of calcium ions (L type Ca channel)

Figure 18.13

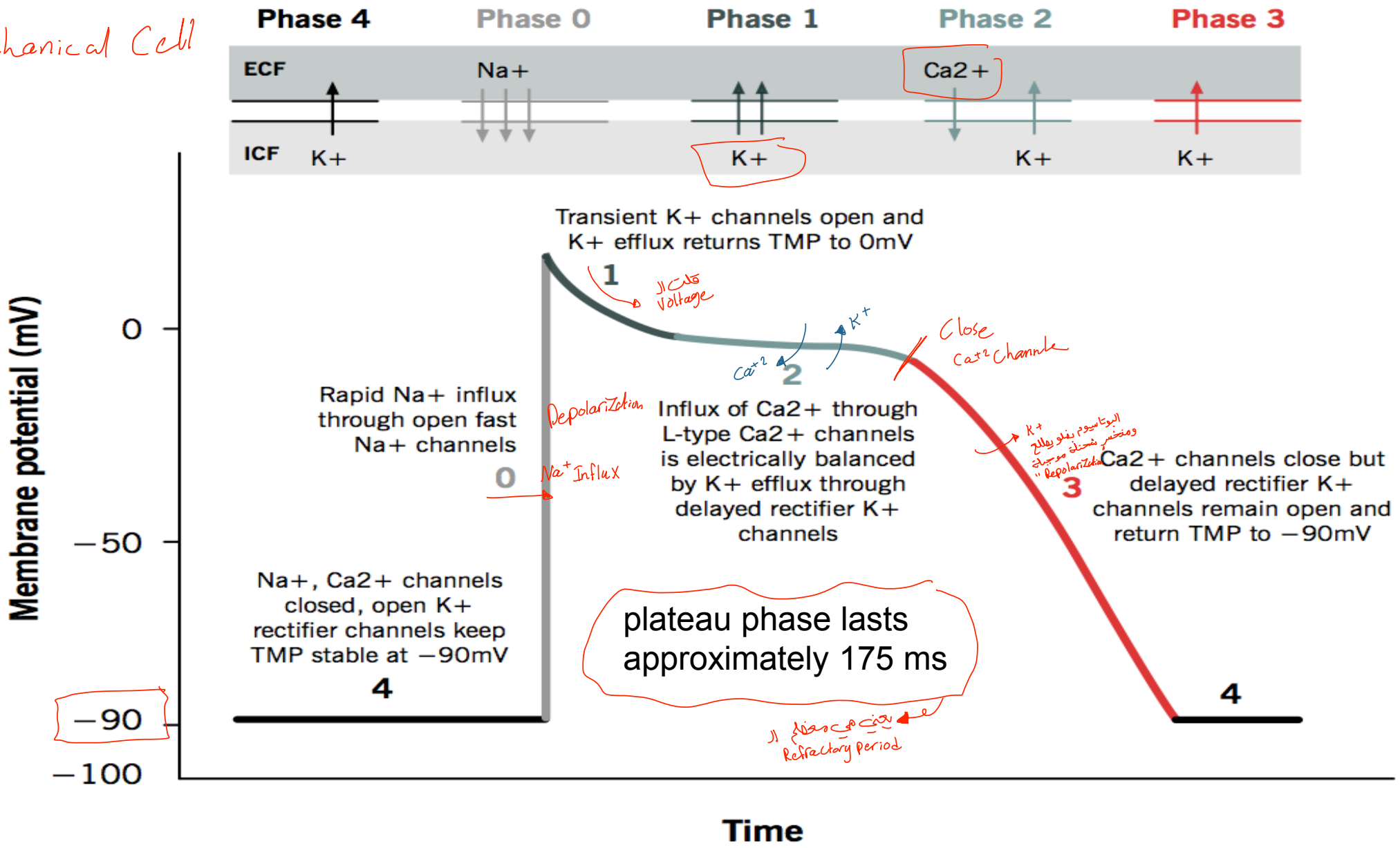
- Special aspects
  - **The action potential of a contractile cell**
    - Ca^{2+} plays a major role again
    - Action potential is longer in duration than a "normal" action potential due to Ca^{2+} entry
    - Phases
      - 4 – resting membrane potential @ -90mV
      - 0 – depolarization
        - Due to gap junctions or conduction fiber action
        - Voltage gated Na^{+} channels open… close at 20mV
      - 1 – temporary repolarization
        - Open K^{+} channels allow some K^{+} to leave the cell
      - 2 – plateau phase
        - Voltage gated Ca^{2+} channels are fully open (started during initial depolarization)
      - 3 – repolarization
        - Ca2+ channels close and K+ permeability increases as slower activated K+ channels open, causing a quick repolarization
  - What is the significance of the plateau phase?

Action potential of cardiac muscles

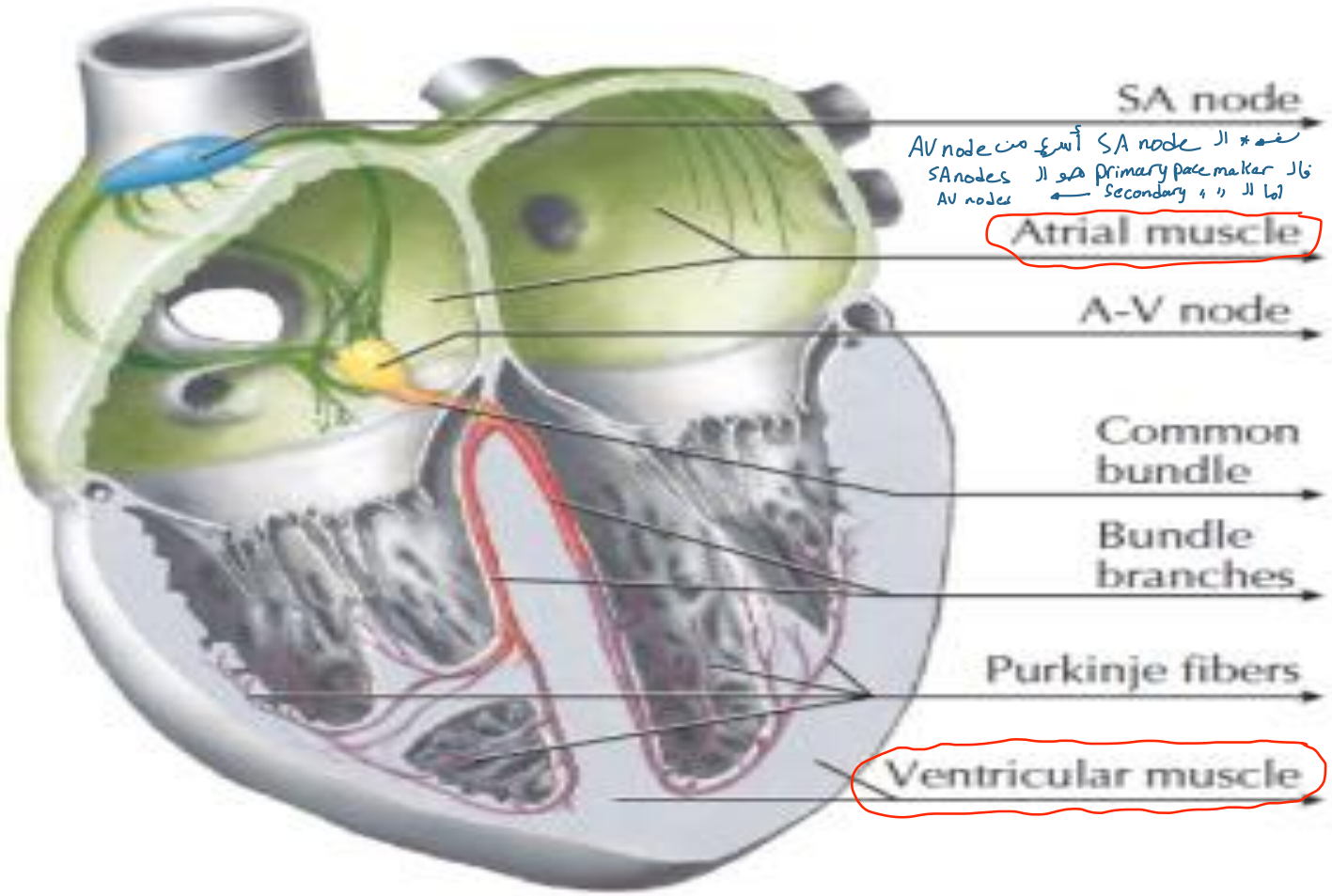
250 ms

Grigoriy Ikonnikov and Eric Wong

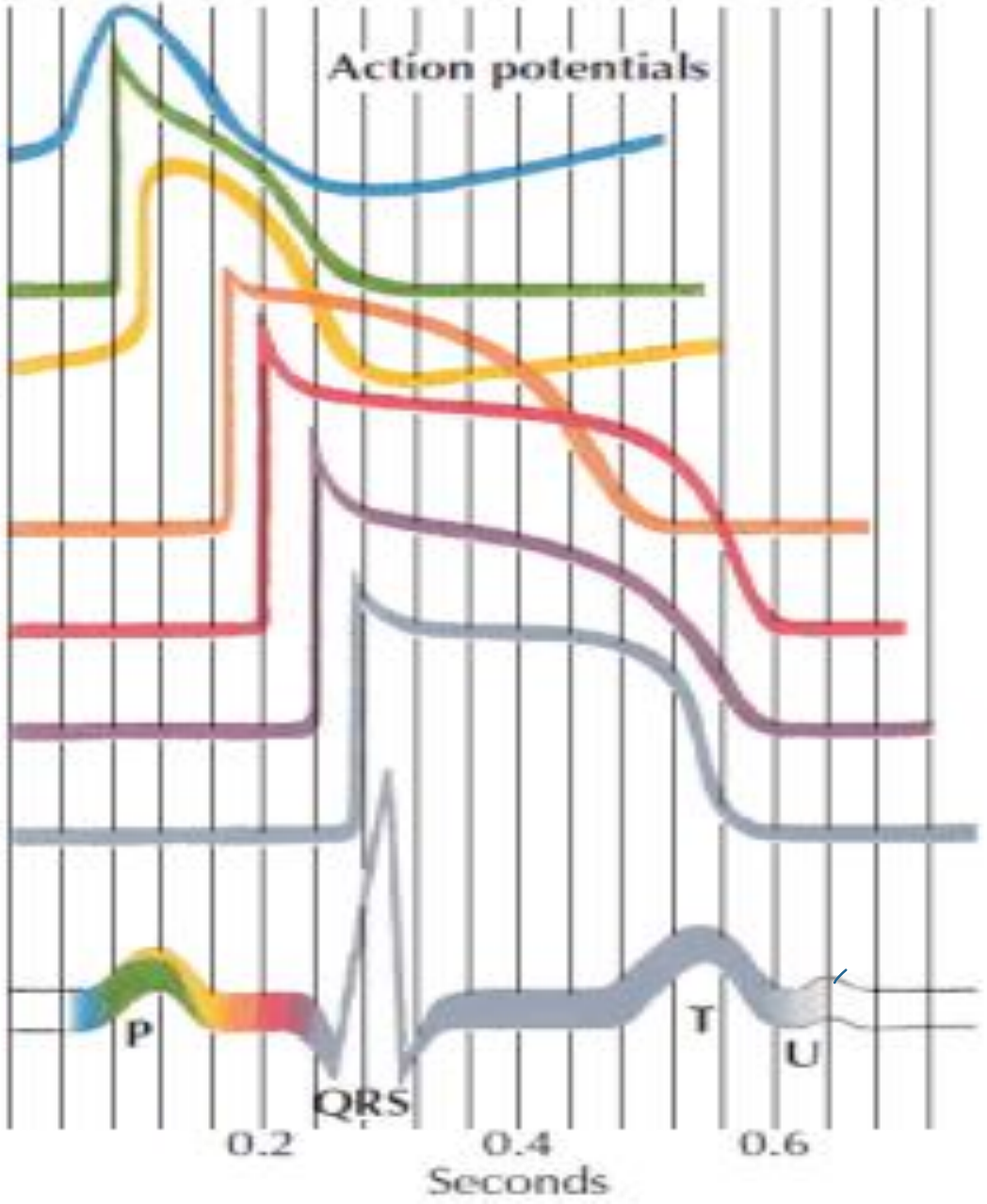
* Mechanical Cell



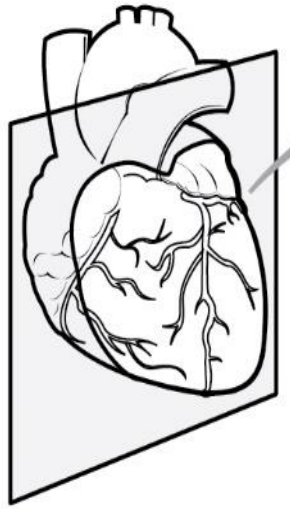
* primary pacemaker → SA node
* Secondary pace maker → AV node



AV node أسرع من SA node الـ * عشان
SA nodes هو الـ primary pacemaker فال
AV nodes ← Secondary " " فال الـ



Bachmann's bundle or the **interatrial band** that conducts the impulse directly from the right atrium to the left atrium.



Frontal plane through heart

Internodal pathway

consist of three bands (anterior, middle, and posterior)

Sinoatrial (SA) node
Anterior internodal
Atrioventricular (AV) node
Middle internodal
Posterior internodal
Right atrium
Right ventricle

Arch of aorta
Bachman's bundle
Left atrium
Atrioventricular (AV) bundle (bundle of His)
Left ventricle
Right and left bundle branches
Purkinje fibers

يساعد على انتشار ال Electricle Conduction in Right sid

* اما بال left side ال هو اللي يساعد بالانتشار Bachmann's bundle

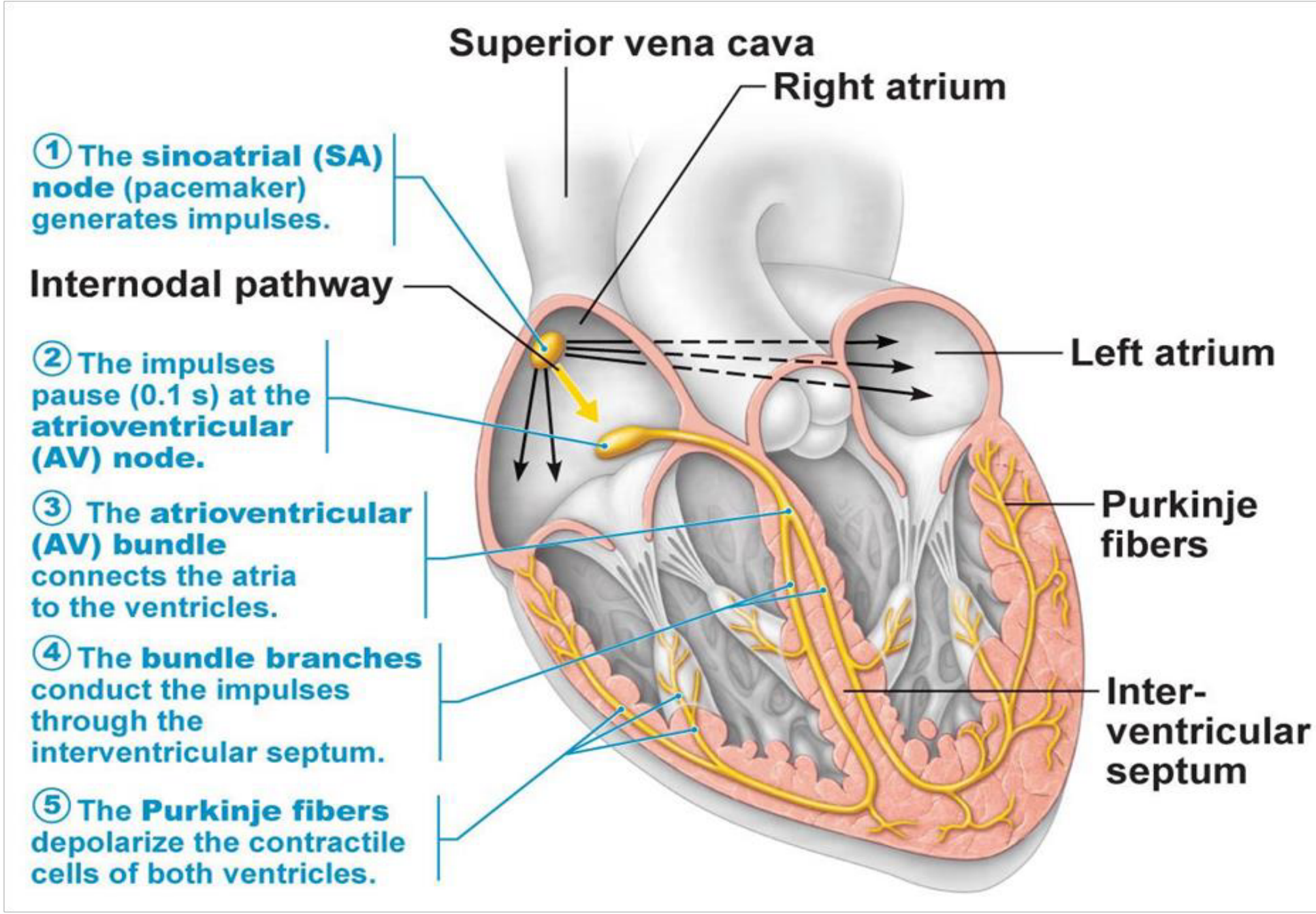
* اما بين الخلايا ال Gap junction هي اللي بتسري

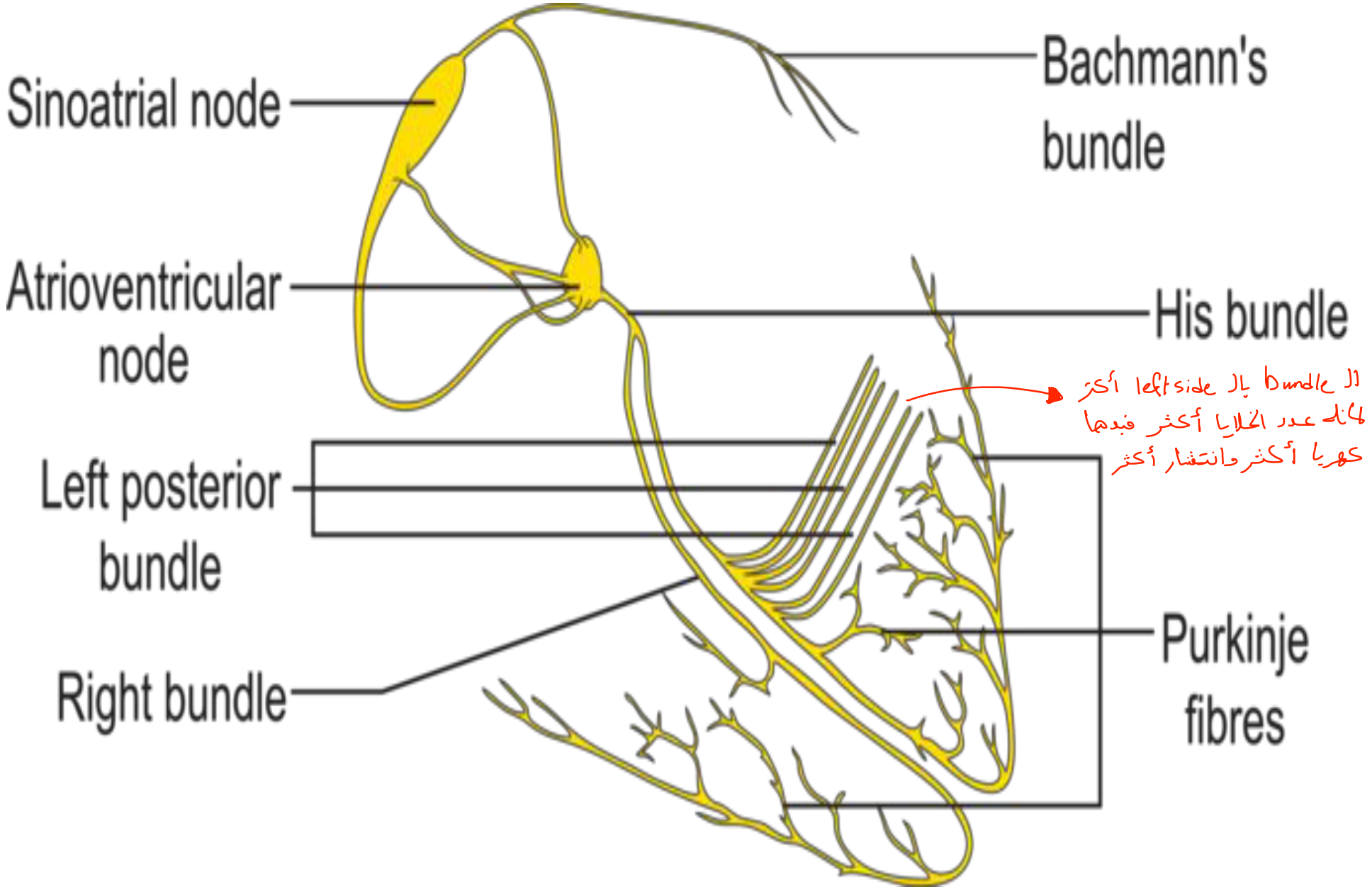
* أول اشي بوصلو كهربا هو ال Right atrium

* الكهرباء بتنزل لتحت عن طريق ال AV node

وليس عن طريق ال valve لانهم منعزلين

هي Electrical ال يساعد على انتشار Conduction in left side


Superior vena cava
Right atrium
① The sinoatrial (SA) node (pacemaker) generates impulses.
Internodal pathway
② The impulses pause (0.1 s) at the atrioventricular (AV) node.
③ The atrioventricular (AV) bundle connects the atria to the ventricles.
④ The bundle branches conduct the impulses through the interventricular septum.
⑤ The Purkinje fibers depolarize the contractile cells of both ventricles.
Left atrium
Purkinje fibers
Inter-ventricular septum


Sinoatrial node
Atrioventricular node
Left posterior bundle
Right bundle
Bachmann's bundle
His bundle
Purkinje fibres
أكثر left side بال bundle ال
هناك عدد الخلايا أكثر فبدها
كهربا أكثر وانتشار أكثر

Heart Physiology: Sequence of Excitation

- Sinoatrial (SA) node generates impulses about 75 times/minute (has the highest rate of depolarization)
- Atrioventricular (AV) node delays the impulse approximately 0.1 second
- Impulse passes from atria to ventricles (50 ms) via the atrioventricular bundle (bundle of His)

Heart Physiology: Sequence of Excitation

- AV bundle splits into two pathways in the interventricular septum (bundle branches)
  - Bundle branches carry the impulse toward the apex of the heart
  - Purkinje fibers carry the impulse to the heart apex and ventricular walls

Coordinating the Pump: Electrical Signal Flow

- **Purkinje fibers:**

- They are very large fibers.

- They transmit AP at a velocity of 1.5 to 4.0 m/sec (6x more than usual ventricular muscle and 150x than the A-V nodal fibers).

- This allows almost instantaneous transmission of the cardiac impulse throughout the entire remainder of the ventricular muscle.

Coordinating the Pump: Electrical Signal Flow

- Right and left ventricular contraction from apex upword

- **Why the AP do not re-enter the Atrial muscle from the ventricles**?

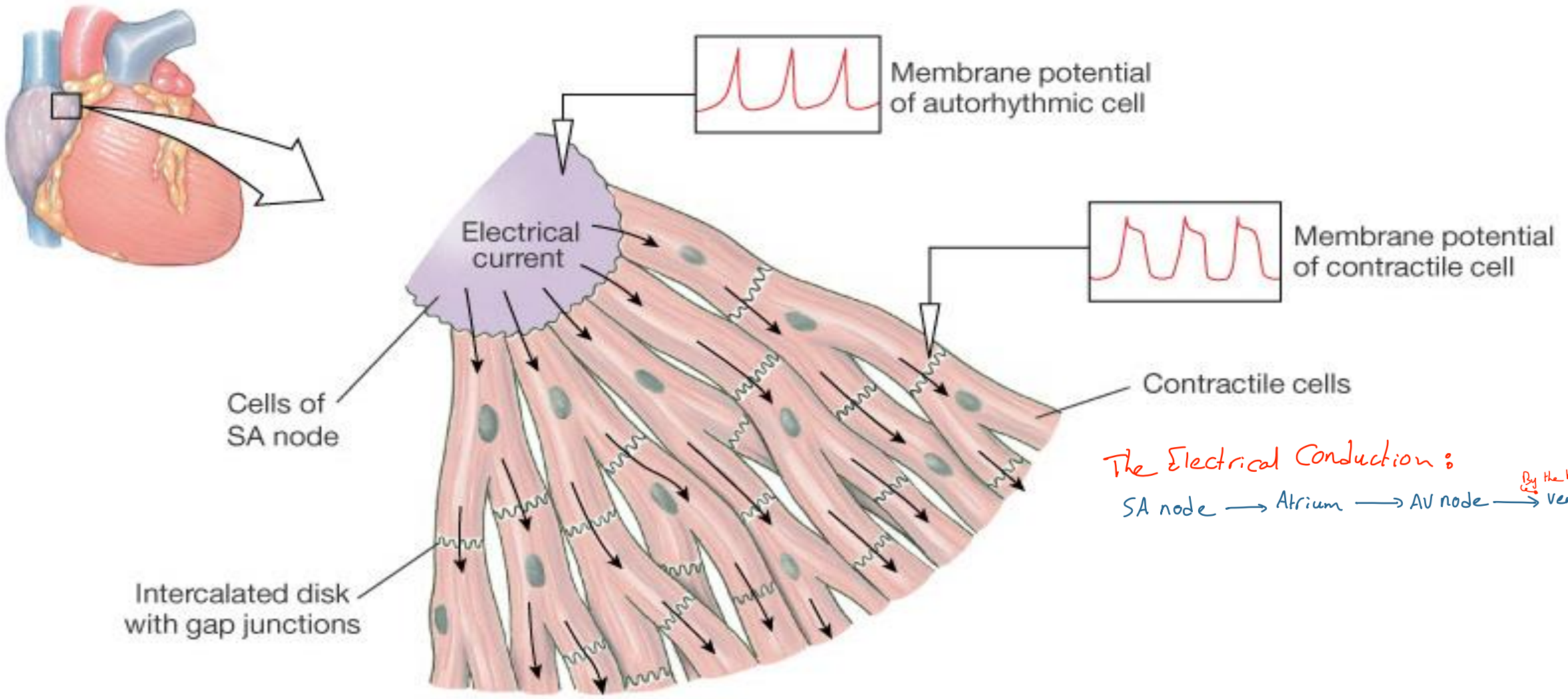
1) One way conduction through the A-V bundle (except in abnormal states).

2) The presence of a continuous fibrous barrier between the atrial muscle and the ventricular muscle (except at the A-V bundle).

* الـ Heart rate تبعنا معتمد على الـ SA node

- The primary pacemaker therefore is the **SA node** and has an inherent rate of 60-100 beats/minute. The SA node has the highest level of automaticity, but escape pacemakers can exist.
- The AV node only generates an impulse if the SA node does not function at its normal rate. The **AV node** fires electrical impulses at a rate of 40-60 beats/ minute.
- **bundle branches and the Purkinje** network will become the initiating pacemaker if the AV node is not able to function at its normal rate. The inherent ventricular rate is 20-40 beats/minute

Coordinating the Pump: Electrical Signal Flow

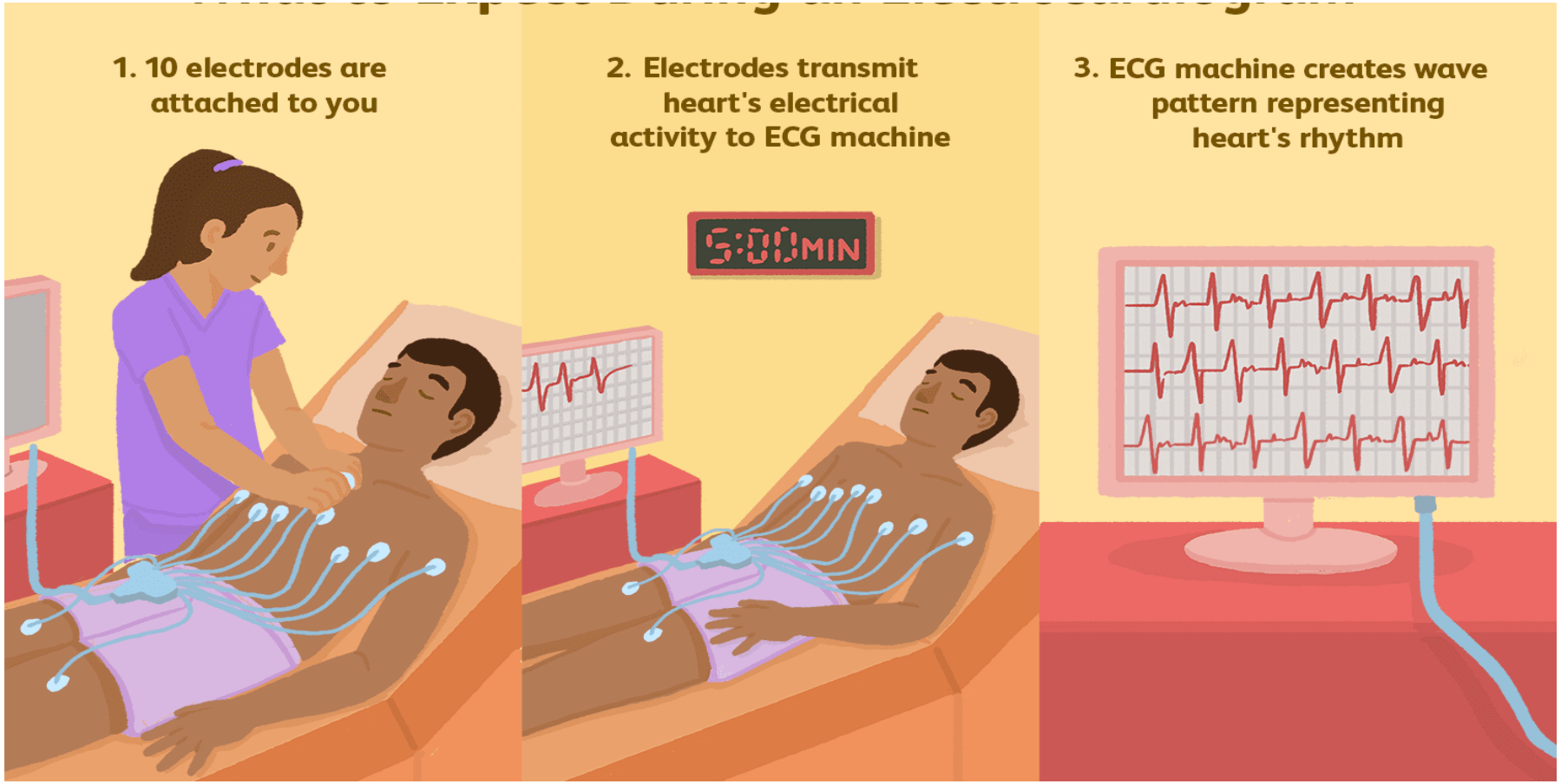


Depolarizations of autorhythmic cells rapidly spread to adjacent contractile cells through gap junctions.

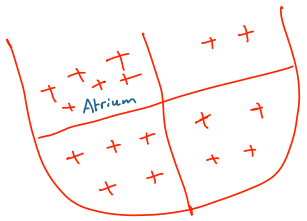
The Electrical Conduction:

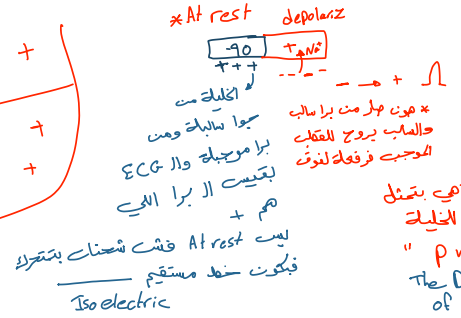
SA node → Atrium → AV node → (By the bundle) → ventricle

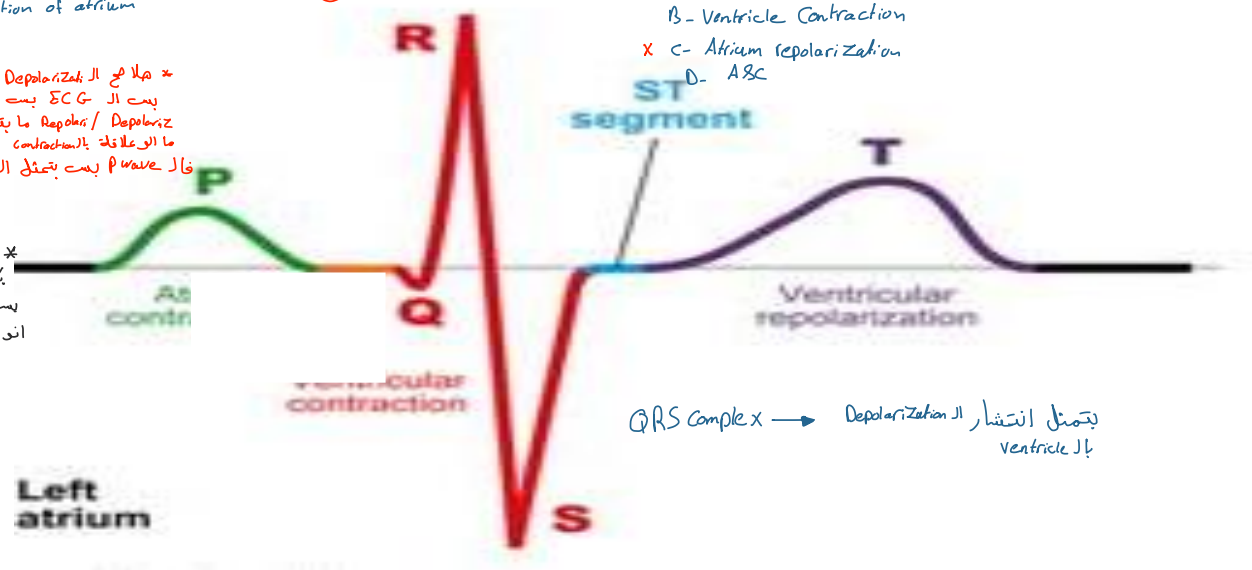
The electrical conduction of the heart can be monitored using Electrocardiograph ECG



Electrocardiography

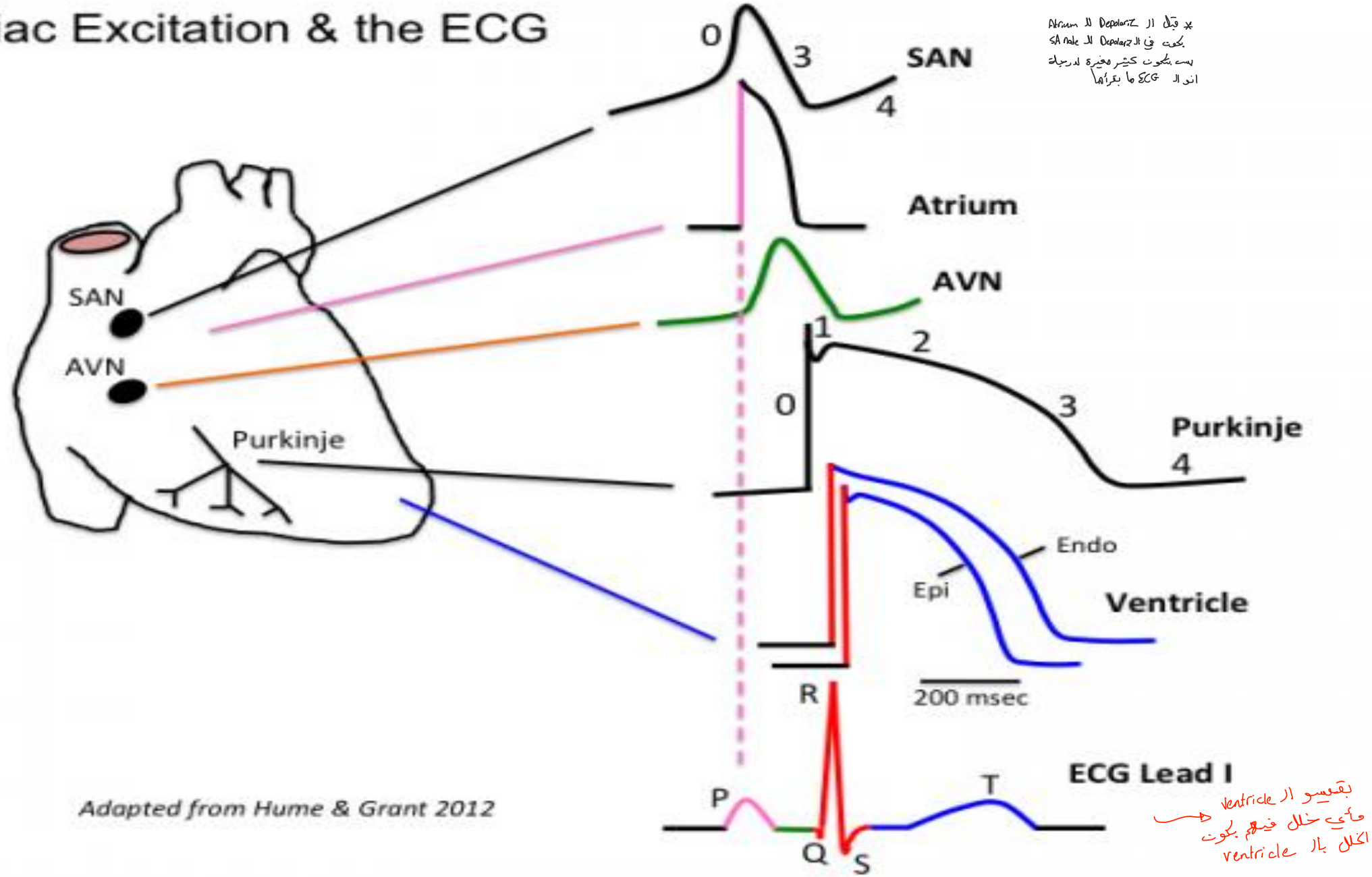






- Electrical activity is recorded by electrocardiogram (ECG) using electrodes
- P wave corresponds to depolarization of atrial
- QRS complex corresponds to ventricular depolarization
- T wave corresponds to ventricular repolarization
- Atrial repolarization record is masked by the larger QRS complex

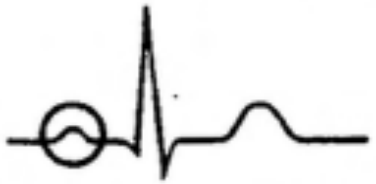
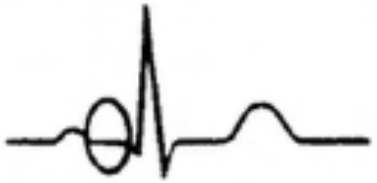
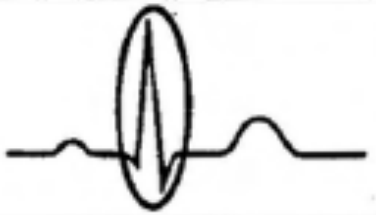
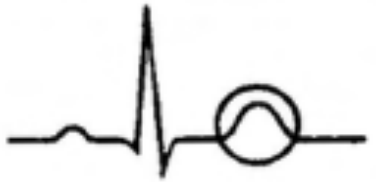
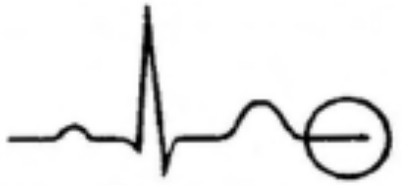
Cardiac Excitation & the ECG

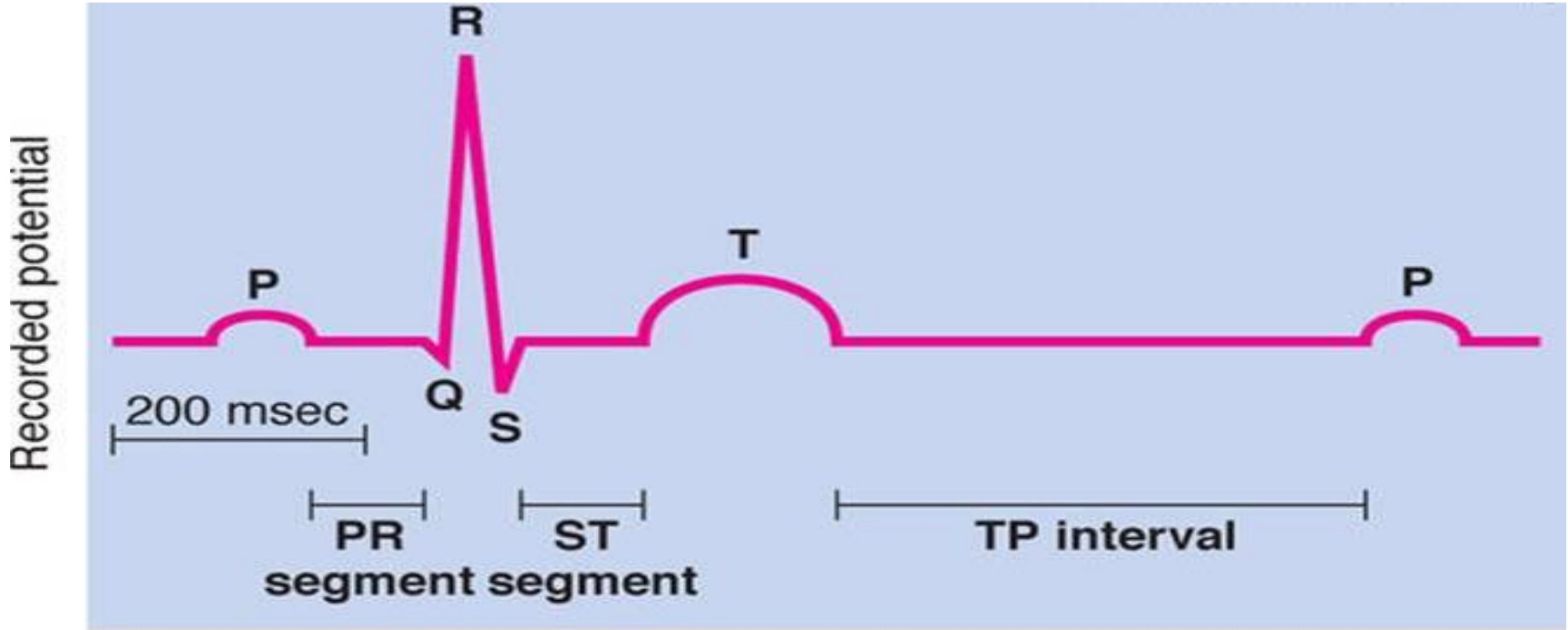


Adapted from Hume & Grant 2012

* قبل ال Atrium ال Depolariz بكمت في ال SA node ال Depolariz بس بكون كتير صغيرة لدرجة انو ال ECG ما بقرأها

بقيس ال Ventricle وأي خلل فيهم بكون الخلل بال Ventricle

Electrical Activity	Graphic Depiction	Associated Pattern
Atrial Depolarization		P Wave
Delay at AV Node		PR Segment
Ventricular Depolarization		QRS Complex
Ventricular Repolarization		T Wave
No electrical activity		Isoelectric Line



P wave = Atrial depolarization

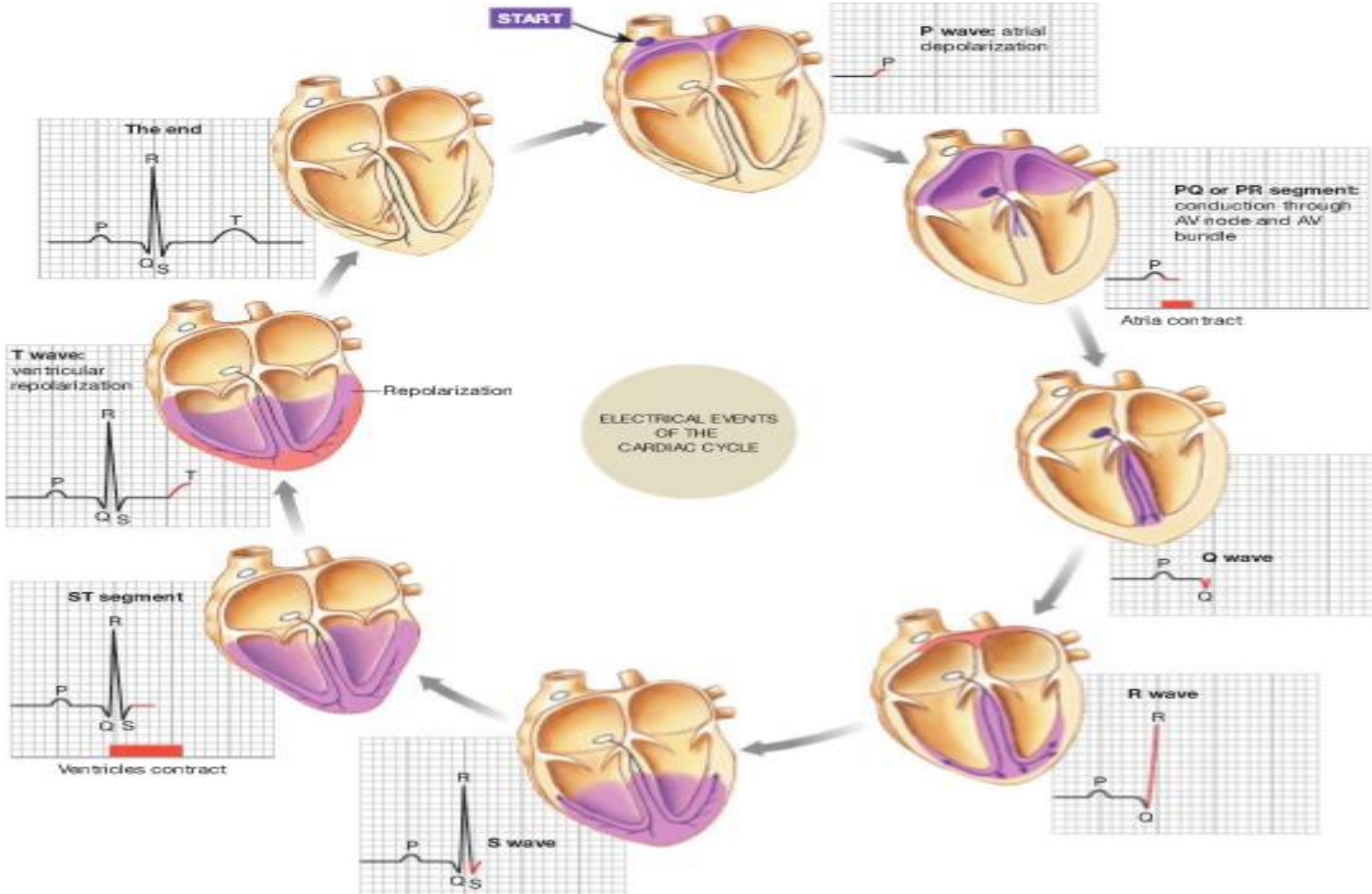
PR segment = AV nodal delay

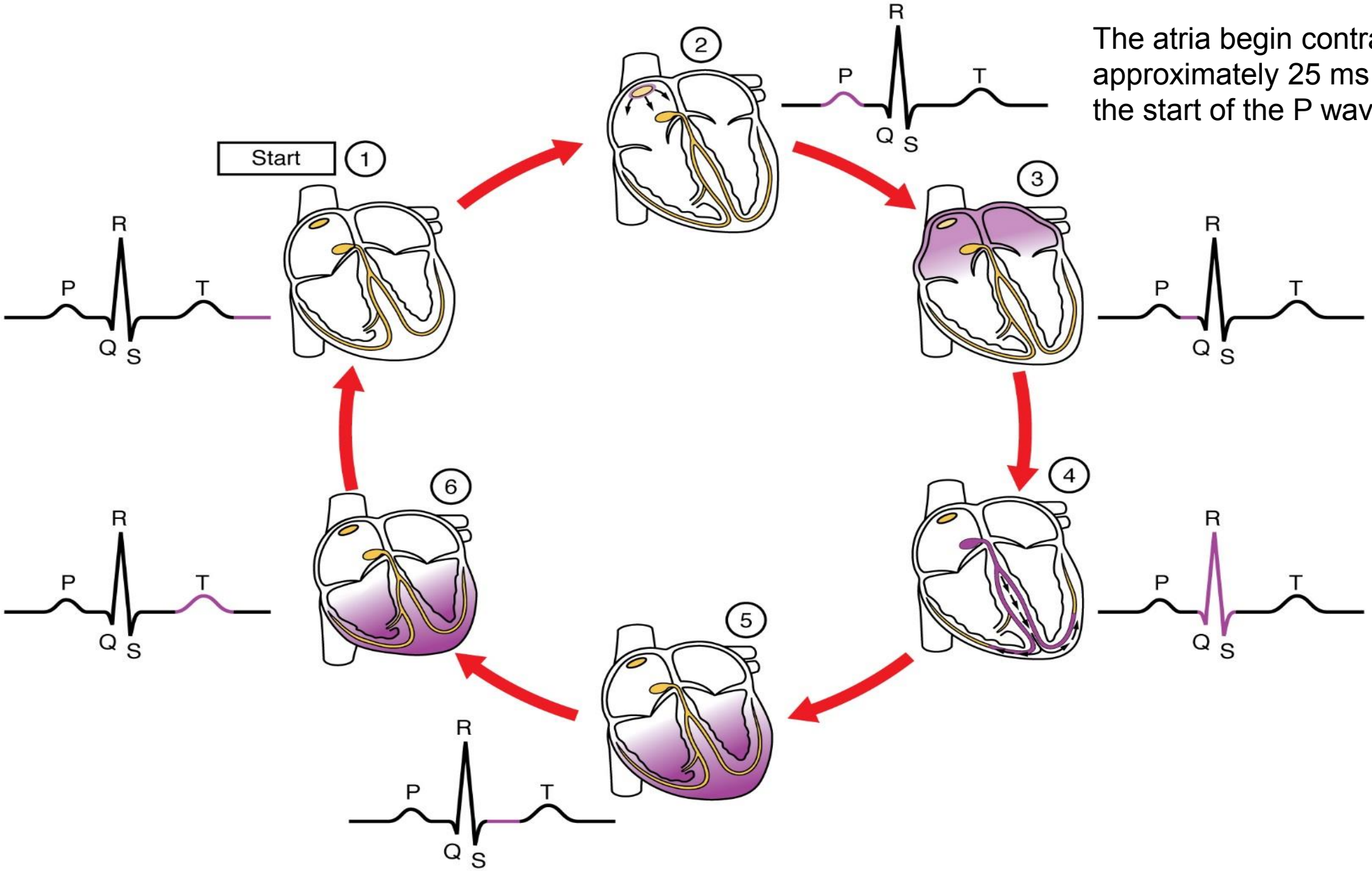
QRS complex = Ventricular depolarization (atria repolarizing simultaneously)

ST segment = Time during which ventricles are contracting and emptying

T wave = Ventricular repolarization

TP interval = Time during which ventricles are relaxing and filling


START
P wave: atrial depolarization
P
PQ or PR segment: conduction through AV node and AV bundle
P
Atria contract
Q wave
P
Q
R wave
R
P
Q
S wave
R
P
Q S
ST segment
R
P
Q S
Ventricles contract
T wave: ventricular repolarization
R
P
T
Q S
Repolarization
The end
R
P
T
Q S
ELECTRICAL EVENTS OF THE CARDIAC CYCLE



The atria begin contracting approximately 25 ms after the start of the P wave

Heart Excitation Related to ECG

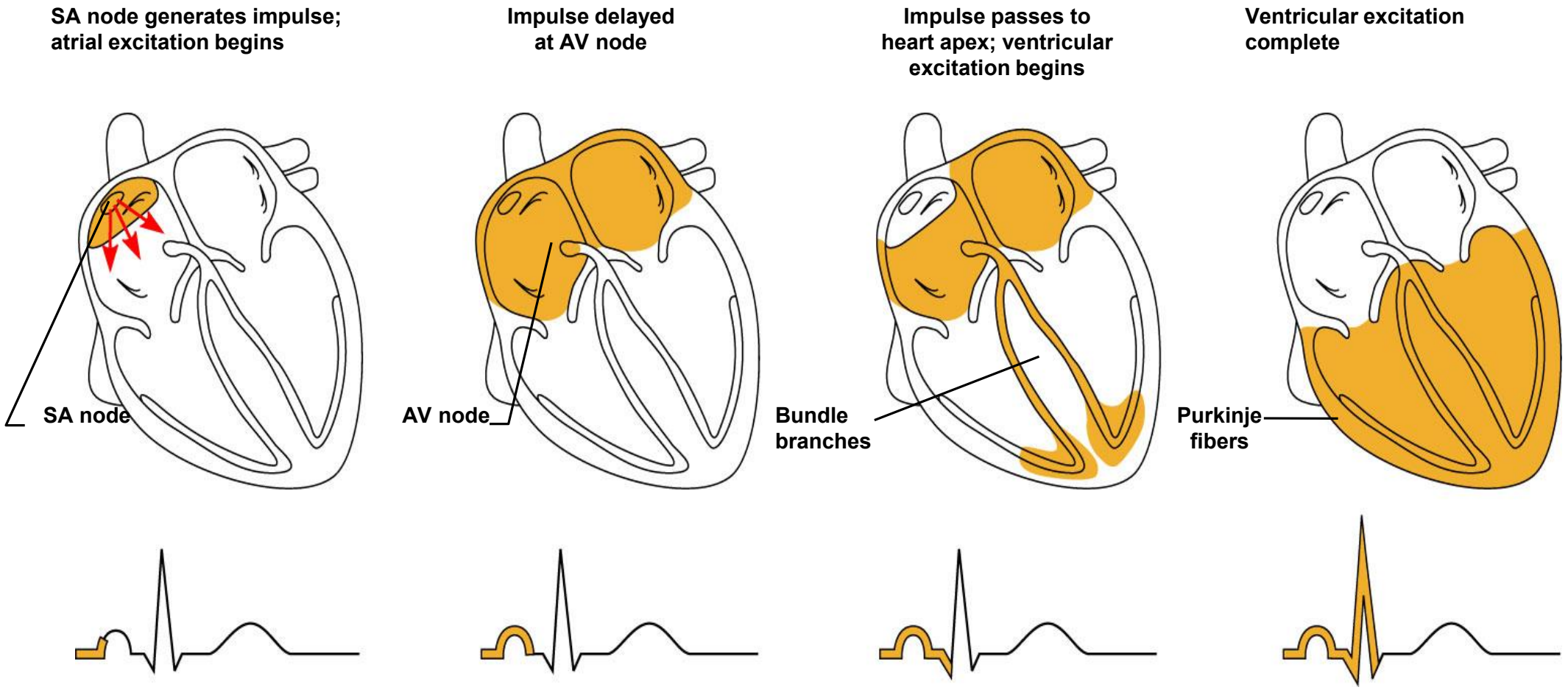
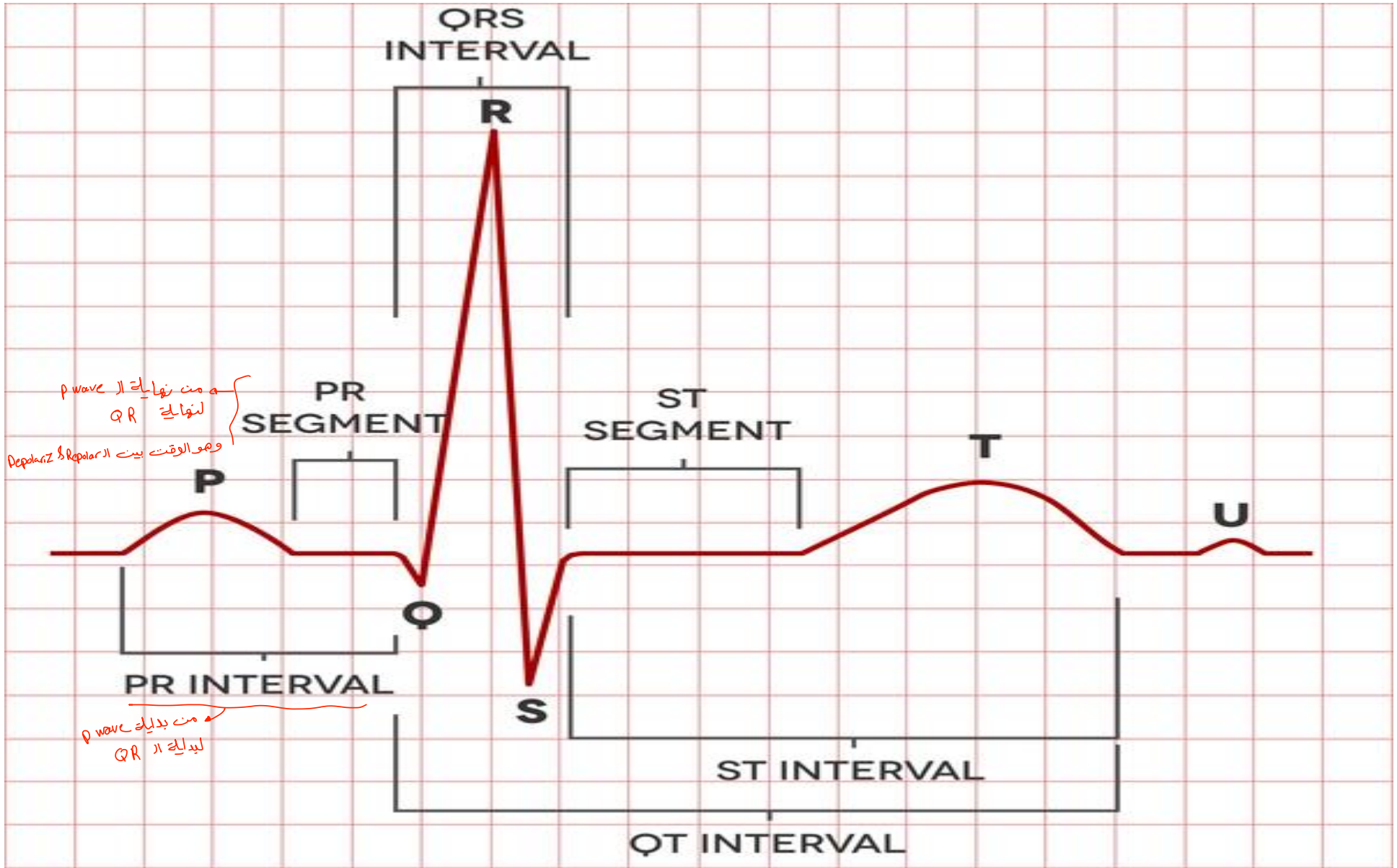


Figure 18.17


QRS INTERVAL
R
PR SEGMENT
ST SEGMENT
T
P
U
Q
S
PR INTERVAL
ST INTERVAL
QT INTERVAL
من نهاية الـ p wave لنهاية QR
وهو الوقت بين الـ Depolariz & Repolar
من بداية الـ p wave لبداية الـ QR

U Wave

- Small rounded deflection (< 1 mm) that occurs immediately after T wave and has same polarity as T wave.
- Best seen in leads V2-V4.
- Repolarization of papillary muscles or purkinje fibers.
- Prominent U wave: hypokalemia, drugs e.g. dofetilide, amiodarone, sotalol, quinidine, procainamide, disopyramide.
- Inverted U wave: Sign of ischemia

*ازا بينت الـ U wave كتير واضحة بكون في أمراض

- **Leads are electrodes which measure the difference in electrical potential between either:**

❖The standard ECG has 12 leads:

- 3 Standard Limb Leads (Bipolar)
- 3 Augmented Limb Leads (Unipolar)
- 6 Precordial Leads (Unipolar)

❑Two different points on the body (**Bipolar leads**).

❑One point on the body and a virtual reference point with zero electrical potential, located in the center of the heart (**Unipolar leads**).

❖The axis of a particular lead represents the viewpoint from which it looks at the heart.

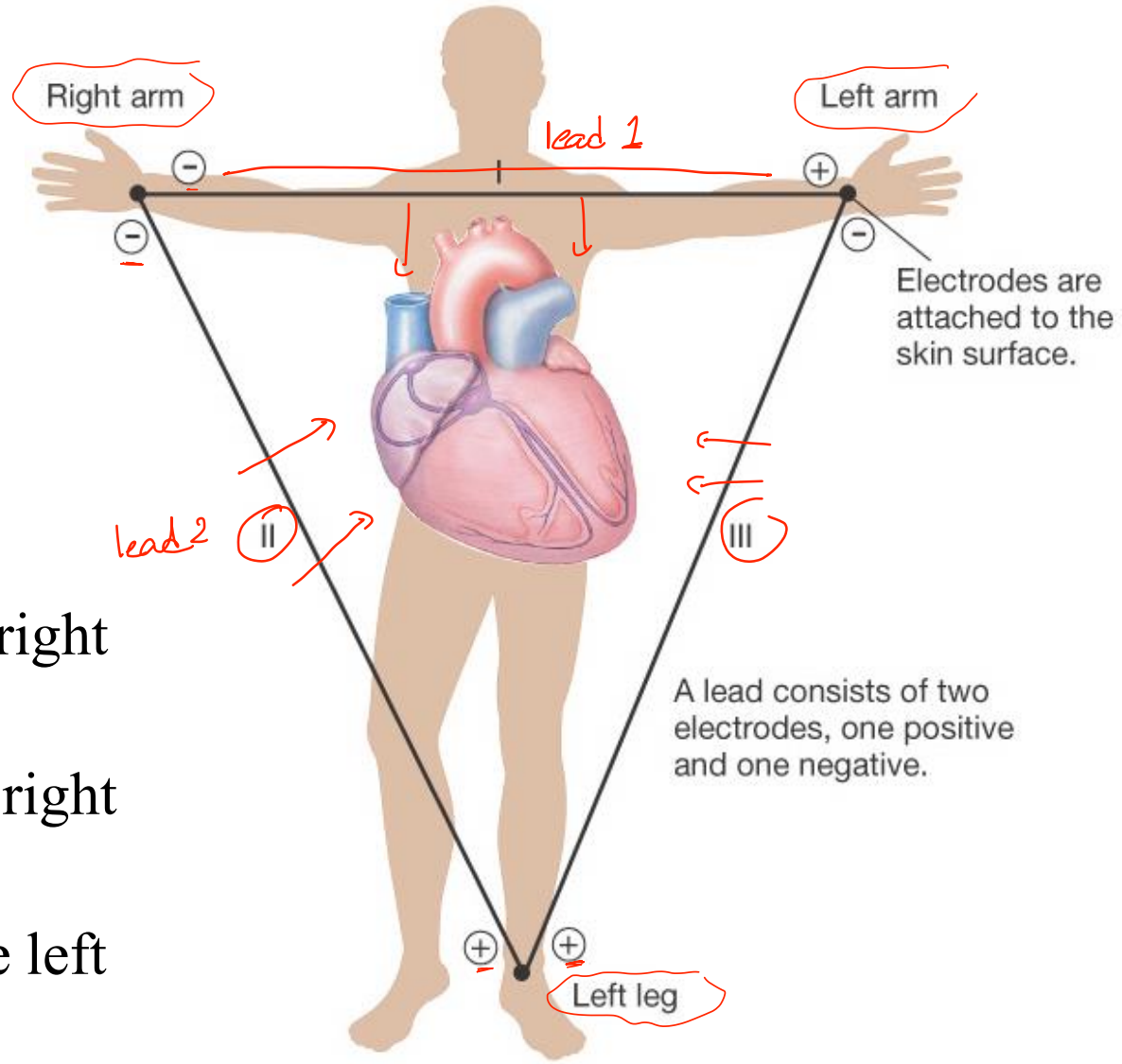
Electrocardiogram (ECG): Electrical Activity of the Heart

Einthoven's triangle:

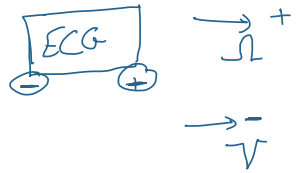
3 leads

1)Bipolar Limb Leads

- 1 positive and 1 negative electrode
  - RA always negative
  - LL always positive
- Provide a view from a vertical plane
- Three limb leads:
  - **Lead I**: -ve terminal is connected to the right arm/+ve terminal to the left arm
  - **Lead II**:-ve terminal is connected to the right arm/+ve terminal to the left leg
  - **Lead III**:-ve terminal is connected to the left arm/+ve terminal to the left leg

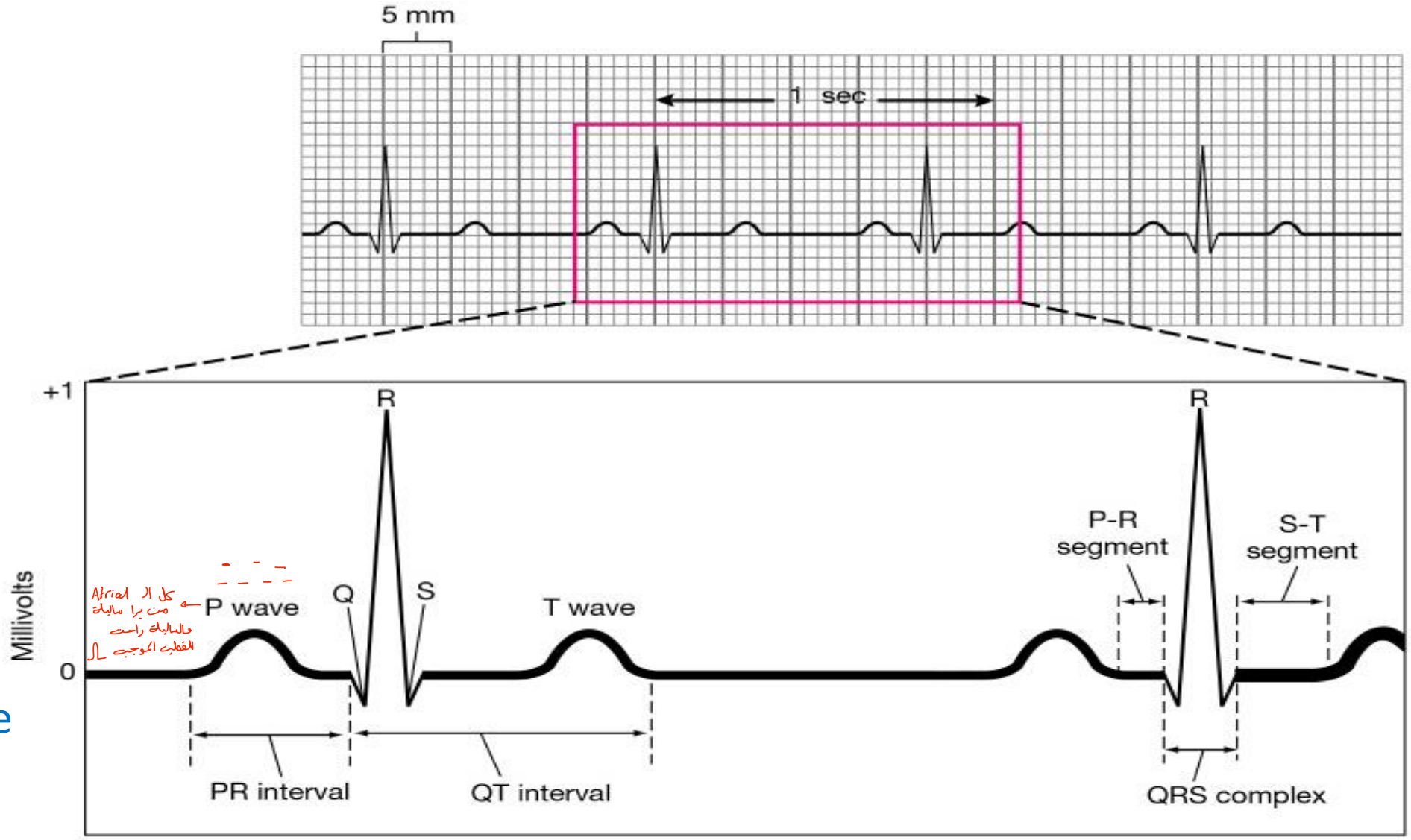


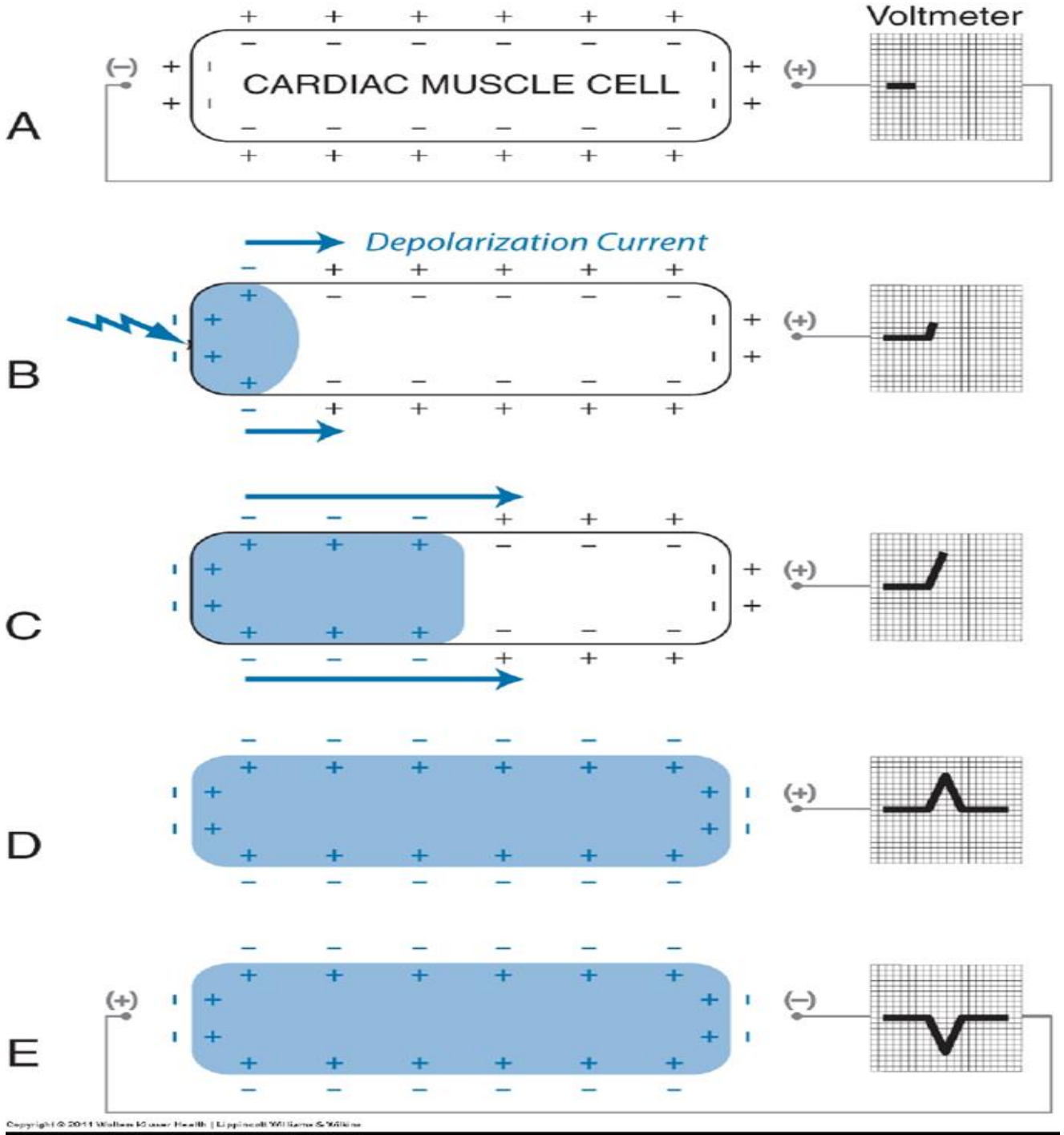
Electrocardiogram (ECG): Electrical Activity of the Heart



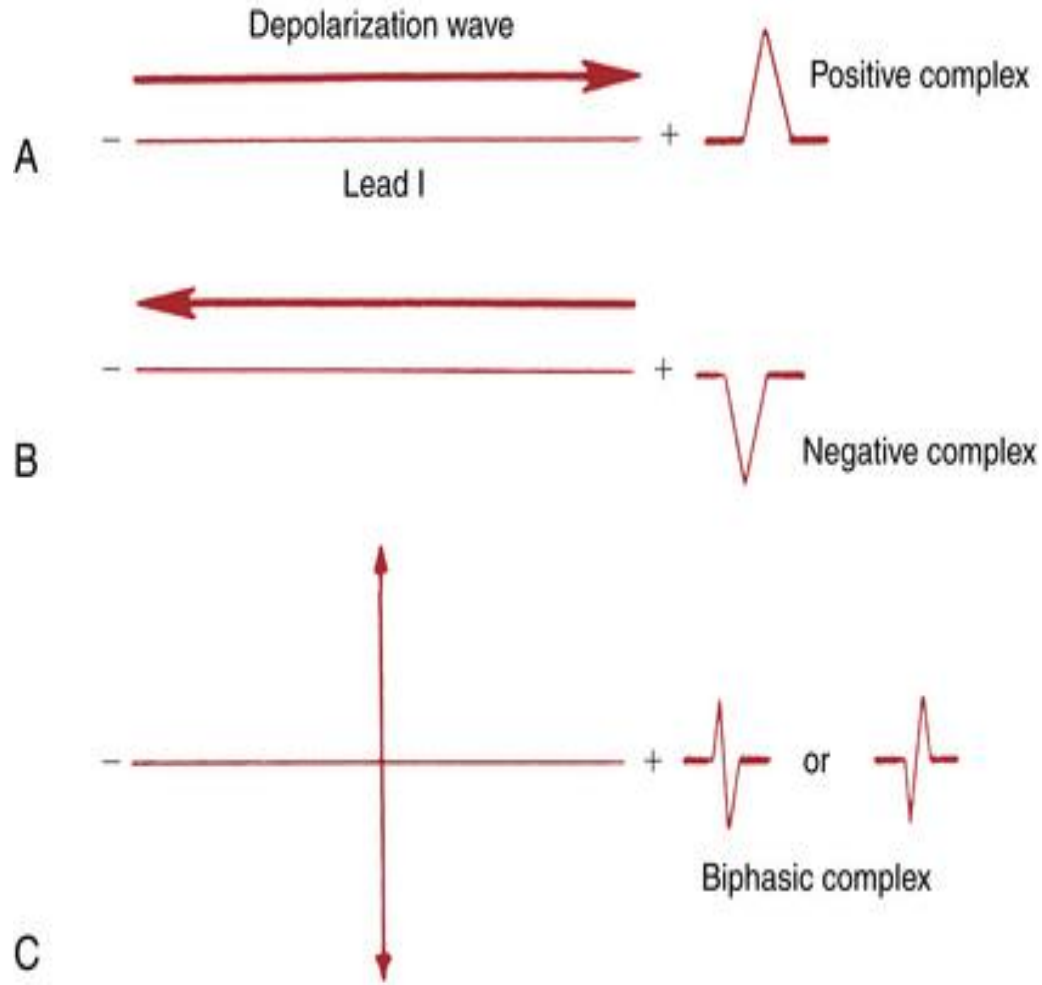
ECG wave goes up→
When an electrical wave moving through the heart is directed toward the positive electrode

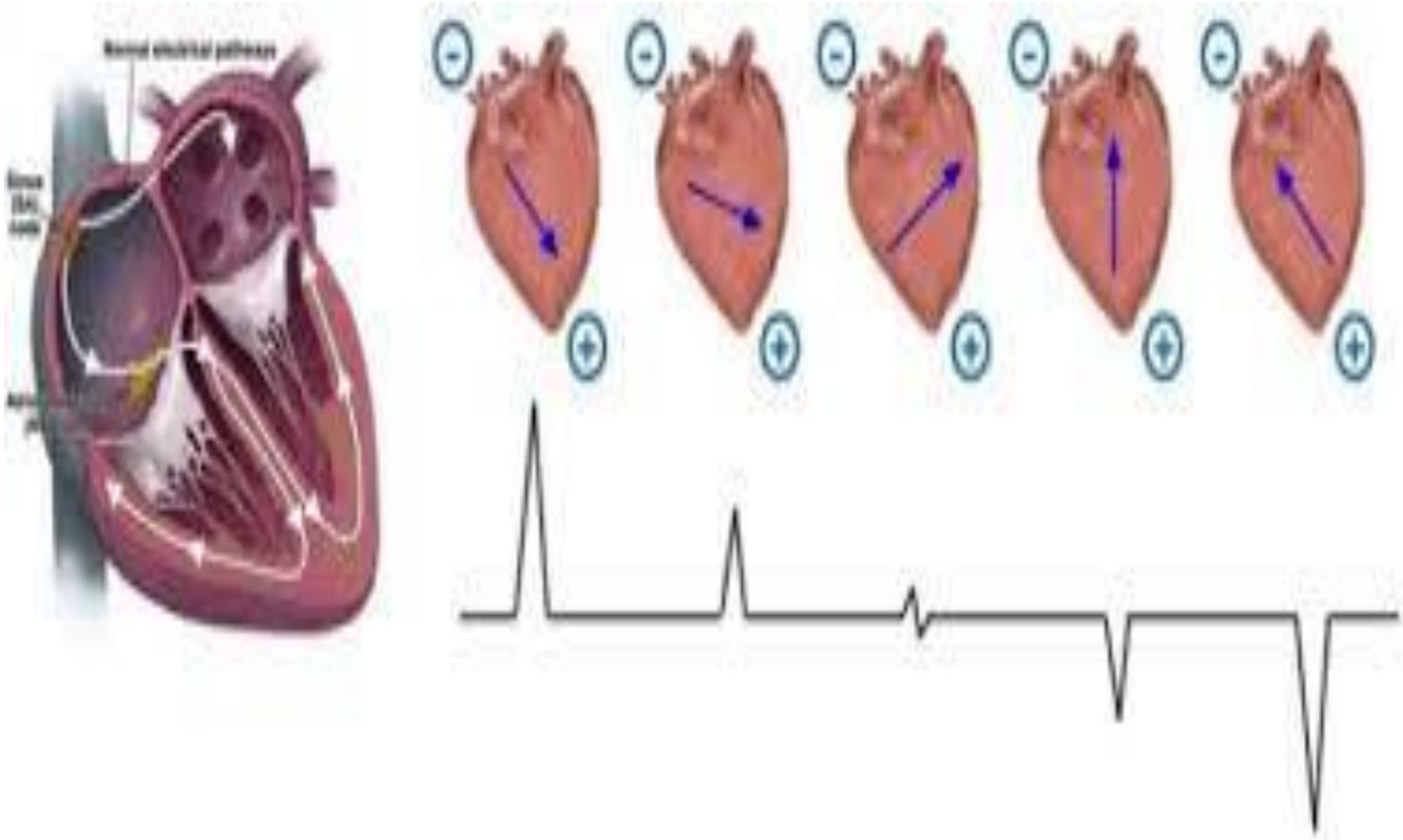
ECG wave points downward→
If net charge movement is toward the negative electrode

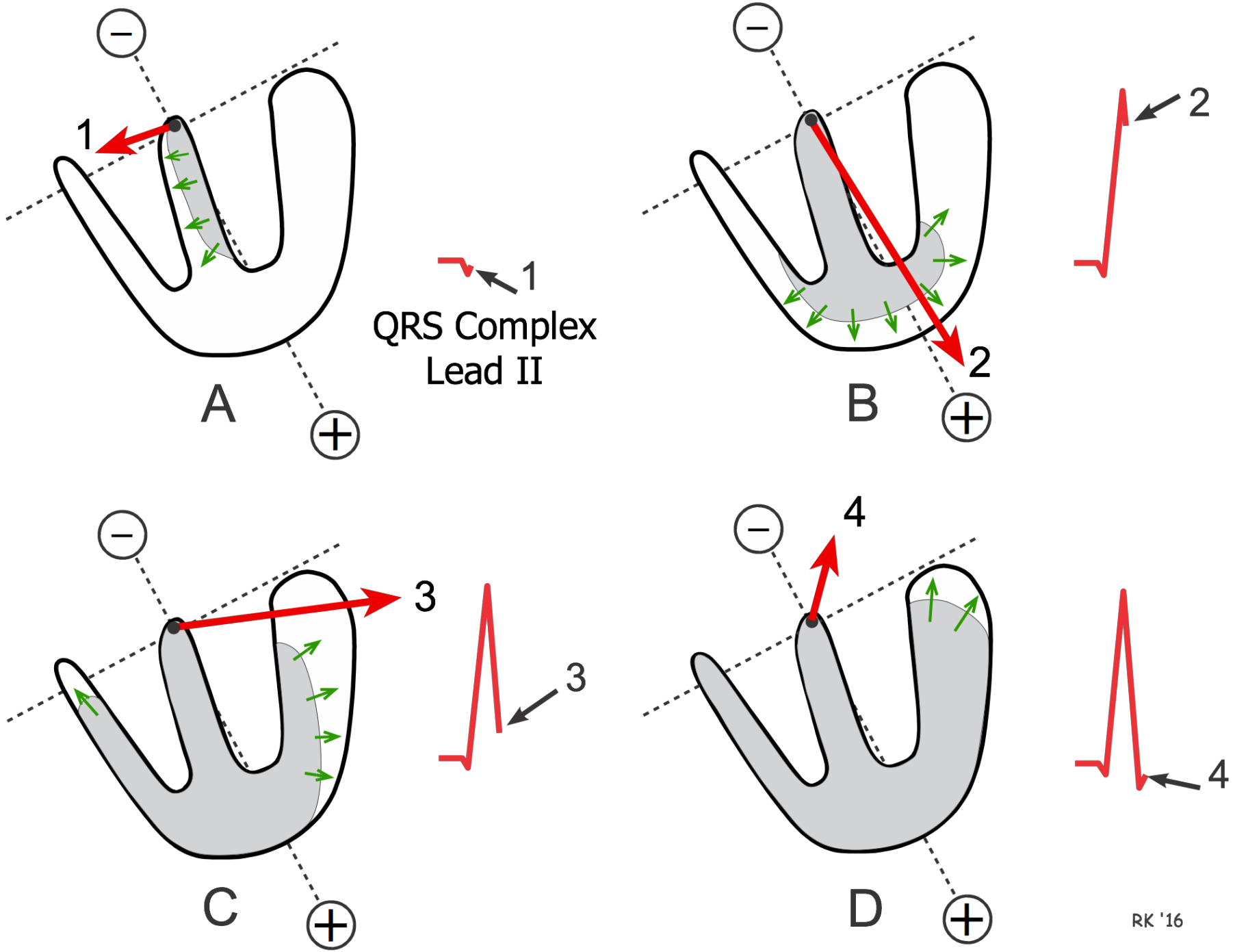




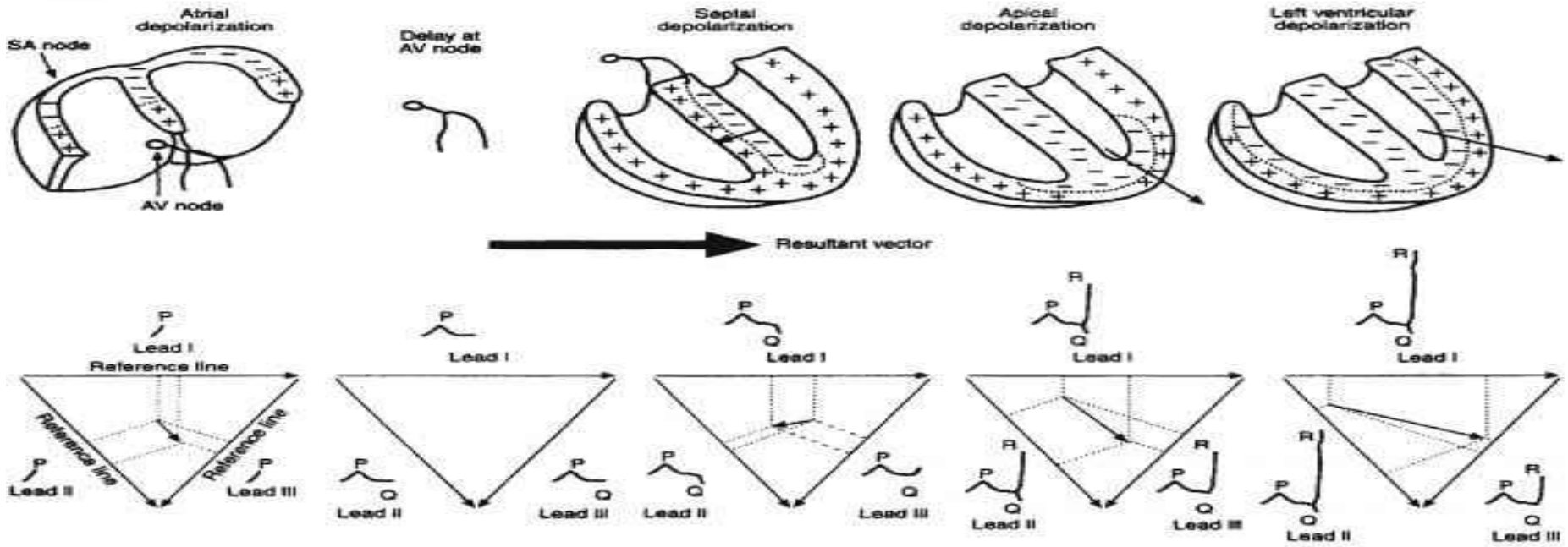
Three Basic Laws of Electrocardiography



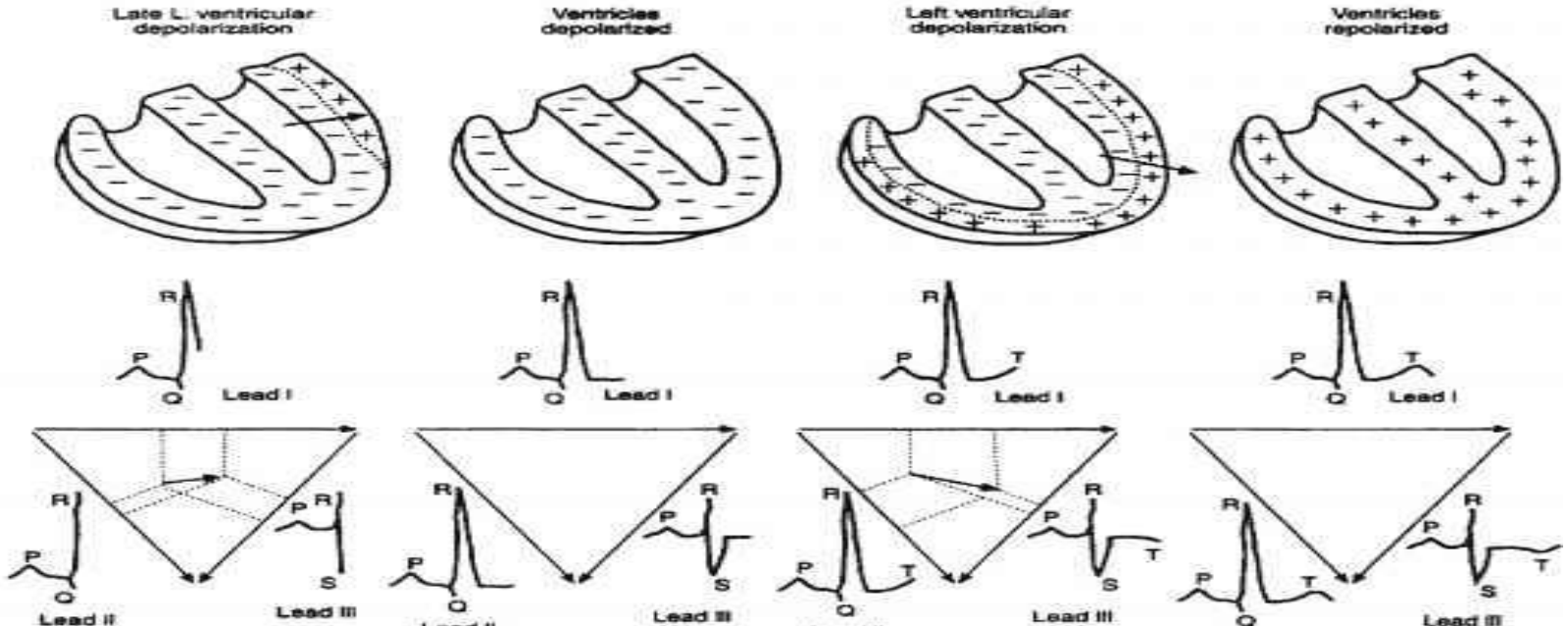



1
A
1
QRS Complex
Lead II
2
B
2
3
C
3
4
D
4
RK '16

Progression of depolarization



End of depolarization and repolarization

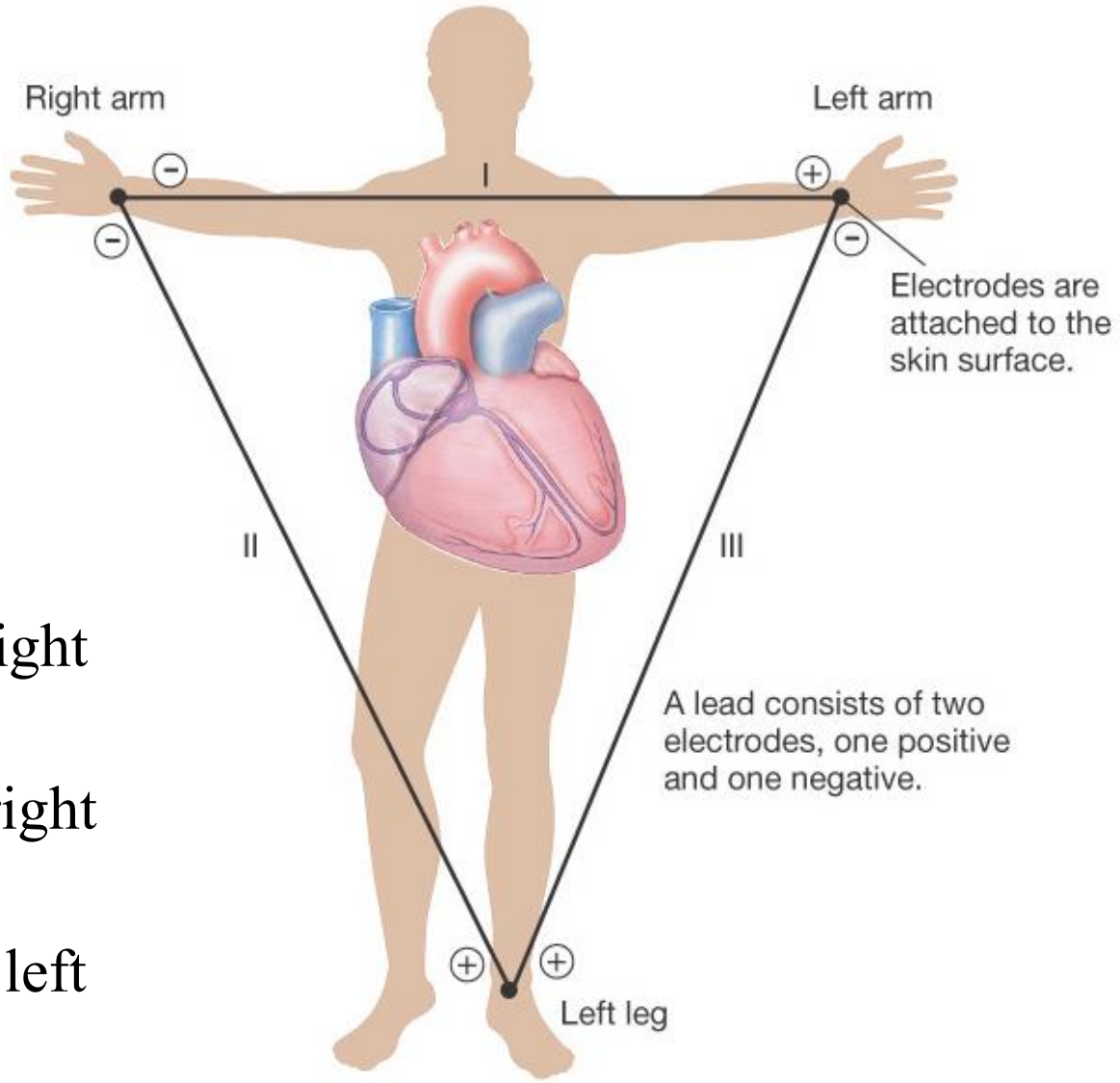


Electrocardiogram (ECG): Electrical Activity of the Heart

Einthoven's triangle:

1)Bipolar Limb Leads

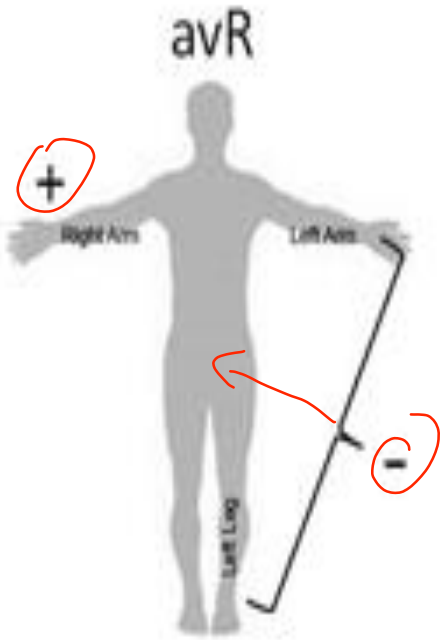
- 1 positive and 1 negative electrode
  - RA always negative
  - LL always positive
- Provide a view from a vertical plane
- Three limb leads:
  - **Lead I**: -ve terminal is connected to the right arm/+ve terminal to the left arm
  - **Lead II**:-ve terminal is connected to the right arm/+ve terminal to the left leg
  - **Lead III**:-ve terminal is connected to the left arm/+ve terminal to the left leg

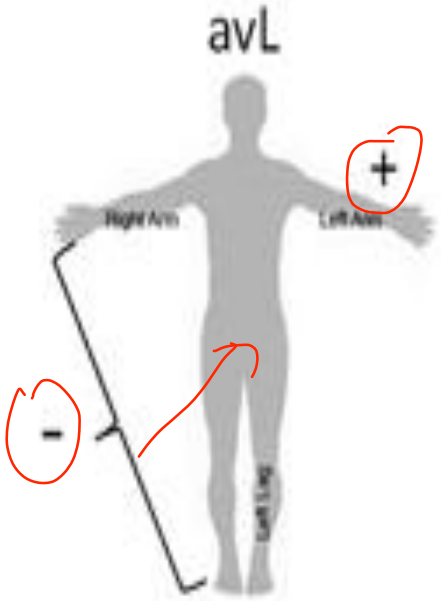


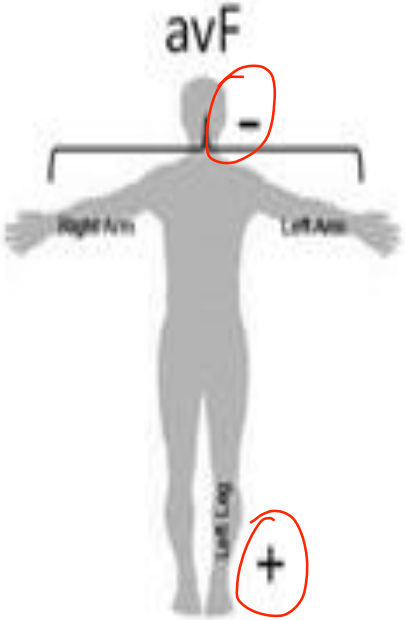
2) Augmented Unipolar Limb leads

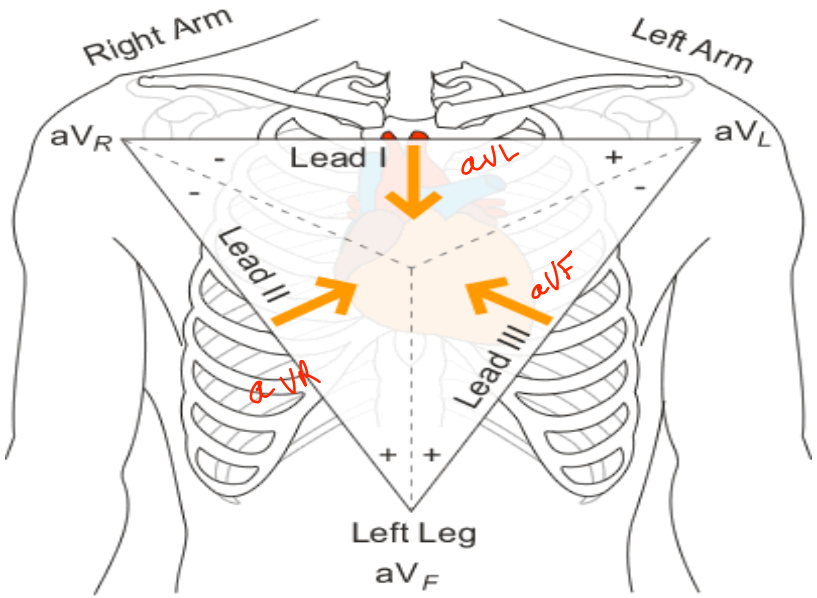
Two limbs are connected through electrical resistance to the negative terminal of the ECG and the third limb is connected to the positive terminal

- aVR when the +ve terminal on (R arm)
- aVL when the +ve terminal on (L arm)
- aVF when the +ve terminal on (left leg)





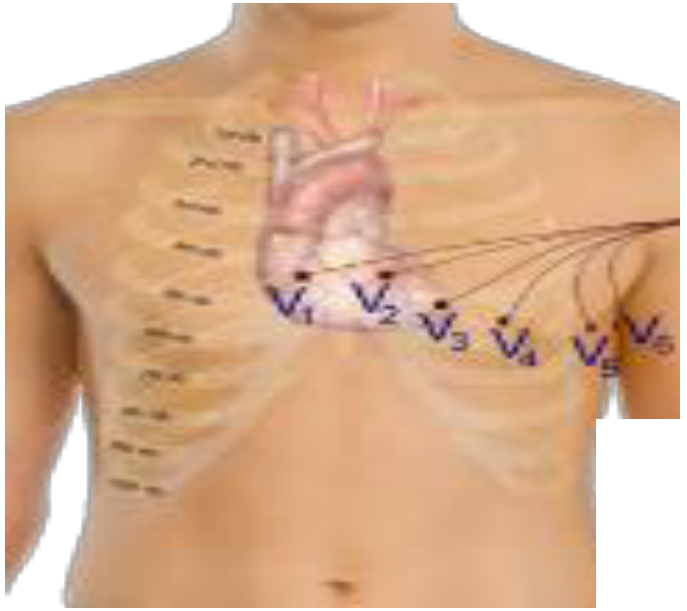




3) Unipolar chest leads (starting from the midline position)

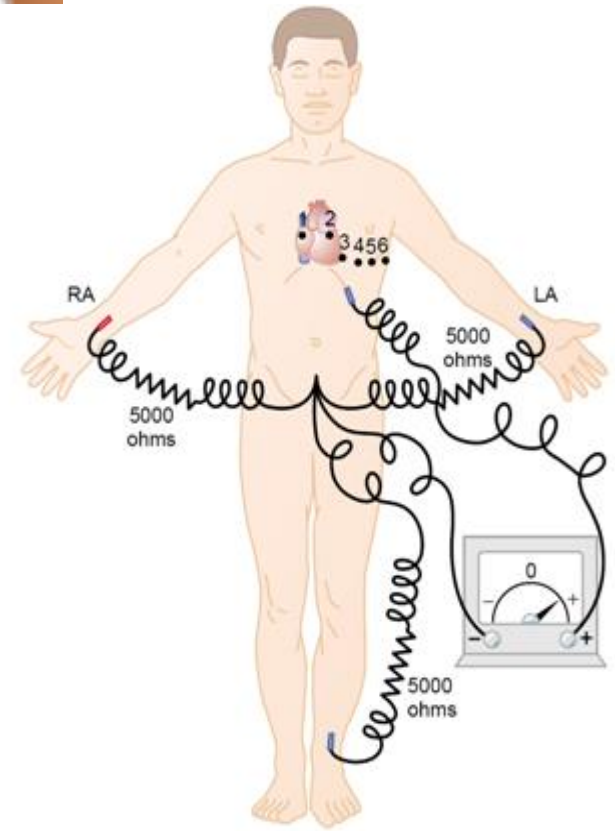
V1, V2, V3, V4, V5, V6

Right side — left side

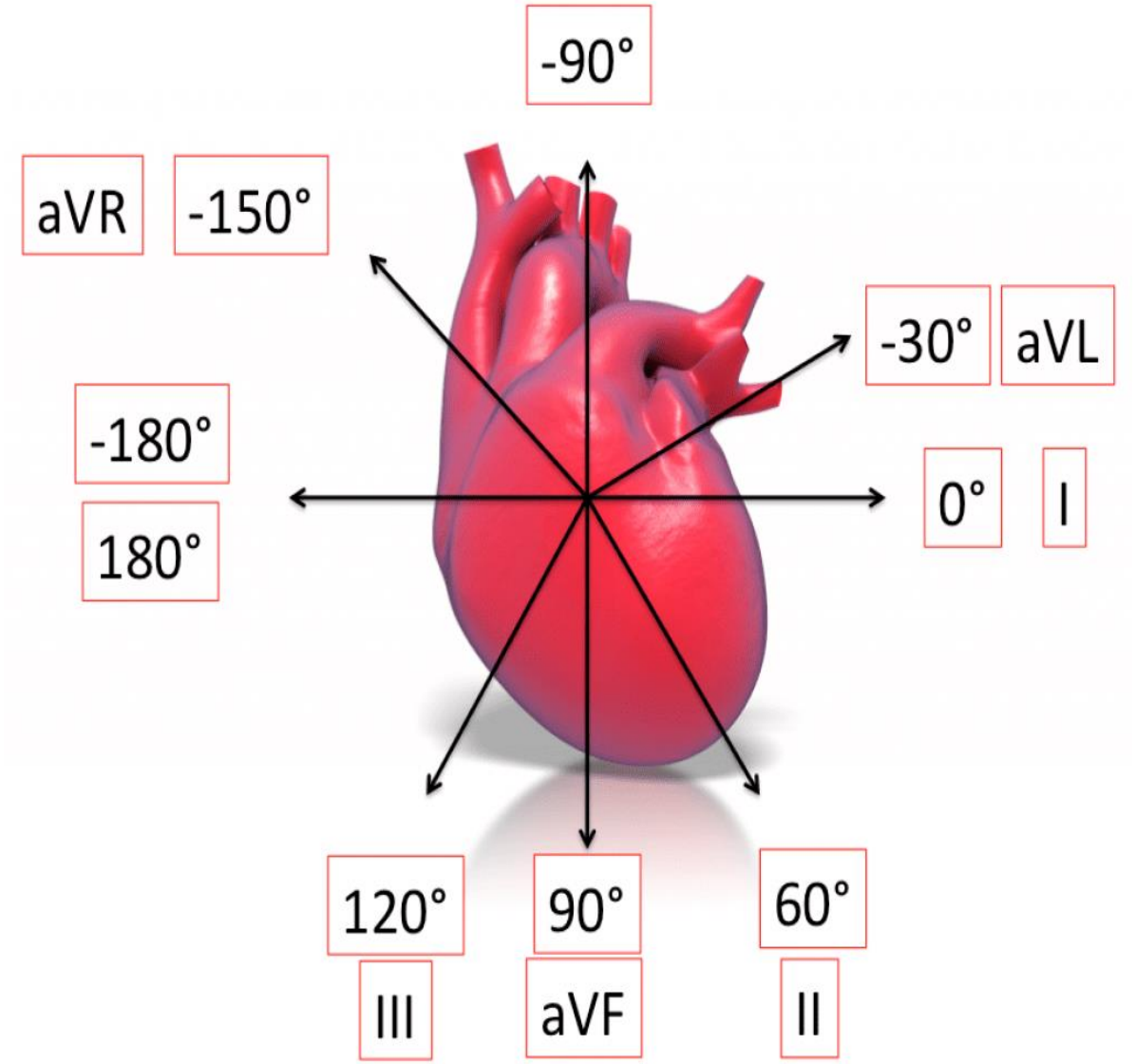


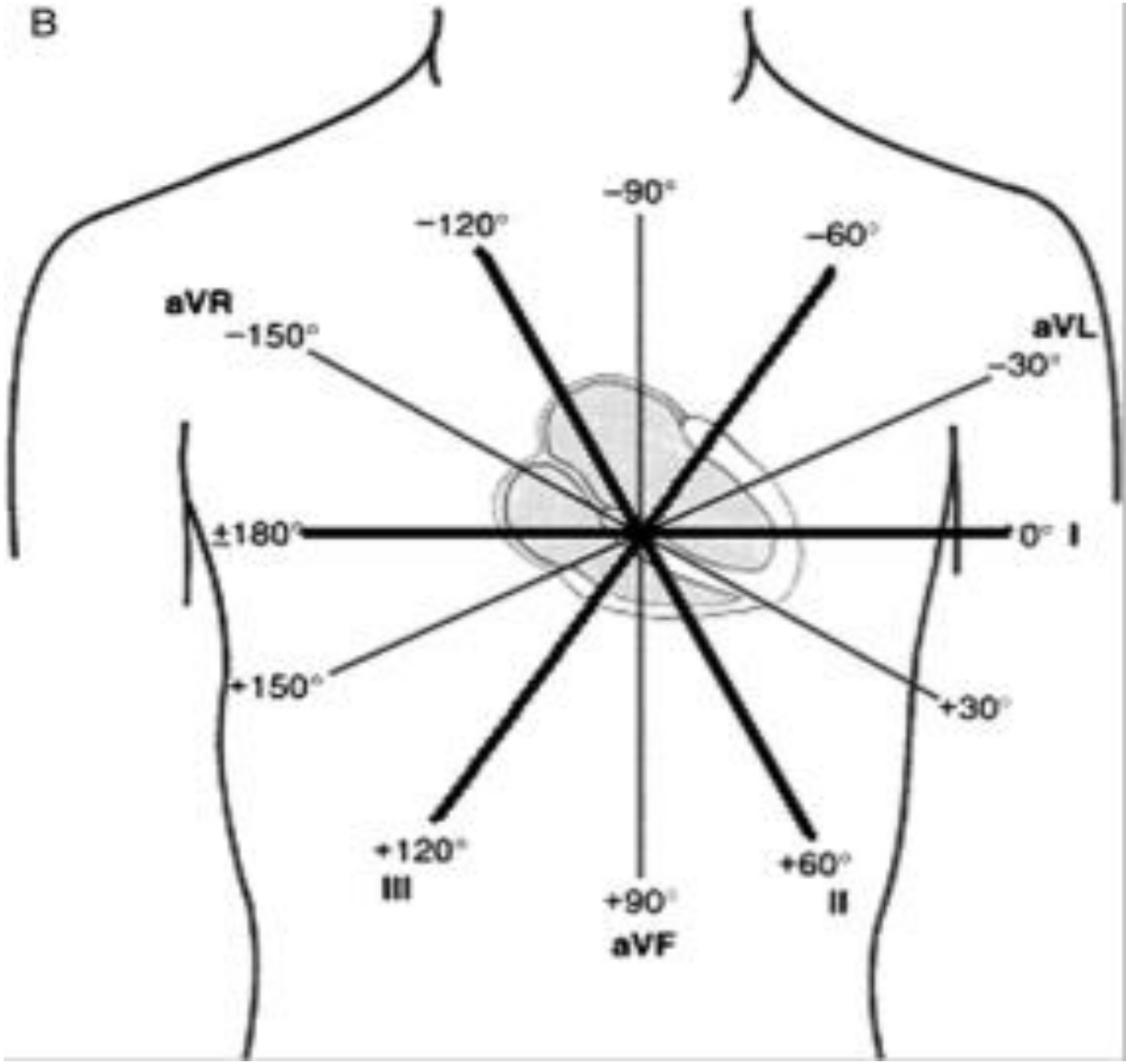
The electrode on the anterior surface of the chest is directly over the heart and connected to the +ve terminal of the ECG

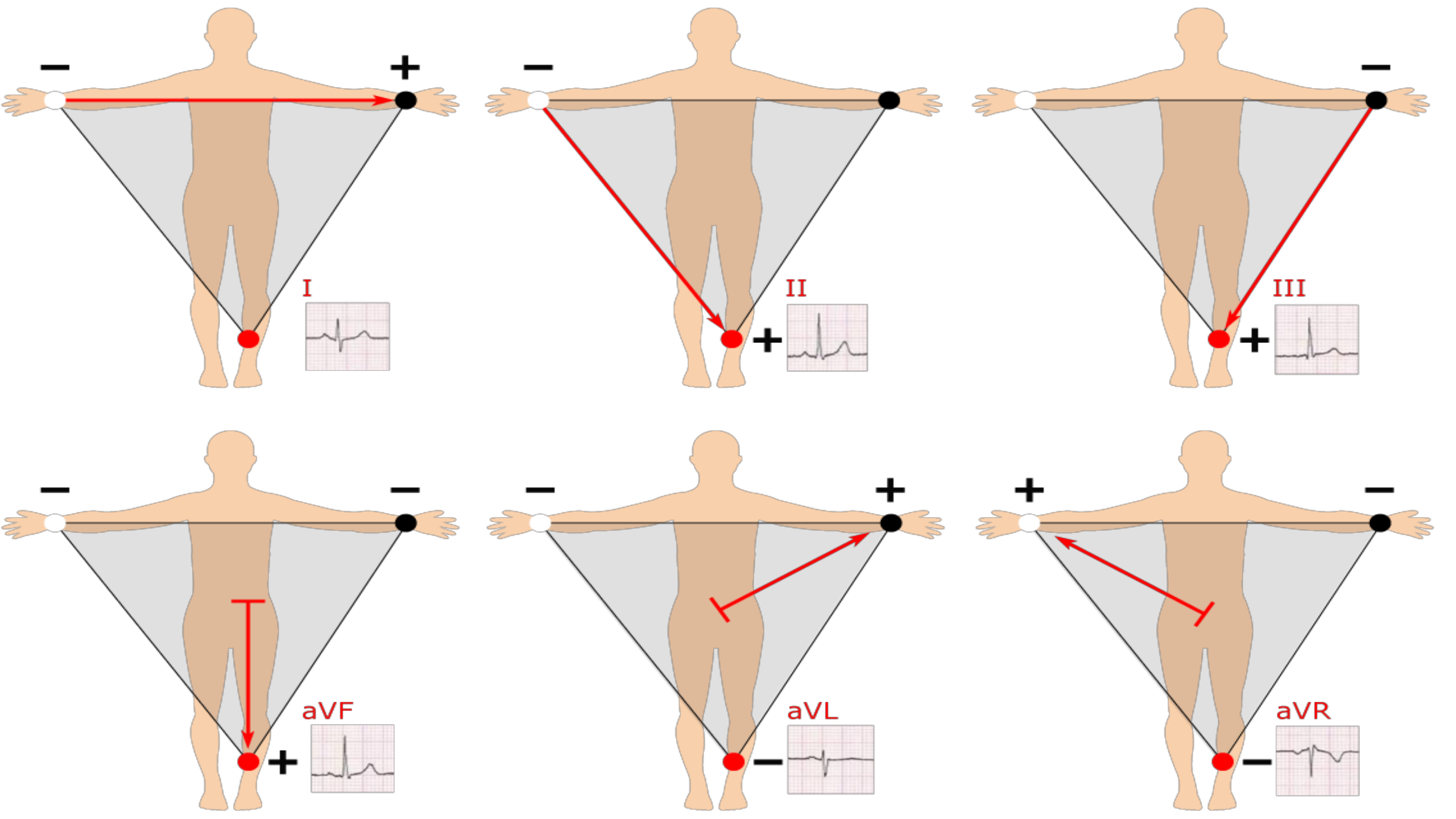
The –ve electrode (the indifferent electrode is connected through equal resistances to the right arm, Left arm and left leg at the same time

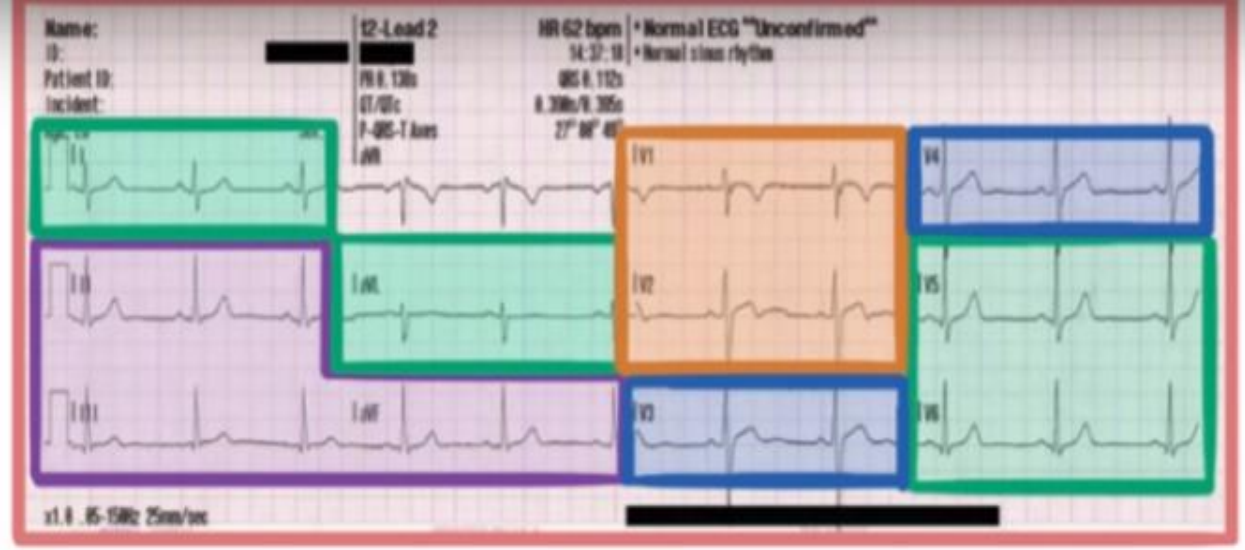


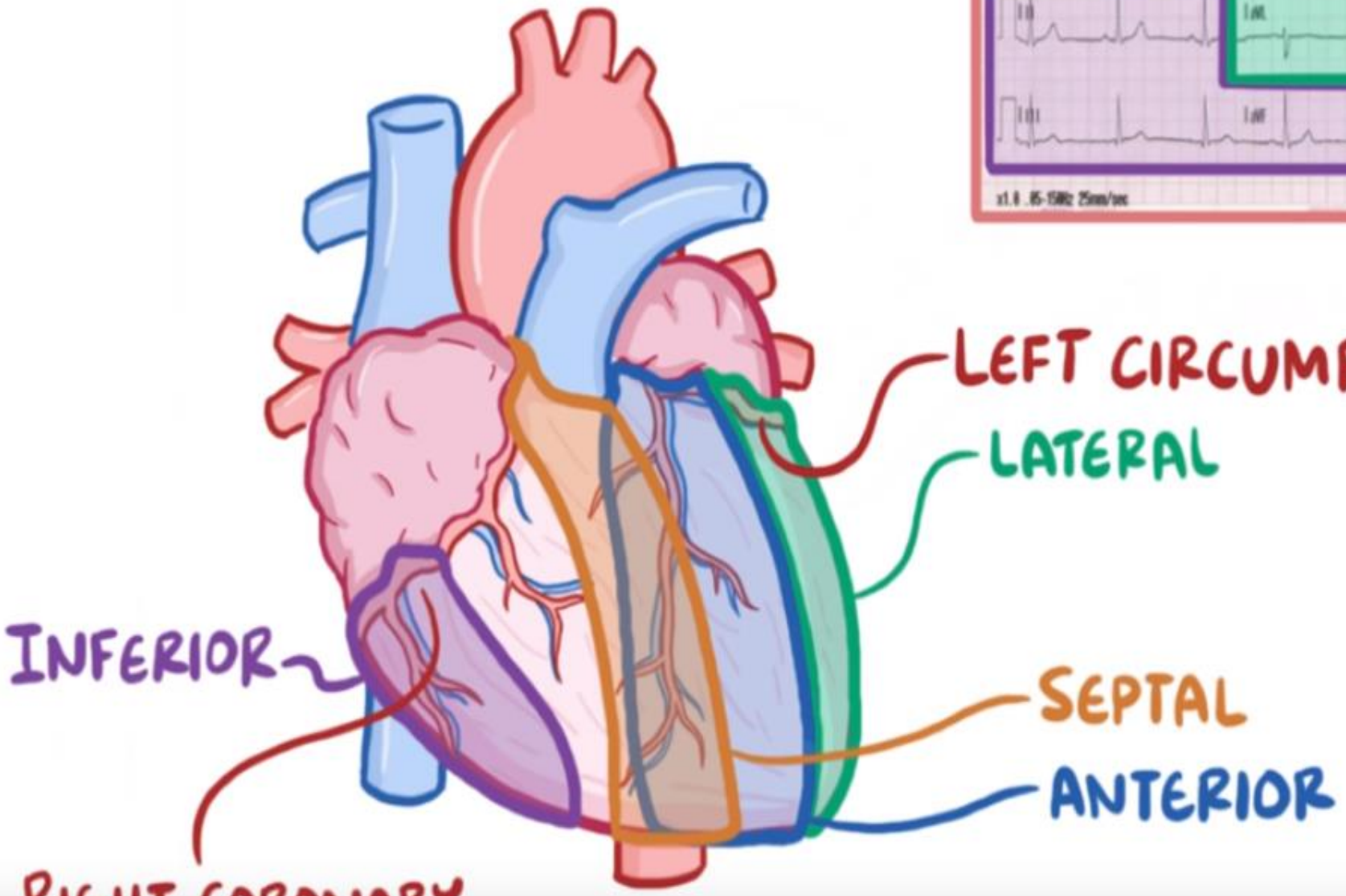
Twelve standard ECG leads that (((view))) the changing pattern of the hearts electrical activity from different perspective






−
+
I
−
II
+
−
III
+
−
−
aVF
+
−
+
aVL
−
+
−
aVR
−





LEFT CIRCUMFLEX ARTERY

LATERAL

INFERIOR

SEPTAL

ANTERIOR

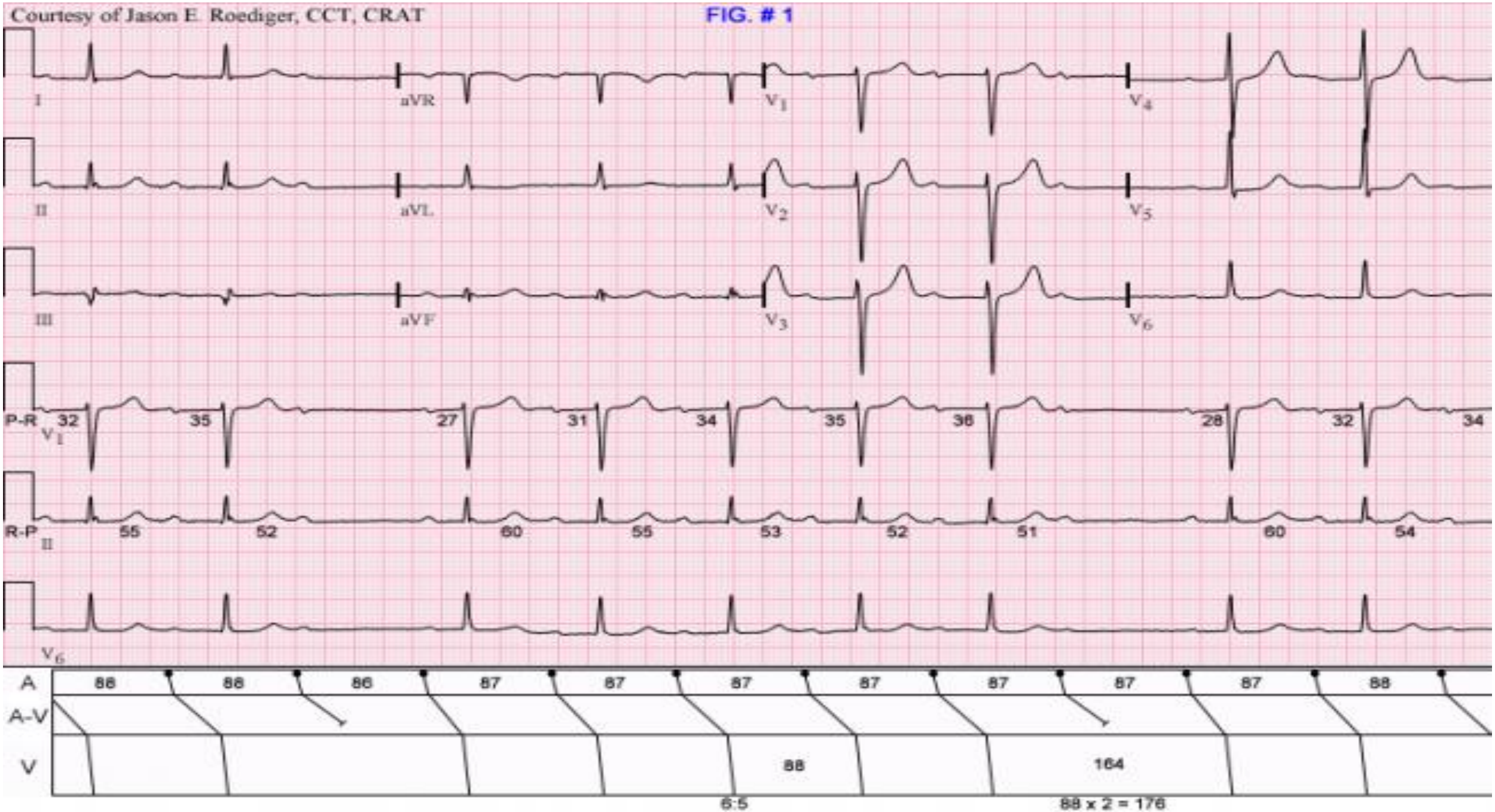
RIGHT CORONARY

ANATOMICAL PRESENTATION

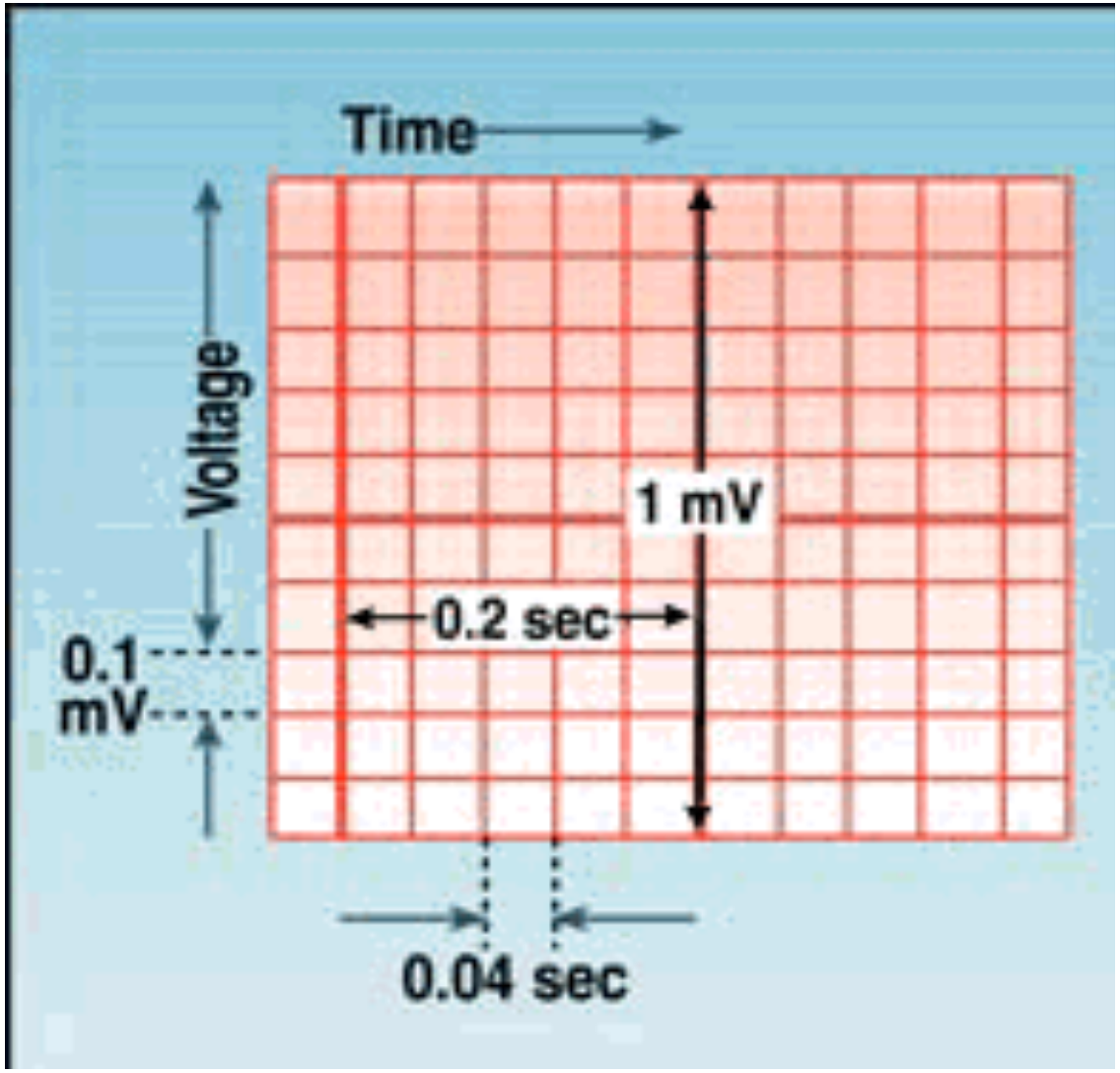
I Lateral	aVR None	V_1 Septal	V_4 Anterior
II Inferior	aVL Lateral	V_2 Septal	V_5 Lateral
III Inferior	aVF Inferior	V_3 Anterior	V_6 Lateral

Courtesy of Jason E. Roediger, CCT, CRAT

FIG. # 1



Components of the ECG Complex



Components of the ECG Complex

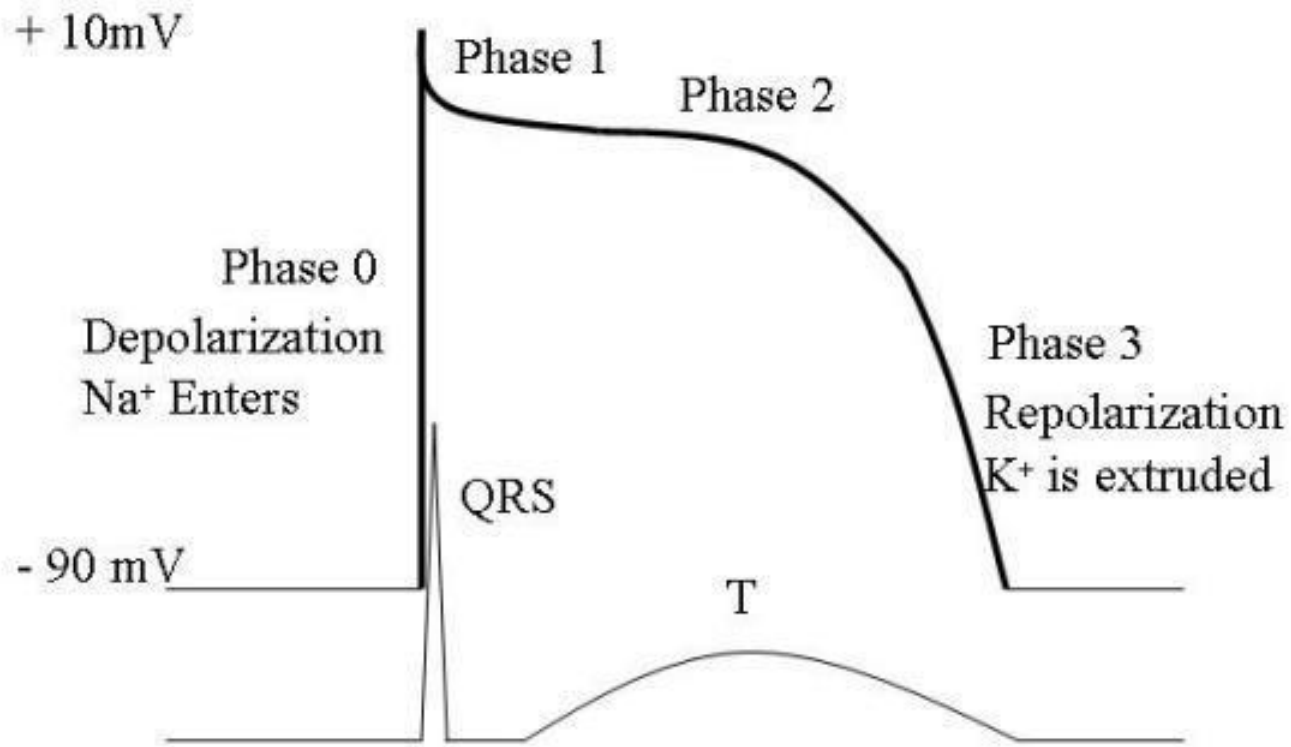
- **P Wave**
  - first upward deflection
  - represents atrial depolarization
  - usually 0.10 seconds or less
  - usually followed by QRS complex
- **QRS Complex**
  - Composition of 3 Waves
    - Q, R & S
    - represents ventricular depolarization
    - much variability
  - usually < 0.12 sec
- **PR Interval**
  - time impulse takes to move through atria and AV node
  - from beginning of P wave to the beginning of QRS complex
  - normally 0.12 - 0.2 sec
  - may be shorter with faster rates

Components of the ECG Complex

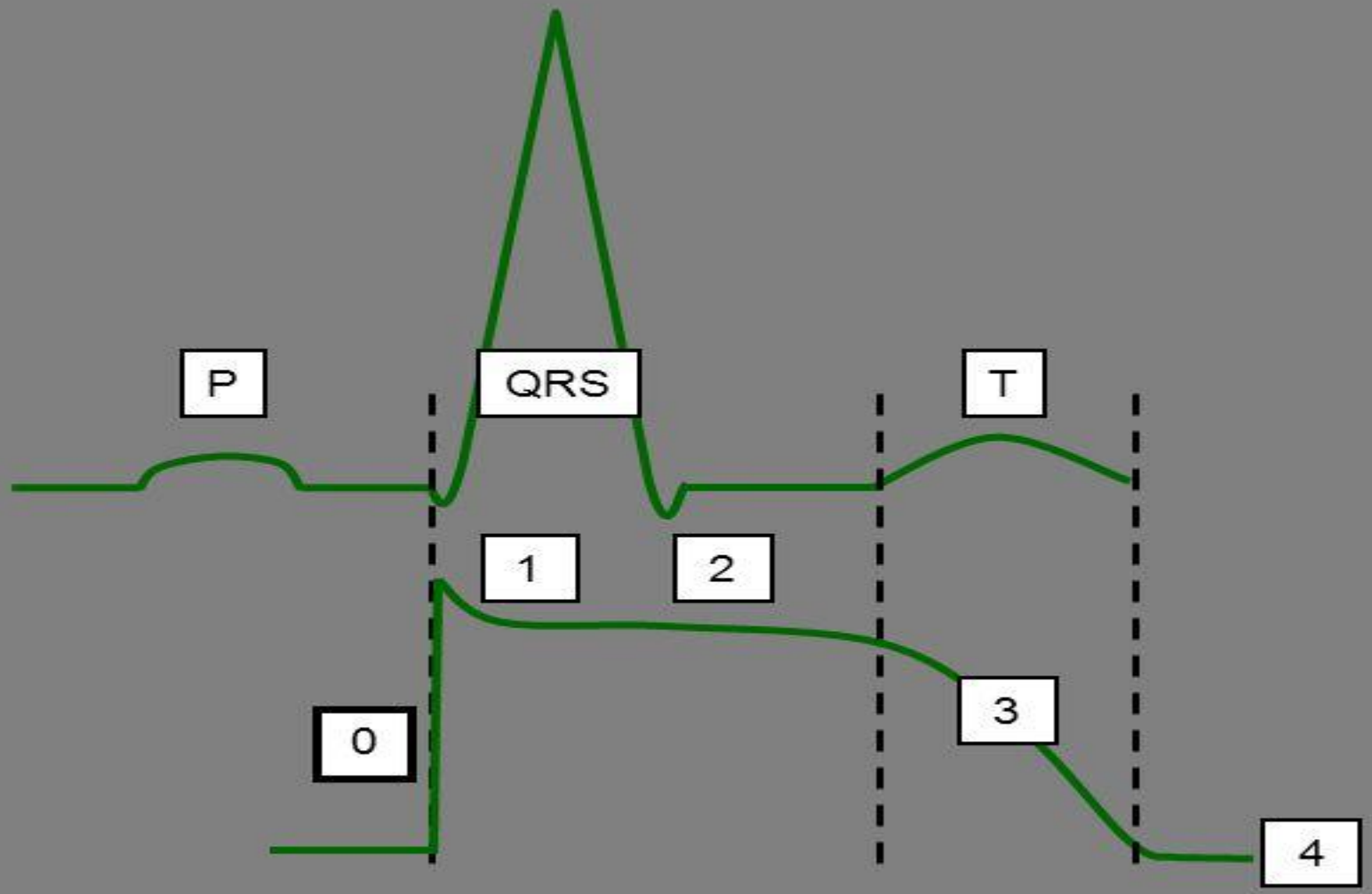
- **QRS Interval**
  - time impulse takes to depolarize ventricles
  - from beginning of Q wave to beginning of ST segment
  - usually < 0.12 sec
- **ST Segment**
  - early repolarization of ventricles
  - measured from end of S wave to onset of T wave
  - elevation or depression may indicate abnormality
- **T Wave**
  - repolarization of ventricles
  - concurrent with end of ventricular systole

Monophasic Action Potential (Cardiac Muscle Cell)

* ECG وقت الجهد



Correspondence between a ventricular action potential & the ECG



The QRS complex is produced by the summed upstrokes (phase 0) of the ventricular myocyte action potentials.
The S-T segment corresponds to the plateaus of the action potentials.
The T wave is produced by ventricular repolarization.

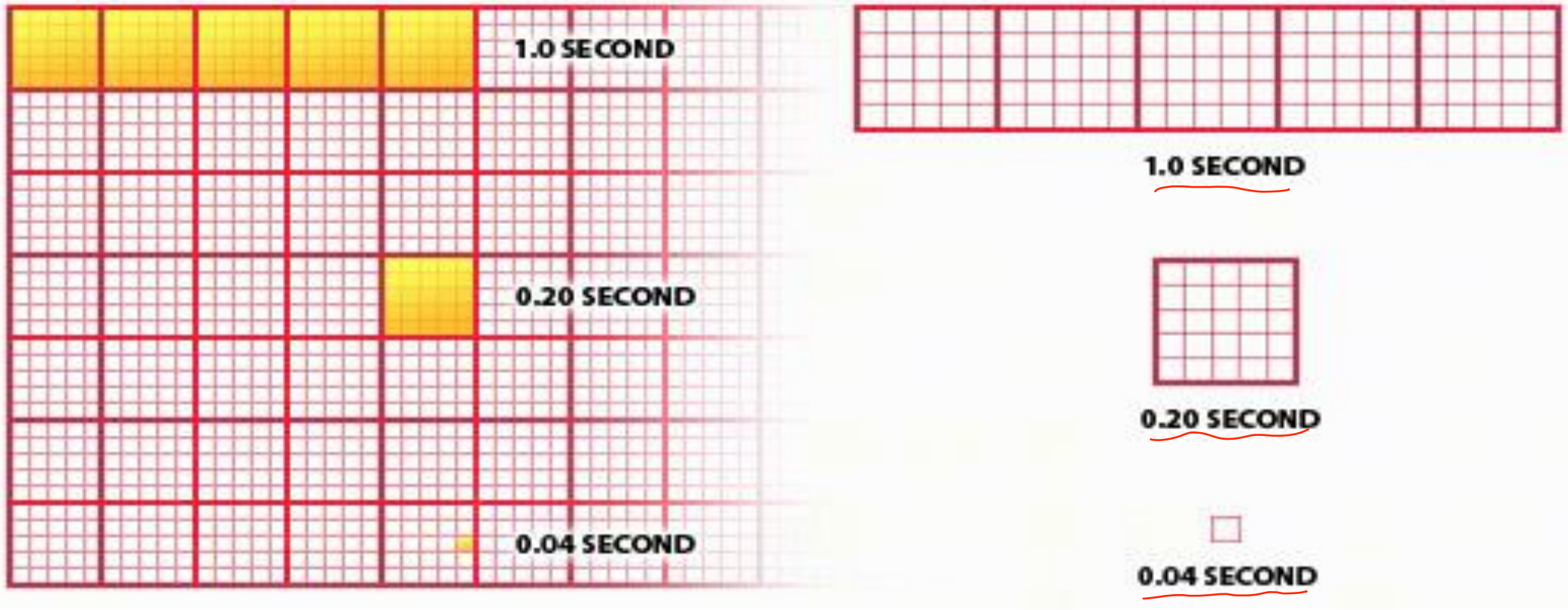
ECG Interpretation
Cardiac Arrhythmias

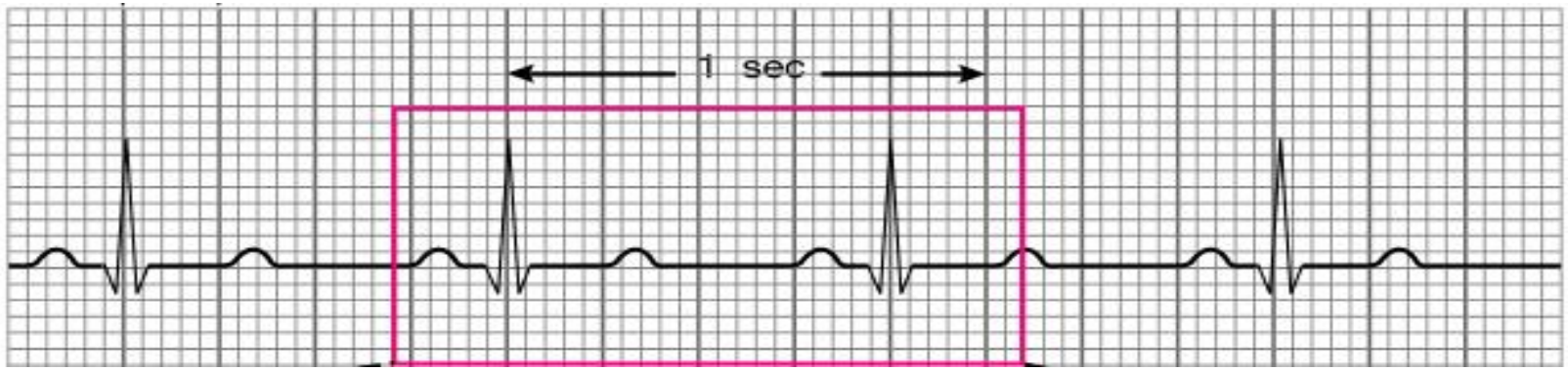
Dr Safa Abdul Ghani

ECG Analysis

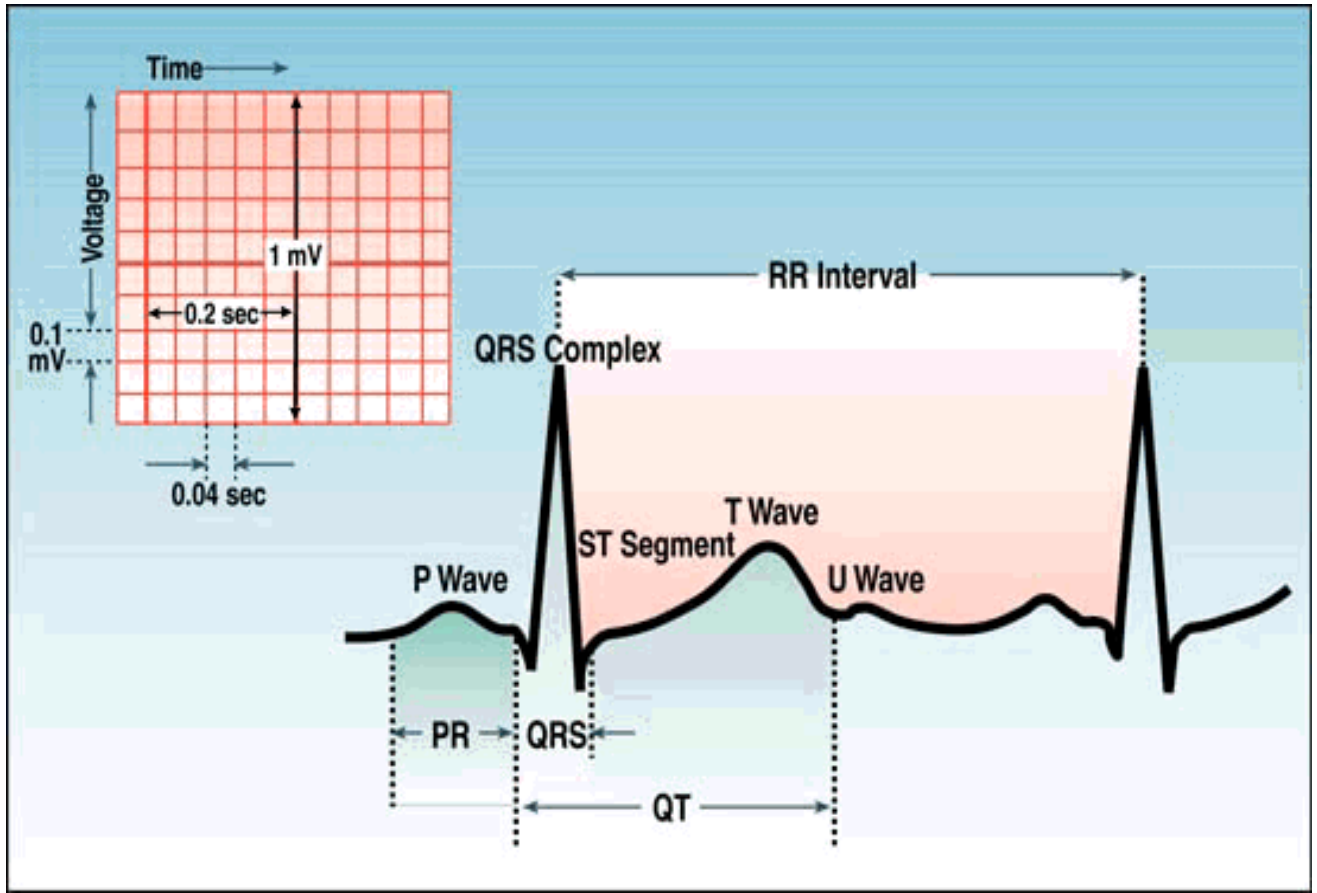
- A monitoring lead can tell you:
  - **How often** the myocardium is depolarizing
  - **How regular** the depolarization is
  - **How long** conduction takes in various areas of the heart
  - **The origin** of the impulses that are depolarizing the myocardium
  - **Heart Axis** (normal !!! right or left axis deviation!!)

Scale Detail

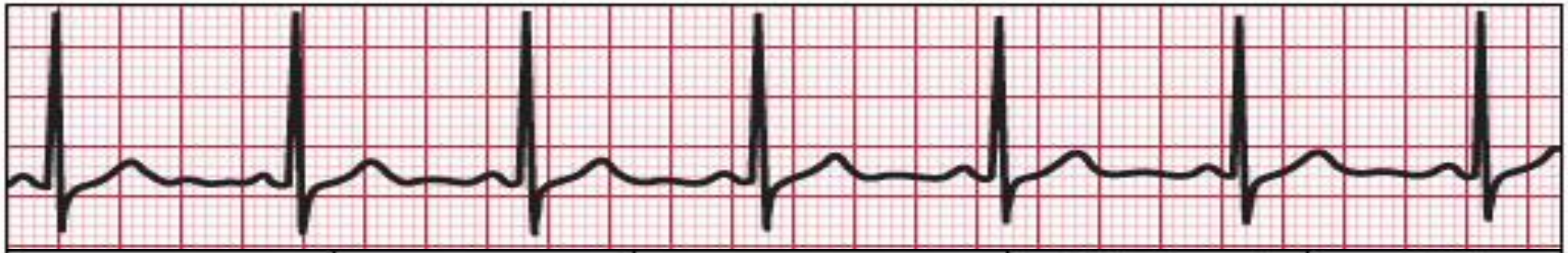




1) First ask yourself are there P waves?
2) What is the QRS width?
3) Is it a Regular rhythm?
4) Are P waves related to the QRS?
5) What is the Heart Rate?



Normal Sinus Rhythm



Heart Rate	Rhythm	P Wave	PR interval (in seconds)	QRS (in seconds)
60-100 bpm	Regular	Before each QRS, identical	.12 to .20	<.12

- Rate (60-100)
- P Waves (present, upright, smooth)
- P:QRS (1:1)
- QRS (present, 0.06-0.12 sec – 1.5-3 small boxes) Narrow
- PR Interval (0.12-0.20sec – 3-5 small boxes)

From beginning of P wave to the beginning of QRS complex

Step 1: Assess the Rhythm

a. Measure the rate.

b. Determine if rhythm is regular, regularly irregular, or irregularly irregular.

c. Determine if QRS complex is narrow or wide.

d. Evaluate the atrial activity. (P wave)

e. Identify the relationship between atrial & ventricular activity. (PR segment)

ECG interpretation: Heart Rate

From one P wave to the next P wave **or** from one R wave to the peak of the next R wave.

Normal resting heart rate = 60- 100 beats per minute (trained athletes often have slower heart rates at rest)

A faster-than-normal rate is known as **tachycardia**

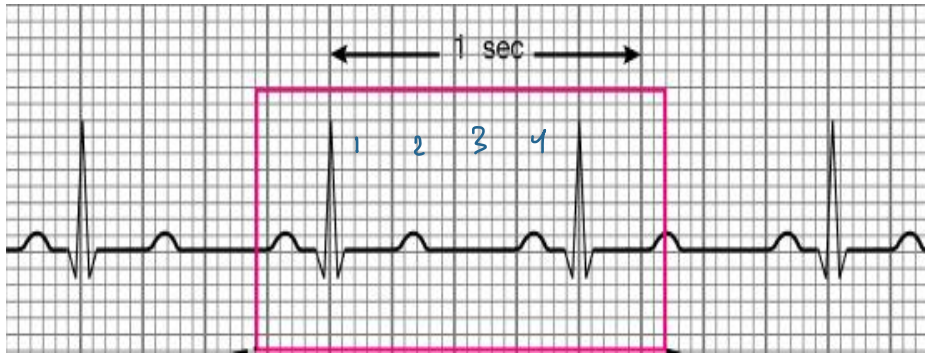
Slower-than-normal rate is called **bradycardia**

- **Heart rate can be calculated simply with the following method:**

Rule of 300: If the rhythm is regular, the heart rate can be "estimated" by using the "Rule of 300"

$$\frac{300}{\text{Number of boxes between QRS - QRS}}$$

- Work out the number of large squares in one R-R interval
- Then divide 300 by this number and you have your answer



e.g. if there are 4 squares in an R-R interval 300/4 = 75 beats per minute

10 Second Rule

As most ECGs record 10 seconds of rhythm per page, one can simply count the number of beats present on the ECG and multiply by 6 to get the number of beats per 60 seconds.

This method works well for irregular rhythms.

Heart Axis??

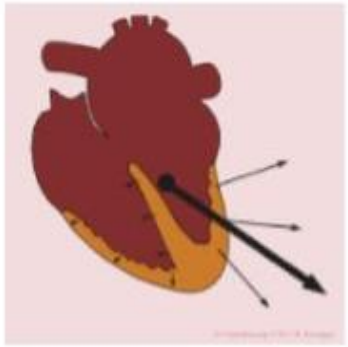
The heart axis points in the direction of the average electrical vector of all the depolarizing heart cells.

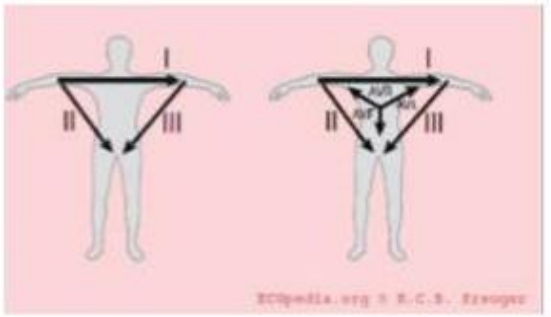
A change of the heart axis or an extreme deviation can be an indication of pathology.

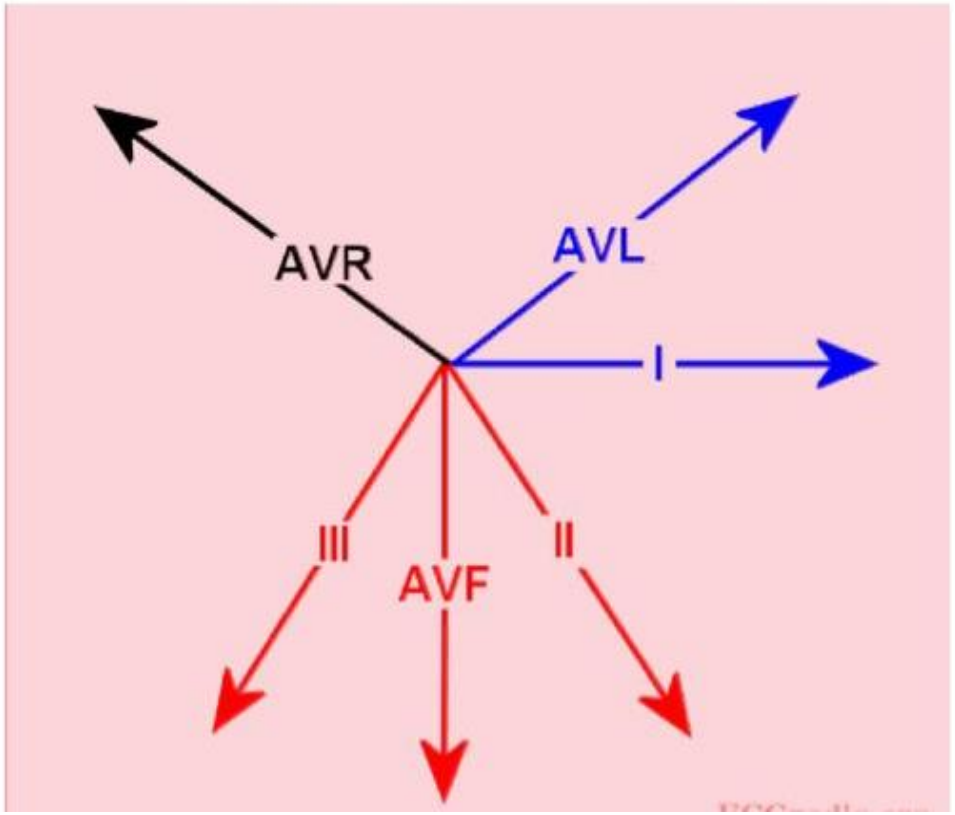
A positive QRS complex (more above than below the baseline) in a certain lead means that the heart axis is going (at least slightly) in that lead's direction.

The heart axis is normal between -30 and +90 degrees.

Therefore, if QRS is positive in both leads I and II, the heart axis is normal.



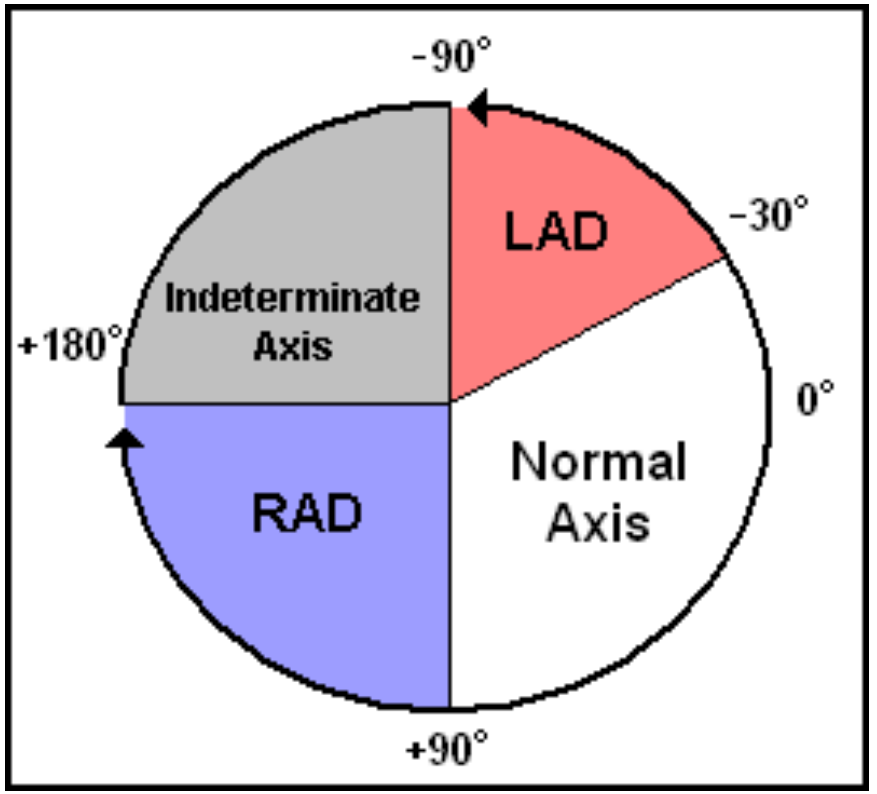




By near-consensus, the normal QRS axis is defined as ranging from -30° to +90°.

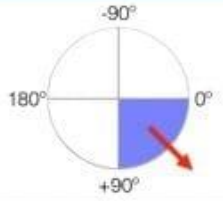
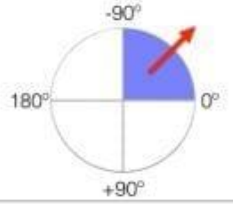
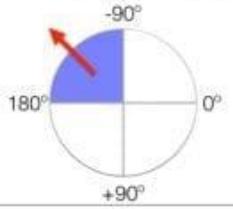
-30° to -90° is referred to as a left axis deviation (LAD)

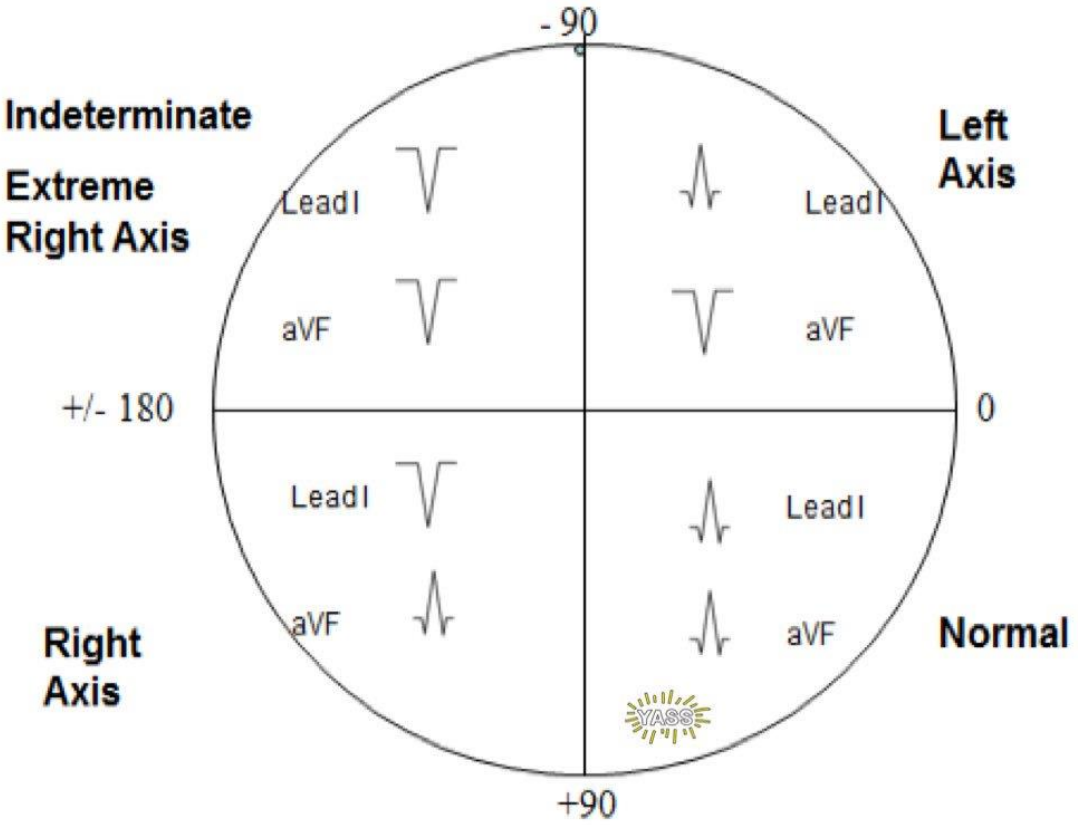
+90° to +180° is referred to as a right axis deviation (RAD)



The direction of the average electrical depolarization with an arrow (vector). This is the heart axis. A change of the heart axis or an extreme deviation can be an indication of pathology.

To determine the heart axis you look at the extremity leads only (not V1-V6). If you focus especially on leads I, II, and AVF you can make a good estimate of the heart axis

Lead 1	Lead aVF	Quadrant	Axis
POSITIVE	POSITIVE		Normal Axis
POSITIVE	NEGATIVE		**Possible LAD
NEGATIVE	POSITIVE		RAD
NEGATIVE	NEGATIVE		Extreme Axis



The QRS Axis

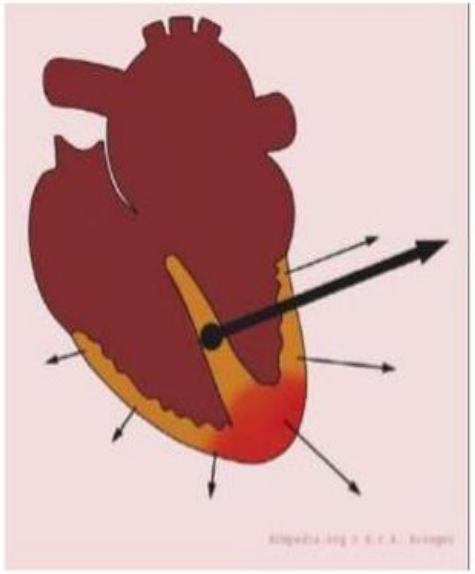
The QRS axis represents the net overall direction of the heart's electrical activity.

Abnormalities of axis can hint at:

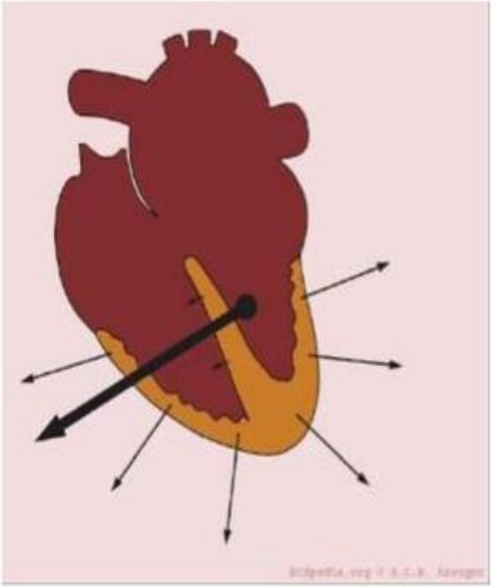
Ventricular enlargement

Conduction blocks (i.e. hemiblocks)

Abnormal heart axis



Heart axis deviation to the left in case of an inferior infarct. Left anterior hemiblock is another common cause. A left axis is present between -30 and -90 degrees.



Heart axis deviation to the right can result from right ventricular overload as in COPD or pulmonary embolism. A right axis is between +90 and +180 degrees.
A left - right arm lead exchange is the most common cause of right axis deviation!

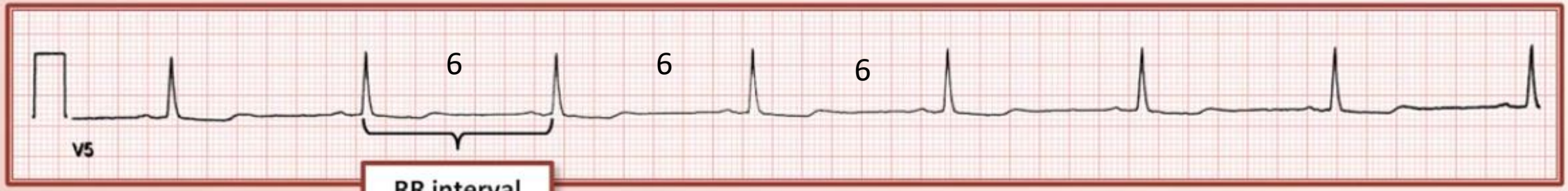
ECG interpretation: Rhythm

- Measure R-R intervals across strip
- Should find regular distance between R waves
- Classification
  - **Regular**
  - **Irregular**

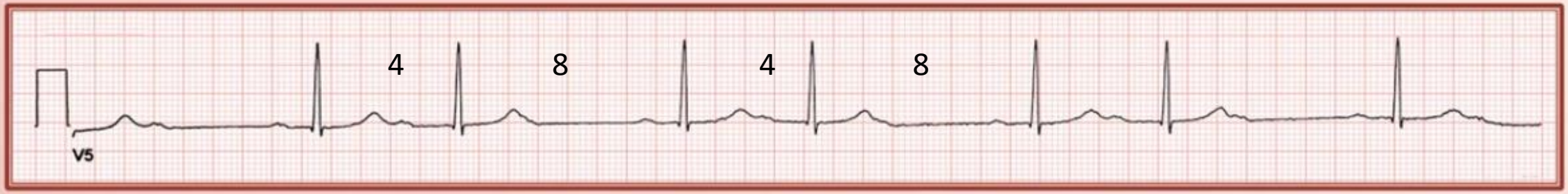
  Can result from a benign extra beat or from atrial fibrillation (SA node has lost control of the pacemaker)

Step 1: Assess the Rhythm

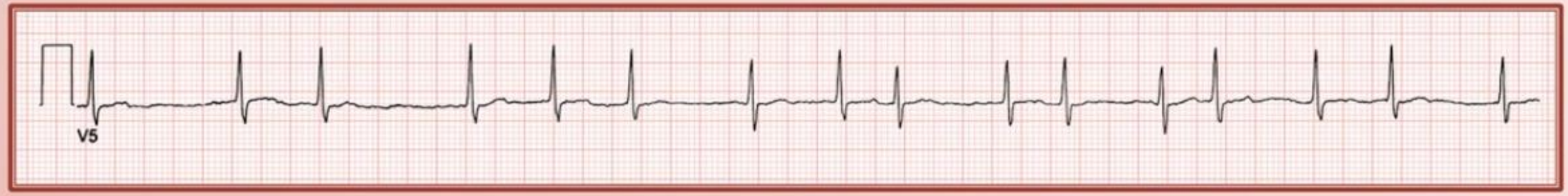
b. Determine if rhythm is regular, regularly irregular, or irregularly irregular.



Regular



Regularly irregular



Irregularly irregular

Step 1: Assess the Rhythm

a. Measure the rate.

b. Determine if rhythm is regular, regularly irregular, or irregularly irregular.

c. Determine if QRS complex is narrow or wide.

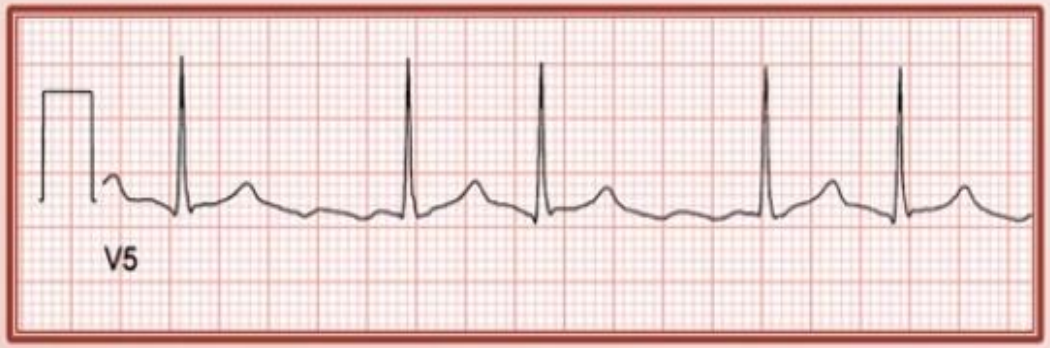
d. Evaluate the atrial activity. (P wave)

e. Identify the relationship between atrial & ventricular activity. (PR segment)

c. Determine if QRS complex is narrow or wide.

Narrow QRS

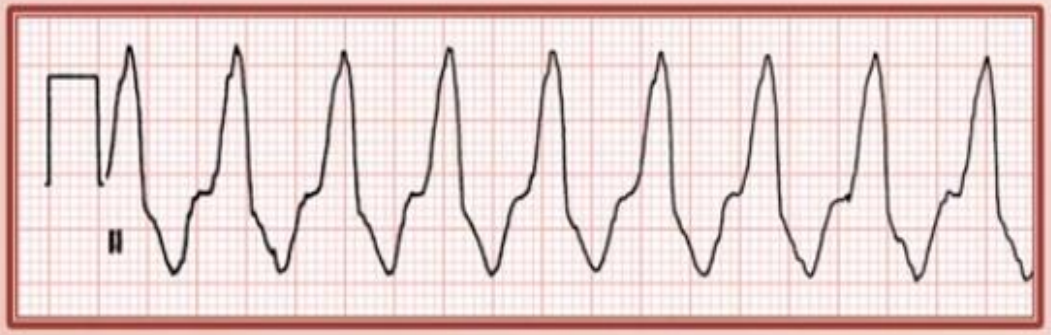
(< 120 ms)



3 small boxes

Wide QRS

(≥ 120 ms)



Etiologies of a Wide QRS Complex

Common

- Bundle branch block
- Ventricular origin of rhythm
- Left ventricular hypertrophy
- Pacemaker

Uncommon

- Drugs (e.g. class Ia and Ic antiarrhythmics)
- Wolff-Parkinson-White pattern
- Profound hyperkalemia

ECG Analysis

- ***QRS Complex: Ventricular Depolarization***

< 0.12 seconds (3 small boxes) is normal (((Narrow)))

(Atrial/supraventricular origin)

- ***Broad QRS Complex*** = Result from abnormal intraventricular conduction

  Ventricular bundle branch block (Ventricular origin)

- ***Increase Height of QRS*** = Result from ventricular hypertrophy

  In V1 = Right ventricular Hypertrophy

  In V5+V6= Left ventricular Hypertrophy

- ***No QRS wave*** = Ventricular Fibrillation
- Q waves: Greater that 1mm across and 2mm deep= Indicate myocardial infarction

a. Measure the rate.

b. Determine if rhythm is regular, regularly irregular, or irregularly irregular.

c. Determine if QRS complex is narrow or wide.

d. Evaluate the atrial activity. **(P wave)**

e. Identify the relationship between atrial & ventricular activity. **(PR segment)**

ECG Analysis

- ***P Waves***
  - Present?
  - Do they all look alike?
  - Regular interval
  - Upright or inverted in Lead II?
    - Upright = atria depolarized from top to bottom
    - Inverted = atria depolarized from bottom to top

ECG Changes & Clinical Diagnosis

P wave: Atrial Depolarization

- ***Tall P wave***= Result from right atrial Hypertrophy

  (Due to tricuspid valve stenosis or pulmonary hypertension)
- ***Broad P wave***= Result from left atrial hypertrophy

  (Due to Mitral stenosis)
- ***No P wave***= Junctional Escape, Junctional Extrasystoly, Junctional Tachycardia, Ventricular Tachycardia, **Atrial Fibrillation**

P wave abnormality

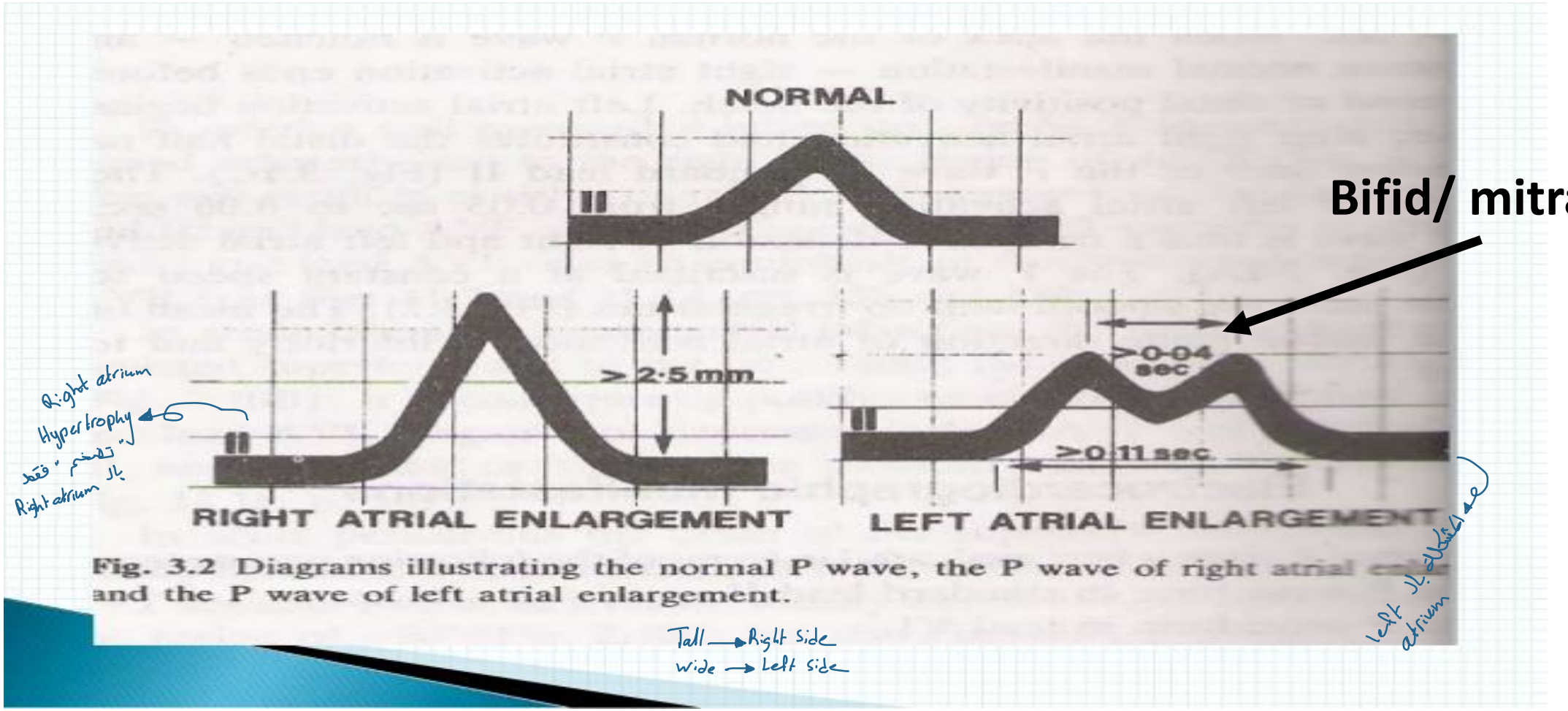
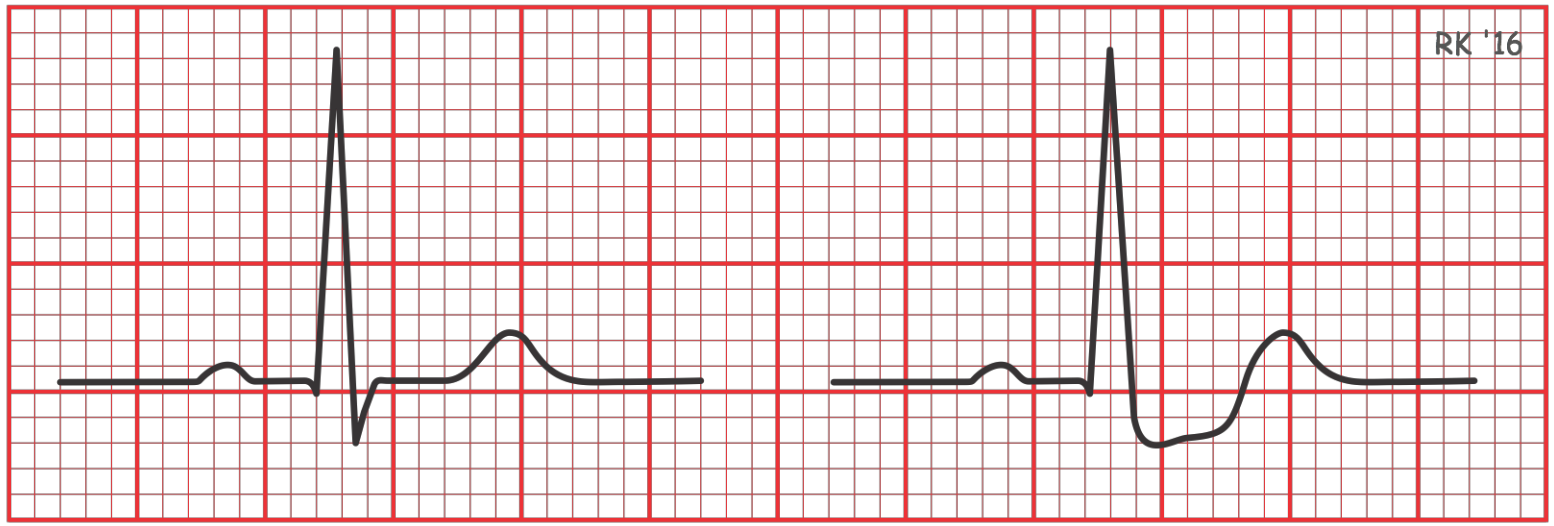


Fig. 3.2 Diagrams illustrating the normal P wave, the P wave of right atrial [illegible] and the P wave of left atrial enlargement.

- **ST segment**:

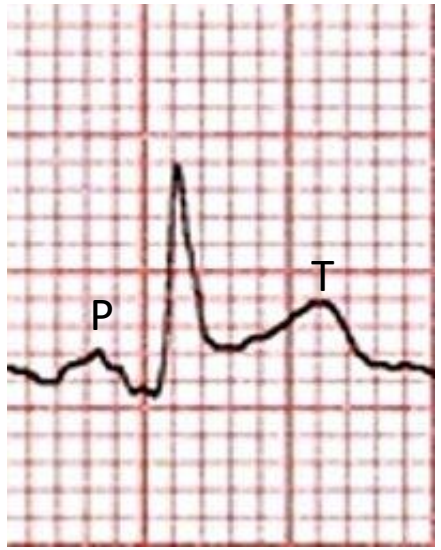
Elevated → Acute Myocardial Infarction, Pericarditis

Depressed ST and T wave Inversion = Ischemia, Ventricular Hypertrophy



Normal

ST Depression



Elevated ST

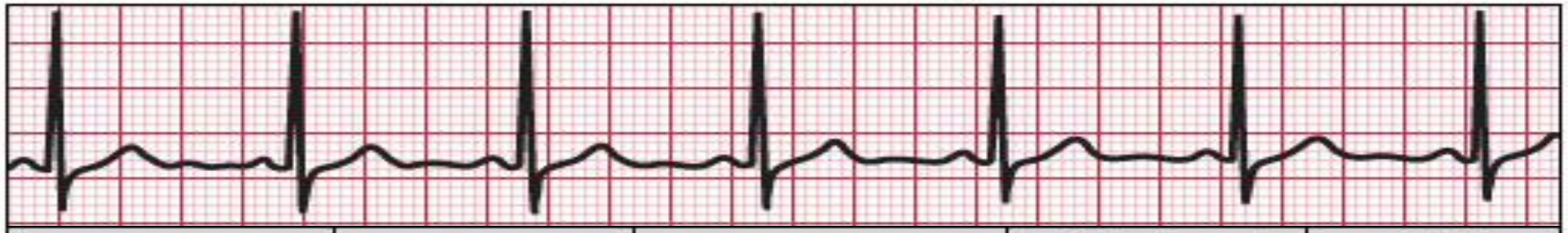
Ventricular hypotrophy

Ischemia

Acute mayocardiac infarction
Pericharditis

1) First ask yourself are there P waves?
2) What is the QRS width?
3) Is it a Regular rhythm?
4) Are P waves related to the QRS?
5) What is the Heart Rate?

Normal Sinus Rhythm



Heart Rate	Rhythm	P Wave	PR interval (in seconds)	QRS (in seconds)
60-100 bpm	Regular	Before each QRS, identical	.12 to .20	<.12

Cardiac Arrhythmias

- is a term for any of a large and heterogeneous group of conditions in which there is abnormal electrical activity in the heart.
- The heart beat may be too fast or too slow, and may be regular or irregular.

- Normal Rhythm (Sinus Rhythm):

أي اشي بطلع عن الطبيعي بصير Arythmias

1. Heart rate 60-100 Bpm
2. SA node origin
3. Normal conduction pathway SA→atria→AV→His→purkenje
4. Normal velocity

Arrhythmia

Arrhythmias are abnormal beats of the heart.

Types of arrhythmias include:

According to heart rate :

- Heartbeats that are too slow (bradycardia)
- Heartbeats that are too fast (tachycardia)

According to etiology

- Delayed after depolarization
- Heart block
- Abnormal pacemaker (Ectopic foci)
- Reentry circus movement

Risk Factors

- Excess caffeine ,stress ,tobacco use ,alcohol use
- Digitalis overdose
- High blood pressure & coronary artery disease
- Heart muscle damage after heart attack (MI)

Aetiology

1. Abnormal rhythmicity of the **pacemaker**
2. Shift of the pacemaker from the sinus node to another place in the heart
3. **Blocks** at different points in the spread of the impulse through the heart
4. Abnormal pathways of impulse transmission through the heart
5. Spontaneous generation of spurious impulses in almost any part of the heart

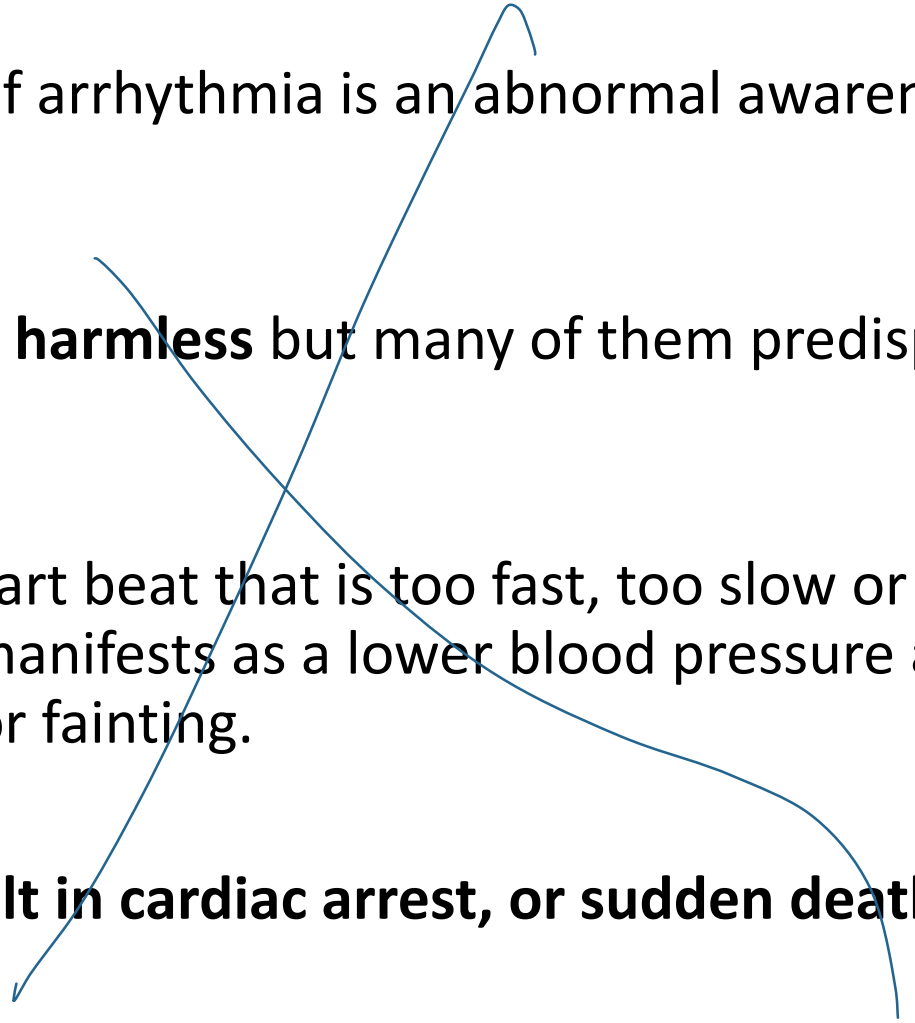
- **Risk Factors:**

  Ischemia, Hypoxia, Acidosis/Alkalosis,

  Electrolyte Abnormalities, Excessive Catecholamine Exposure, Autonomic Influences, Drug Toxicity (e.g.antiarrhythmic drugs)

Manifestation

- The most **common symptom** of arrhythmia is an abnormal awareness of heartbeat, termed *palpitations*.
- Some of these arrhythmias are **harmless** but many of them predispose to adverse outcomes.
- If an arrhythmia results in a heart beat that is too fast, too slow or too weak to supply the body's needs, this manifests as a lower blood pressure and may cause lightheadedness or dizziness, or fainting.
- Some types of arrhythmia **result in cardiac arrest, or sudden death**.
- ECG is the best way to diagnose and assess the risk of any given arrhythmia.



Cardiac Arrhythmias

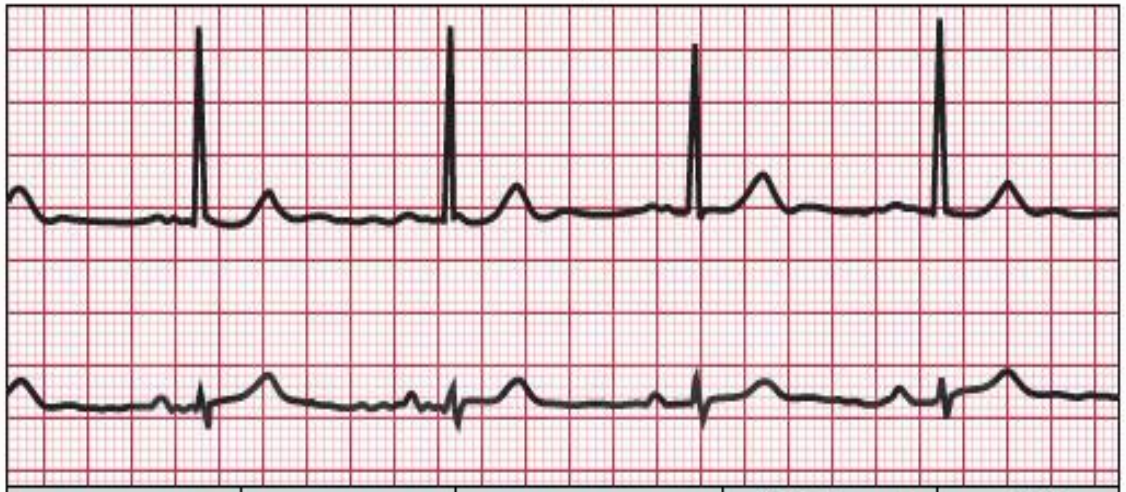
Abnormal rhythmicity of the pacemaker:

- Tachycardia: Heart rate in excess of 100bpm
- Bradycardia: Heart rate less than 60 bpm
- Sinus arrhythmia: Heart rate varies, can be either faster or slower ---5% during respiratory cycle and up to 30% during deep respiration

Abnormal rhythmicity of the pacemaker:

- Tachycardia: Heart rate in excess of 100bpm
- Bradycardia: Heart rate less than 60 bpm

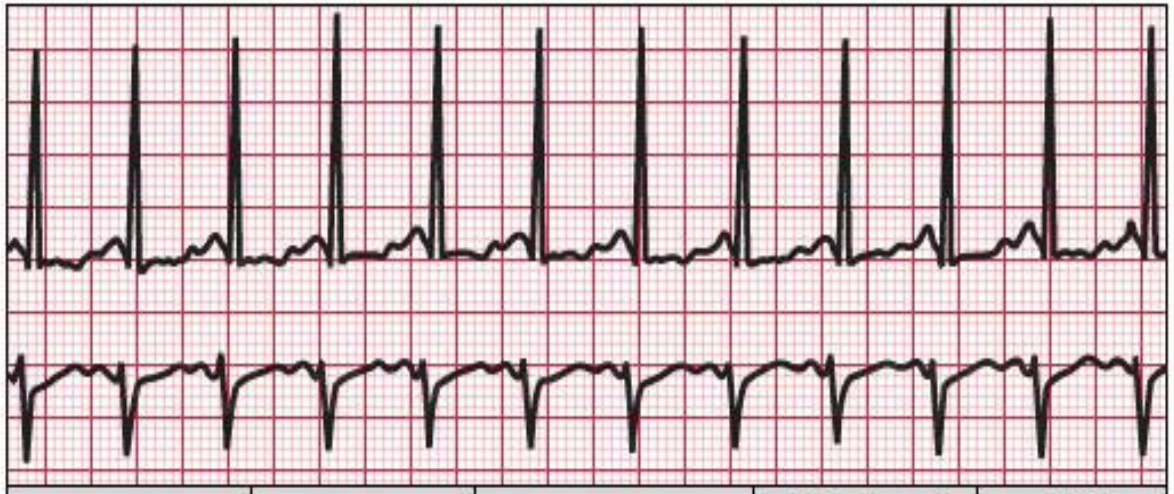
Sinus Bradycardia



Heart Rate	Rhythm	P Wave	PR interval (in seconds)	QRS (in seconds)
< 60 bpm	Regular	Before each QRS, identical	.12 to .20	<.12

Maybe due to: a normal response to sleep or in well conditioned athlete, abnormal drops in rate could be caused by vagal stimulation, hypothyroidism or pharmacologic agents, such as digoxin

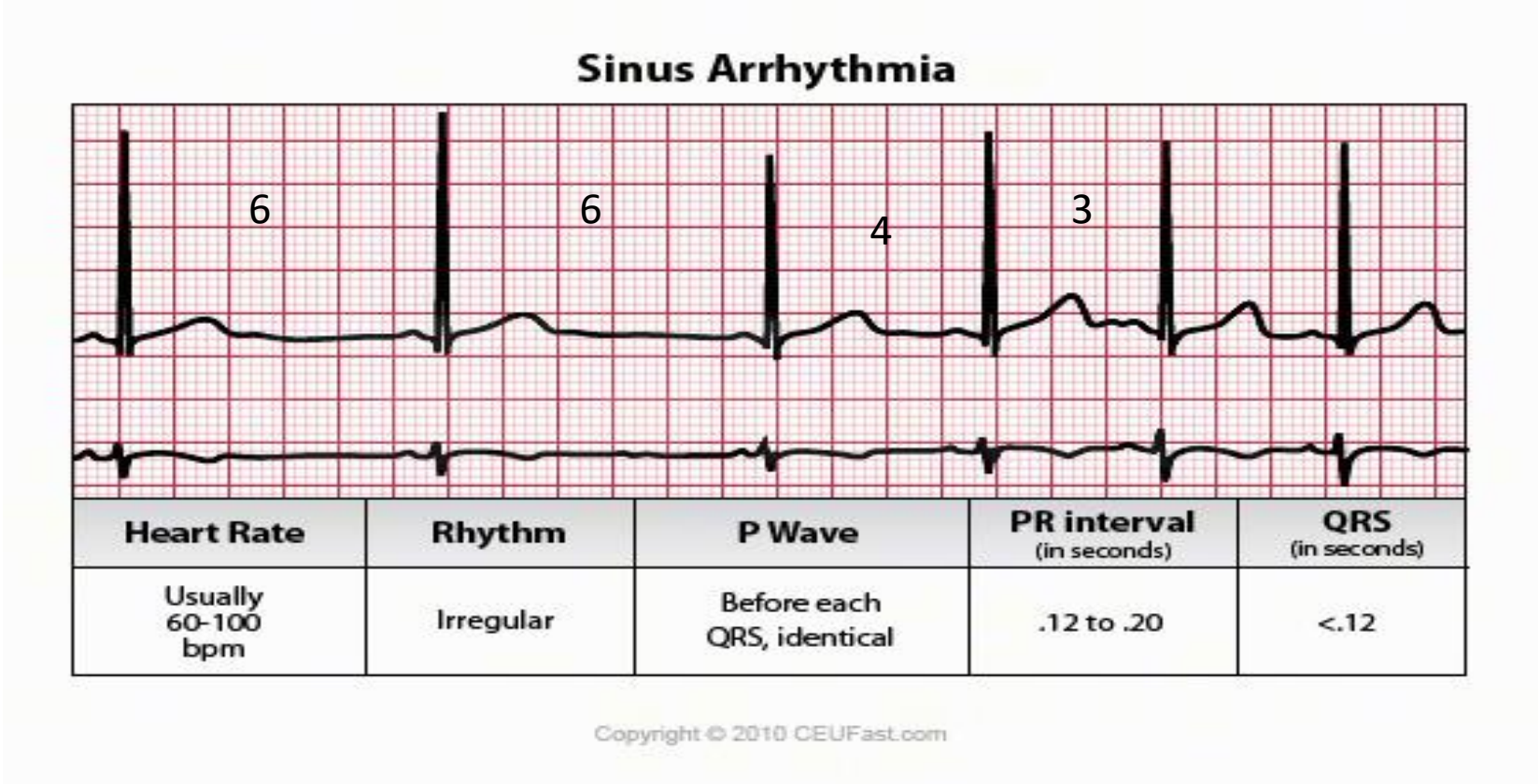
Sinus Tachycardia



Heart Rate	Rhythm	P Wave	PR interval (in seconds)	QRS (in seconds)
> 100 bpm	Regular	Before each QRS, identical	.12 to .20	<.12

Maybe the result of stress, exercise, pain, fever, pump failure, hyperthyroidism, drugs-caffeine, nitrates, atropine, epinephrine, and isoproterenol, nicotine

Sinus Arrhythmia



Rate: Usually 60-100 beats/min but may be either faster or slower
Commonly seen in the elderly and the young and usually does not require treatment. Heart rate increases with inspiration and decreases with expiration

Premature Contractions

- A premature contraction is a contraction of the heart before the time that normal contraction would have been expected.
- This condition is also called *extrasystole, premature beat,* or *ectopic beat*

➢Premature contractions (“ectopics”) are classified by their origin — atrial (PACs), junctional (PJCs) or ventricular (PVCs)

1. Premature atrial contractions: Occasional shortened intervals between one contraction and succeeding, frequently occurs in healthy people. Conditions such as smoking, lack of sleep, ingestion of too much coffee, alcoholism, and use of various drugs can also initiate such contractions.

Premature Contractions

2. A-V Nodal or A-V Bundle Premature Contractions (Junctional):

These contractions have the same significance and causes as atrial premature contractions.

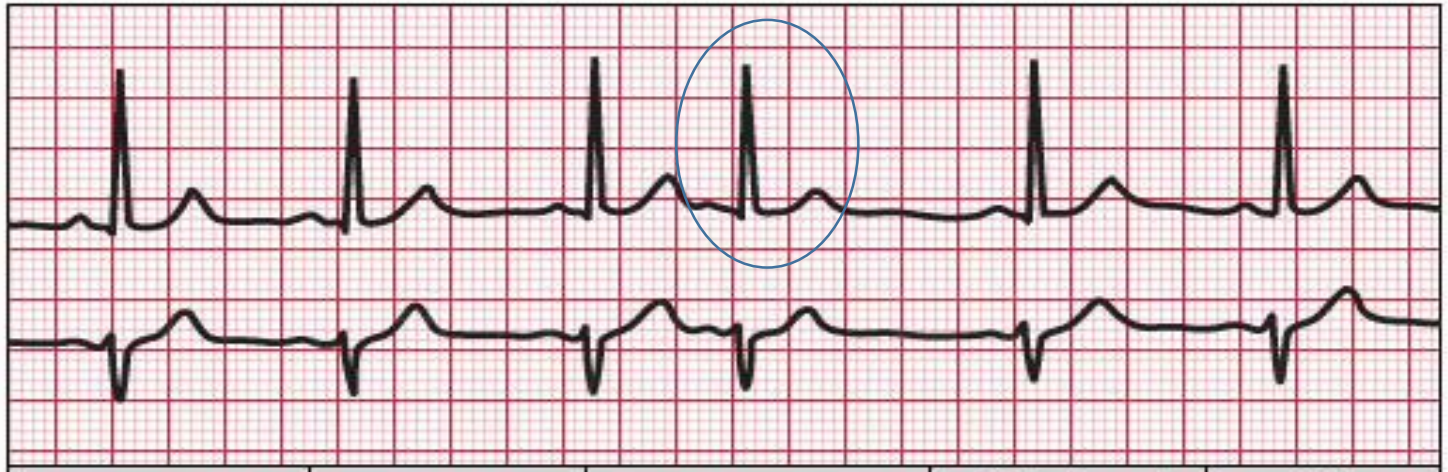
3. Premature Ventricular Contractions:

- Some PVCs are relatively benign.
- They can result from factors as cigarettes, coffee, lack of sleep, various mild toxic states, and even emotional irritability.
- PVCs also can result from signals that originate around the borders of infarcted or ischemic areas of the heart. The presence of such PVCs can lead to lethal ventricular fibrillation

Premature Atrial Complexes (PACs)

- These arise from ectopic pacemaking tissue within the atria.
- There is an **abnormal P wave (premature/ hidden)**, usually followed by a normal QRS complex

Premature Atrial Contraction • Isolated PAC's: Occur Single



Heart Rate	Rhythm	P Wave	PR interval (in seconds)	QRS (in seconds)
N/A	Irregular	Premature & abnormal or hidden	<.20	<.12

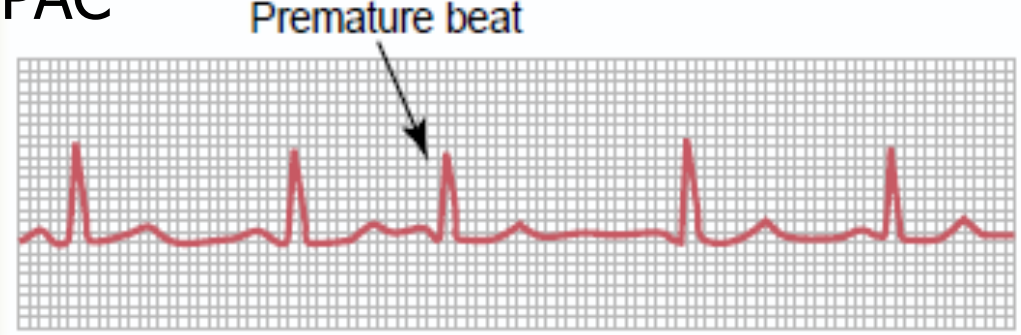
Irregular since the impulse occurs early

PAC occurs when an irritable site within the atria discharges before the next SA node is due to discharge

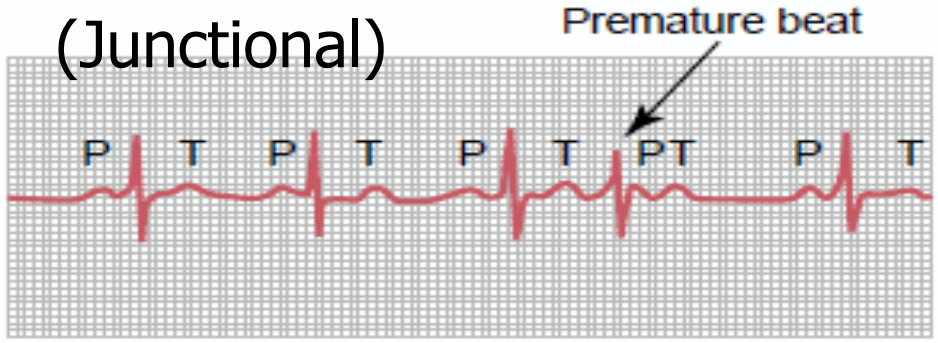
Premature Contractions

Premature beats are identified by **their site of origin** (atrial, junctional, and ventricular)

PAC

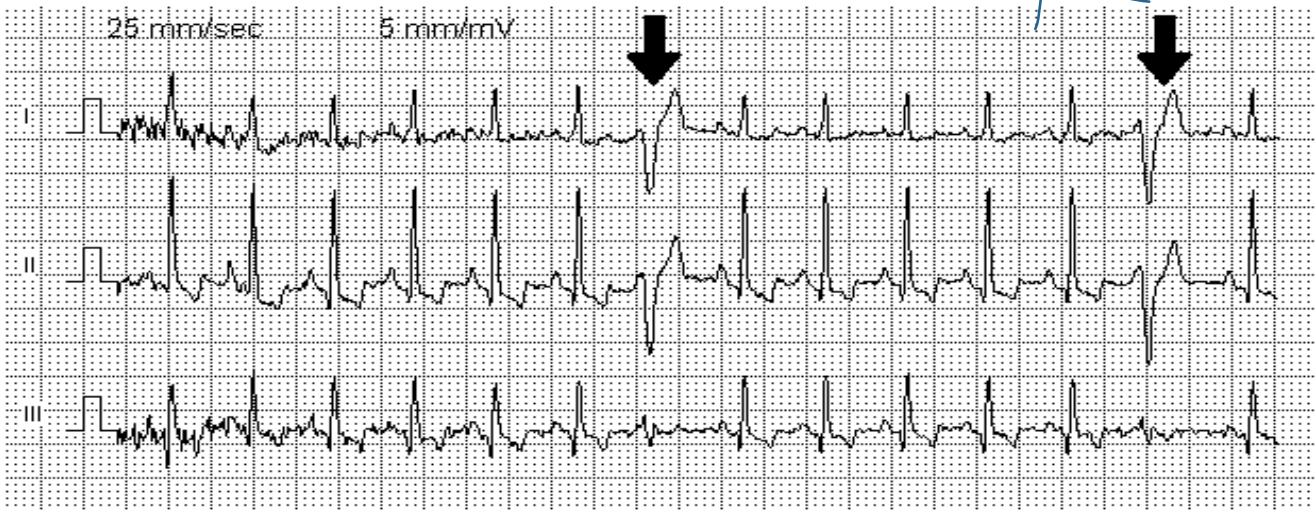


A-V nodal PC
(Junctional)



PVC

- **Broad QRS complex** (≥ 120 ms) with abnormal morphology.
- **Premature** — i.e. occurs earlier than would be expected for the next sinus impulse.
- **Discordant** ST segment and T wave changes.
- Usually followed by a full **compensatory pause**.



Ventricular & Atrial Fibrillation

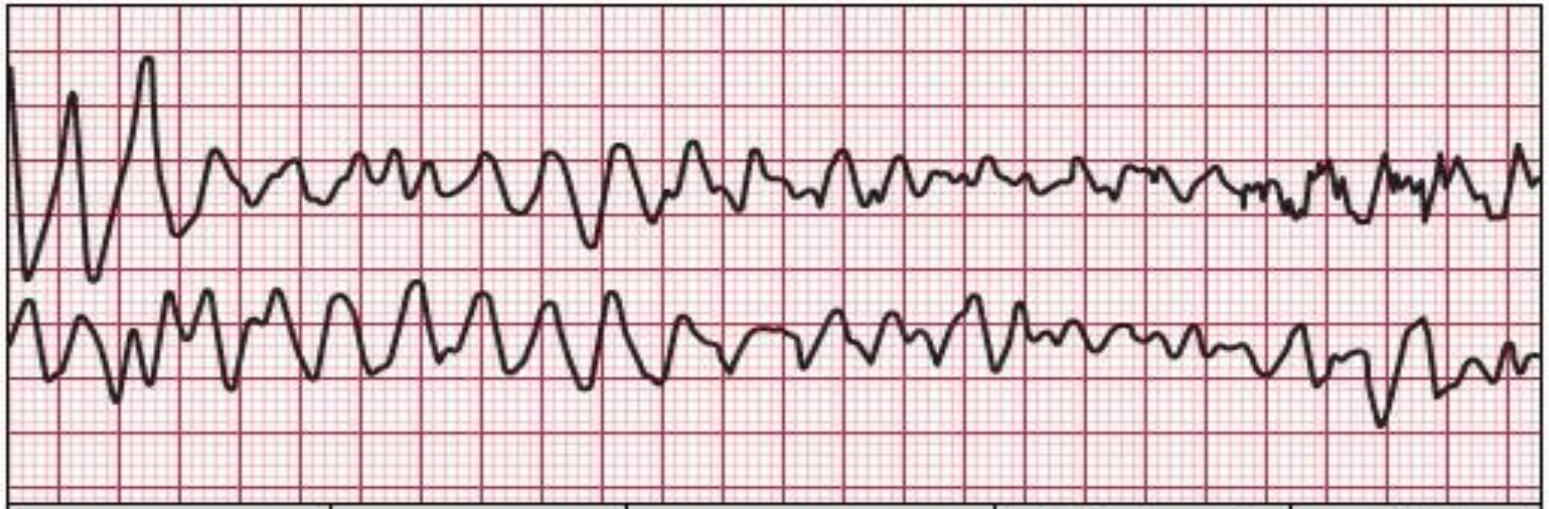
Fibrillation is a fast, chaotic beating of a heart chamber. If it's in the top chamber, it's atrial fibrillation. If in the bottom chambers, it's ventricular fibrillation

Ventricular fibrillation:

- The **most serious of all cardiac arrhythmias**, if not stopped within 1 to 3 minutes, is almost fatal.

- It is a condition in which there is **uncoordinated contraction** of the cardiac muscle of the ventricles in the heart, making them tremble rather than contract properly.
- Multiple factors can spark the beginning of ventricular fibrillation:
  (1) sudden electrical shock of the heart, or
  (2) ischemia of the heart muscle, of its specialized conducting system,
  (3) both factors.

Ventricular Fibrillation

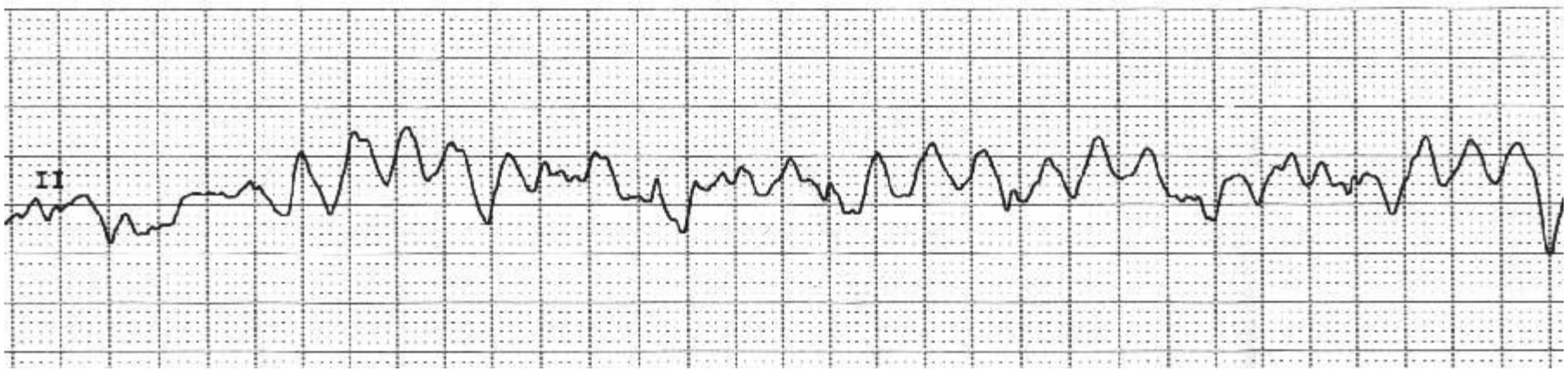


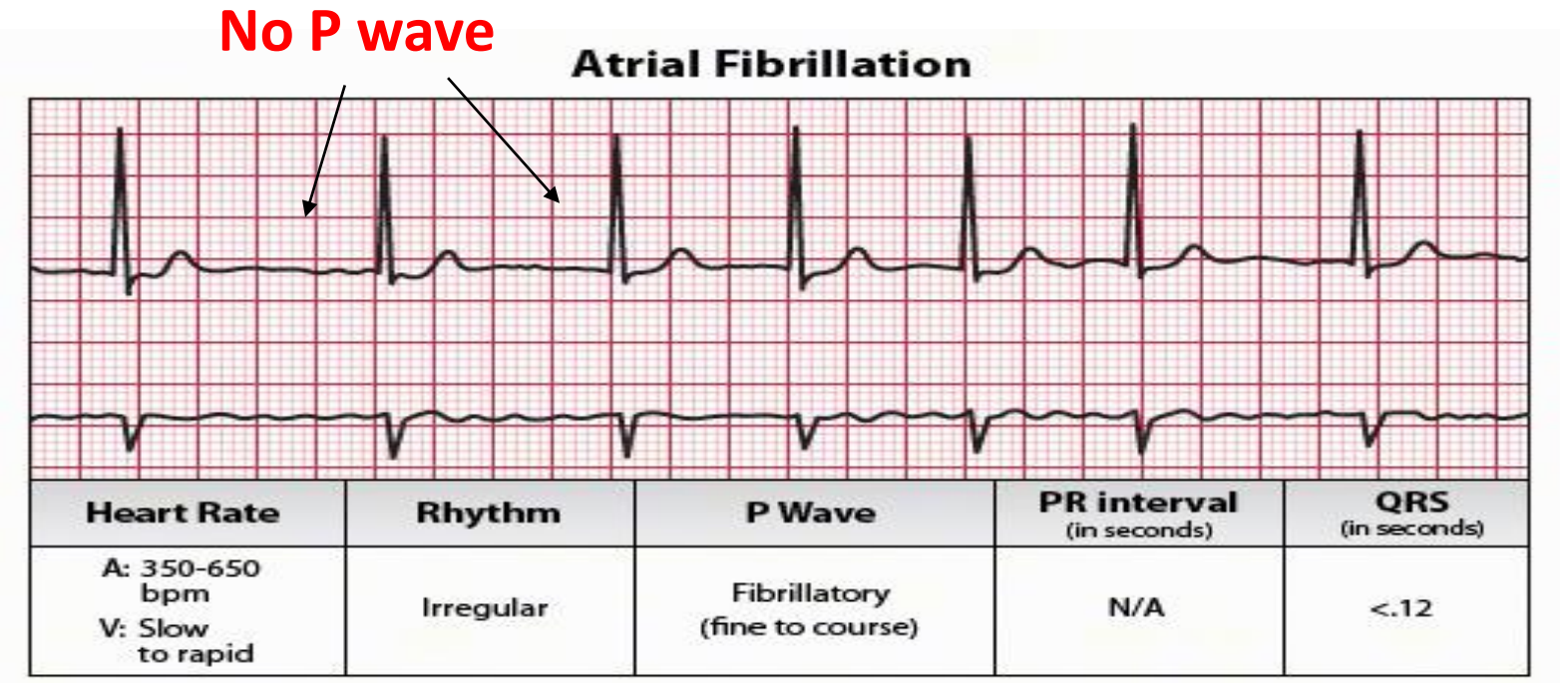
Heart Rate	Rhythm	P Wave	PR interval (in seconds)	QRS (in seconds)
300-600	Extremely irregular	Absent	N/A	Fibrillatory baseline

Ventricular Fibrillation (VF)
Rate: rapid and disorganized
Rhythm: irregular and chaotic
P Wave: absent but can be recognizable
PRI: not measurable
QRS: fibrillatory waves ((no wave)).

Ventricular Fibrillation

- ECG it is characterized by a chaotic irregular appearance with complexes of varying amplitude and morphology.
- Untreated, VF rapidly leads to death; the only effective therapy is electrical defibrillation.

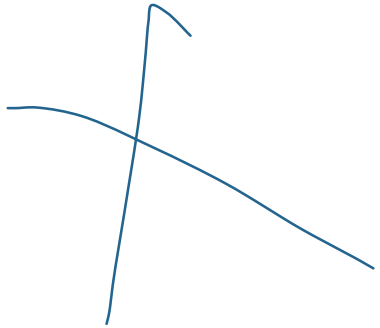




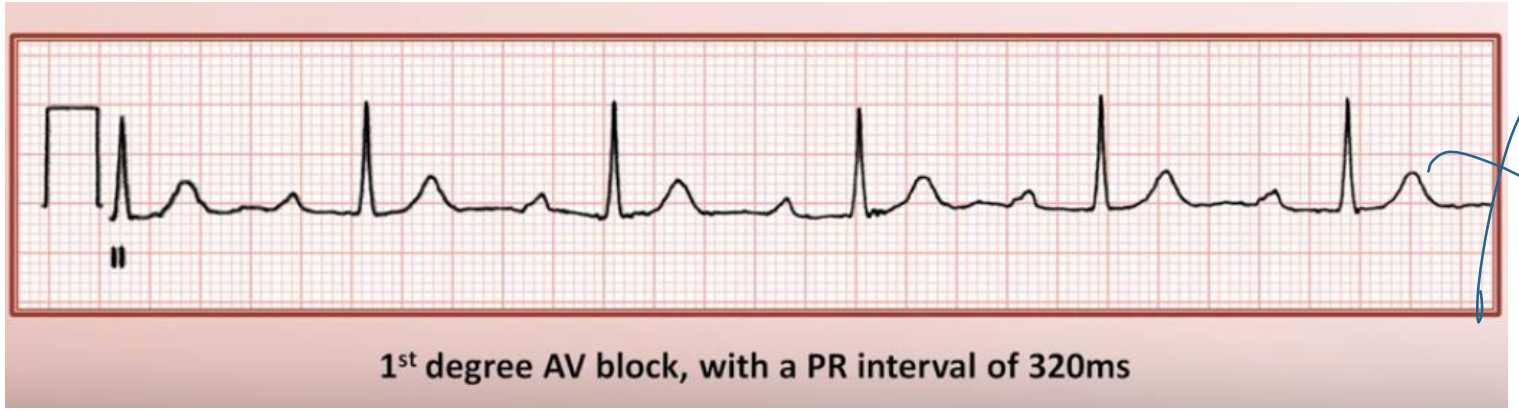
Heart Rate	Rhythm	P Wave	PR interval (in seconds)	QRS (in seconds)
A: 350-650 bpm V: Slow to rapid	Irregular	Fibrillatory (fine to course)	N/A	<.12

Atrial rate usually > 400, Ventricular rate variable
Rhythm: Atrial and ventricular very **irregular**
P waves: No identifiable P waves, Erratic, wavy baseline
PRI: None
QRS: Usually <.10
The AV node protects the patient from having too high a ventricular response, and blocks the majority of the impulses.
Blood may pool or stagnate in the atria and the patient is at risk for **clot formation**.
May be due to: ischemia, Myocardial Infarction hypoxia, or drug therapy.
Treatment may consist of beta-blockers (Inderal), calcium blockers (verapamil), or synchronized cardioversion in an attempt to restore the patient to a sinus rhythm.

AV Block

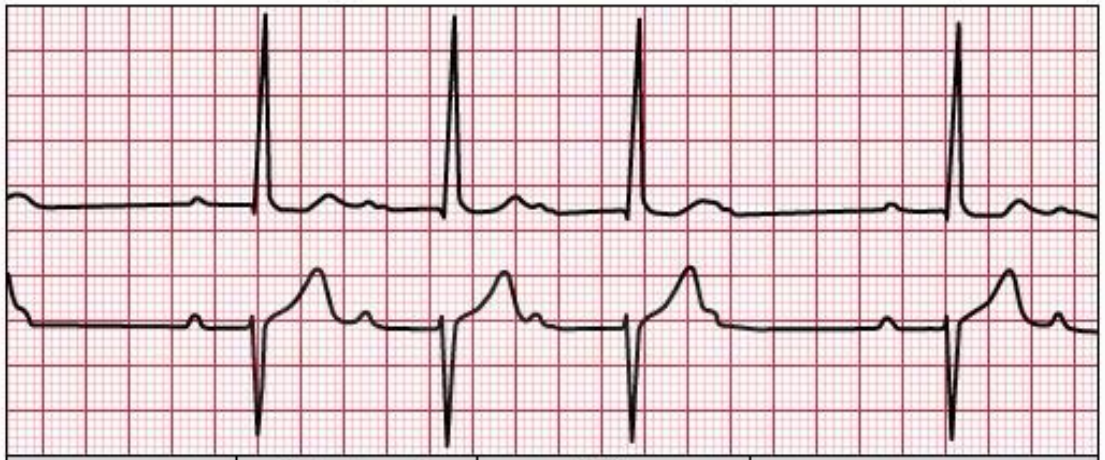


- A problem with conduction of signals through the AV node may exist.
- In heart block →AP from the SA node fail to be transmitted through the AV node to the ventricles. In these conditions, one or more P waves may occur without initiating a QRS complex.
- In the most severe form of heart block (third-degree)→ the atria depolarize regularly at one pace while the ventricles contract at a much slower pace



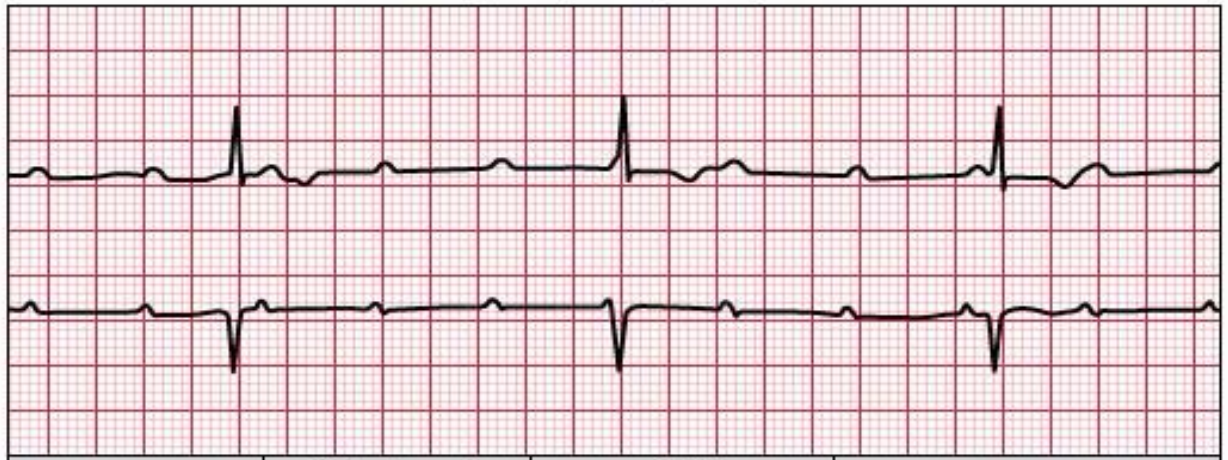
1st degree AV block, with a PR interval of 320ms

Second Degree AV Block - Mobitz (Wenckebach)



P Wave	PR Interval (in seconds)	QRS (in seconds)	Characteristics
Conduction intermittant	Increasingly Prolonged	Before each QRS, identical	QRS dropped in a repeating pattern

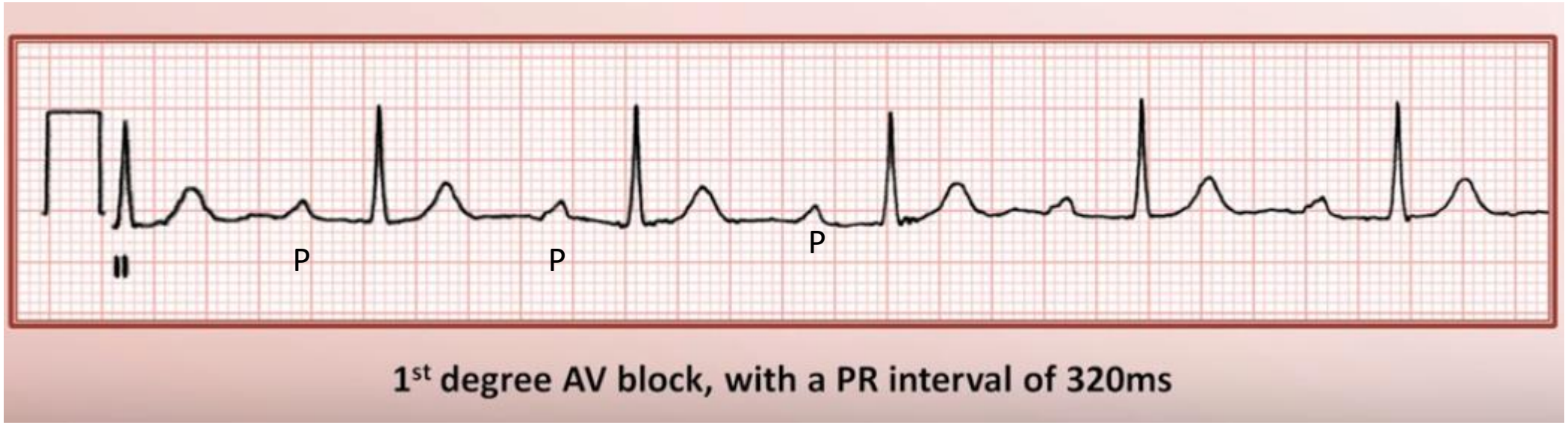
Third Degree (complete) AV Block



P Wave	PR Interval (in seconds)	QRS (in seconds)	Characteristics
Normal but not related to QRS	None	N/A	No relationship between P&RS

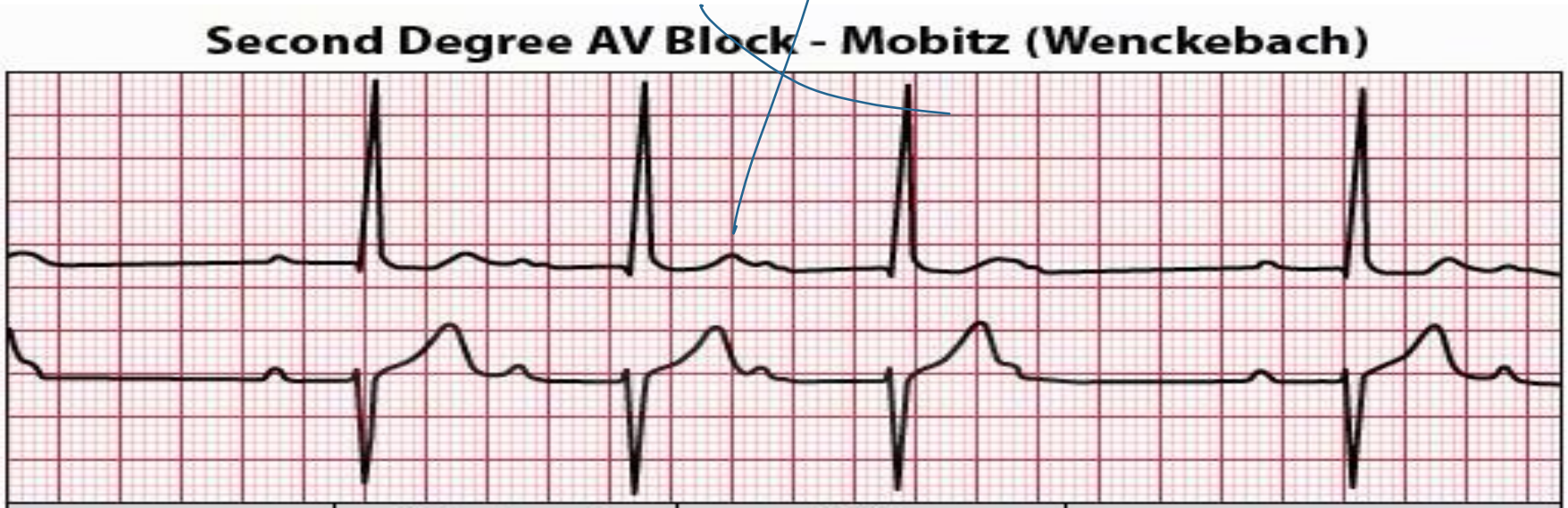
First Degree AV Block:

PRI longer than 0.20 sec
There is No Block at all just a **delay in conduction**.
Every P wave is married to a QRS; no missed beats



1st degree AV block, with a PR interval of 320ms

Second Degree AV Block:



P Wave	PR Interval (in seconds)	QRS (in seconds)	Characteristics
Conduction intermittant	Increasingly Prolonged	Before each QRS, identical	QRS dropped in a repeating pattern

Type I (Mobitz I)

progressive prolongation of the PR interval, followed by a blocked P wave

1. decreasing RR intervals until pause
2. the pause is less than preceding 2 RR intervals
3. the RR interval after the pause is greater than the RR interval just prior to pause

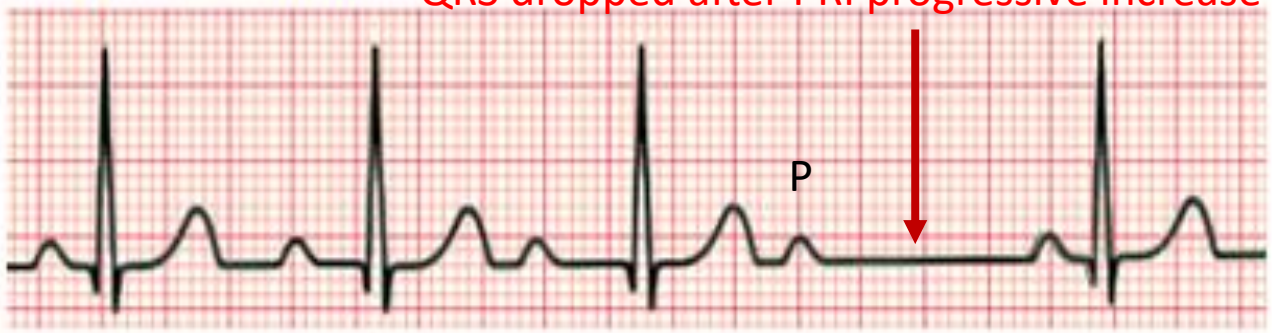
Type II (Mobitz II)
PRI is fixed (no progressive increase in PRI)
QRS is dropped without warning; there will always be more P Waves than QRS

The P waves are married to the QRS

The level of conduction problem is usually lower than the AV node, often involving the **Bundle of His**

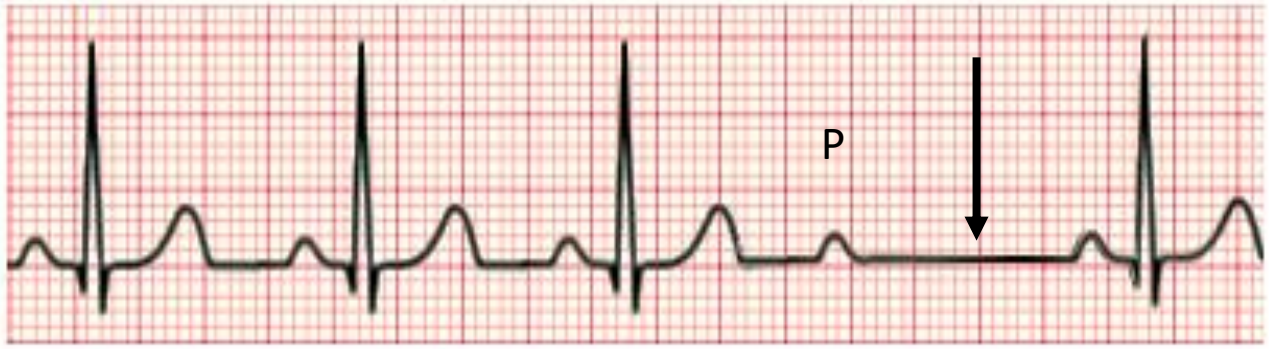
Mobitz I or Wenckebach

QRS dropped after PRI progressive increase

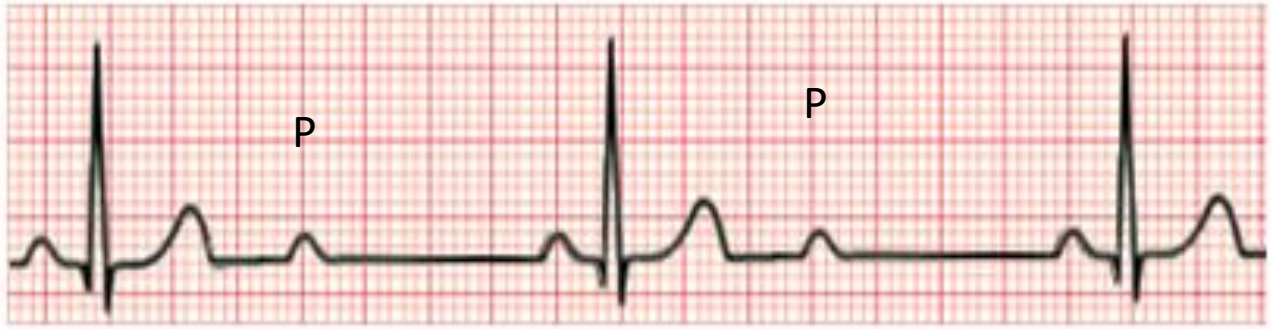


Mobitz II

QRS dropped without warning



2:1 block

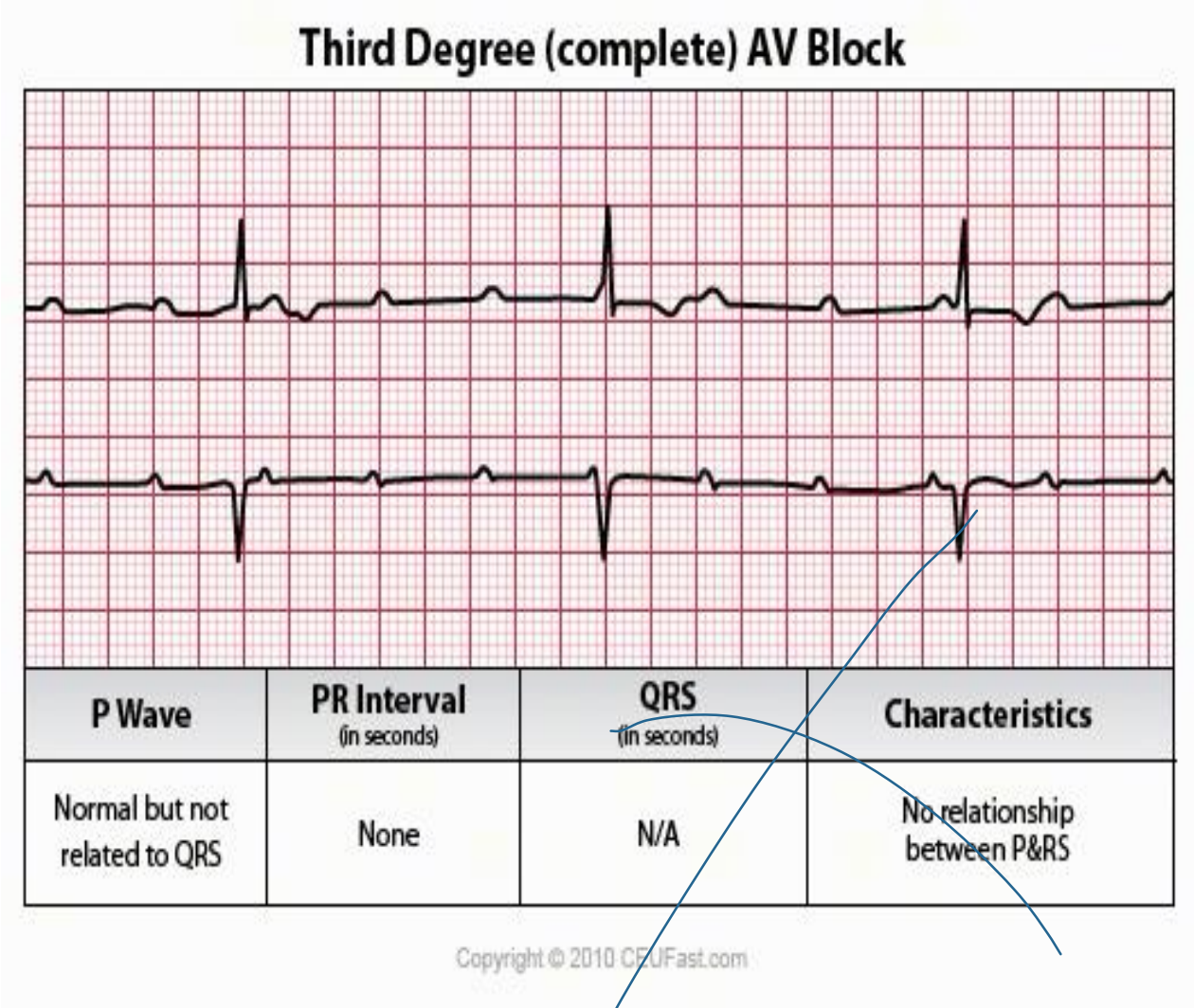


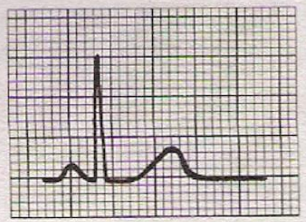
Third Degree (Complete Heart Block)

There is complete heart block so that none of the impulses from above are conducted to the ventricles

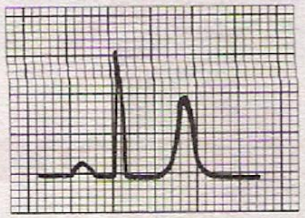
The atria and the ventricles are controlled independently by separate pacemakers

P Waves are NOT married to the QRS

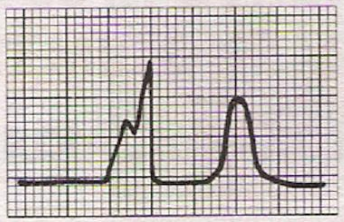




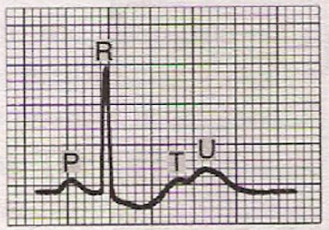
Normal tracing (plasma K^+ 4–5.5 meq/L). PR interval = 0.16 s; QRS interval = 0.06 s; QT interval = 0.4 s (normal for an assumed heart rate of 60).



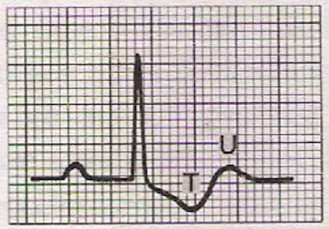
Hyperkalemia (plasma K^+ ±7.0 meq/L). The PR and QRS intervals are within normal limits. Very tall, slender peaked T waves are now present.



Hyperkalemia (plasma K^+ ±8.5 meq/L). There is no evidence of atrial activity; the QRS complex is broad and slurred and the QRS interval has widened to 0.2 s. The T waves remain tall and slender. Further elevation of the plasma K^+ level may result in ventricular tachycardia and ventricular fibrillation.



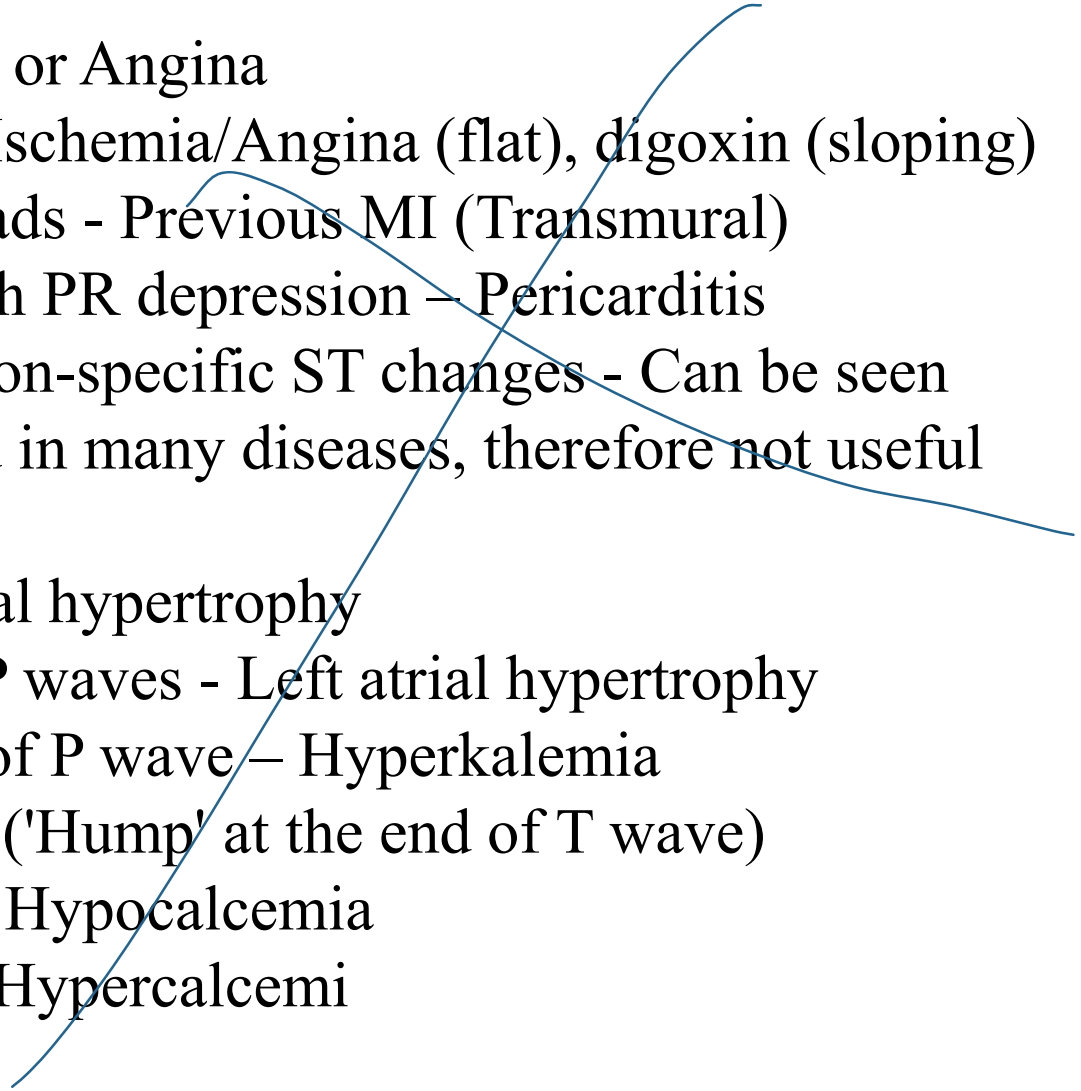
Hypokalemia (plasma K^+ ±3.5 meq/L). PR interval = 0.2 s; QRS interval = 0.06 s; ST segment depression. A prominent U wave is now present immediately following the T. The actual QT interval remains 0.4 s. If the U wave is erroneously considered a part of the T, a falsely prolonged QT interval of 0.6 s will be measured.



Hypokalemia (plasma K^+ ±2.5 meq/L). The PR interval is lengthened to 0.32 s; the ST segment is depressed; the T wave is inverted; a prominent U wave is seen. The true QT interval remains normal.

Clinical Significance of different waves and segments of ECG

ST Elevation - Acute MI or Angina
ST depression >1 mm - Ischemia/Angina (flat), digoxin (sloping)
Q waves in 2 or more leads - Previous MI (Transmural)
Diffuse ST elevation with PR depression – Pericarditis
T wave inversions and non-specific ST changes - Can be seen both in normal cases and in many diseases, therefore not useful for diagnosis.
Tall P waves - Right atrial hypertrophy
Broad (and often bifid) P waves - Left atrial hypertrophy
Peaked T waves or loss of P wave – Hyperkalemia
U waves - Hypokalemia ('Hump' at the end of T wave)
Prolonged QT interval – Hypocalcemia
Shortened QT interval - Hypercalcemi



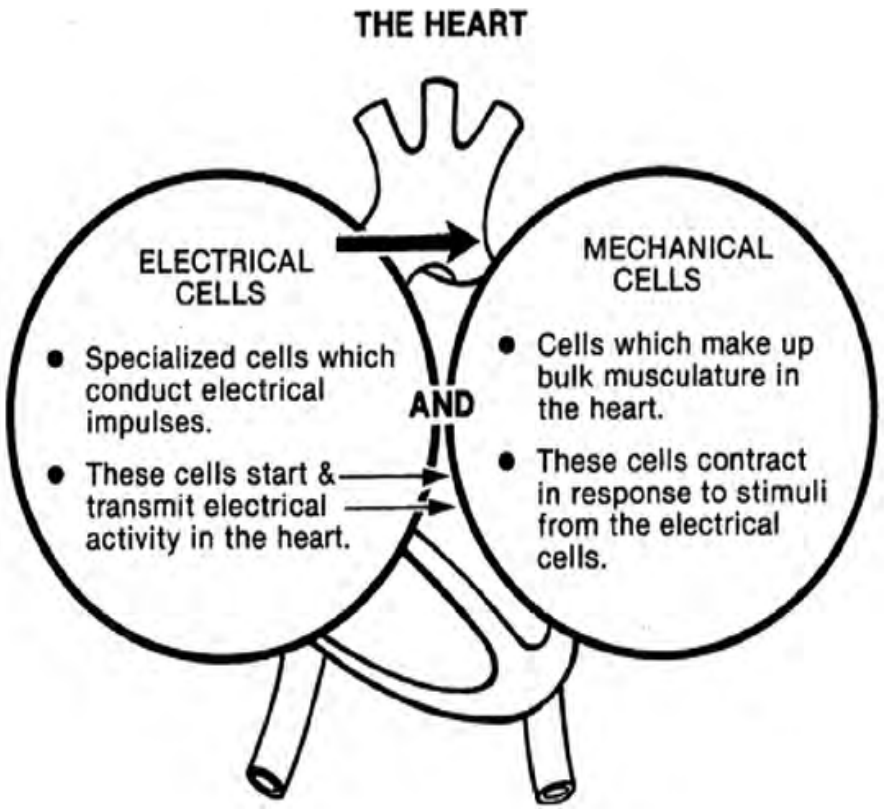
Mechanical activity of the heart

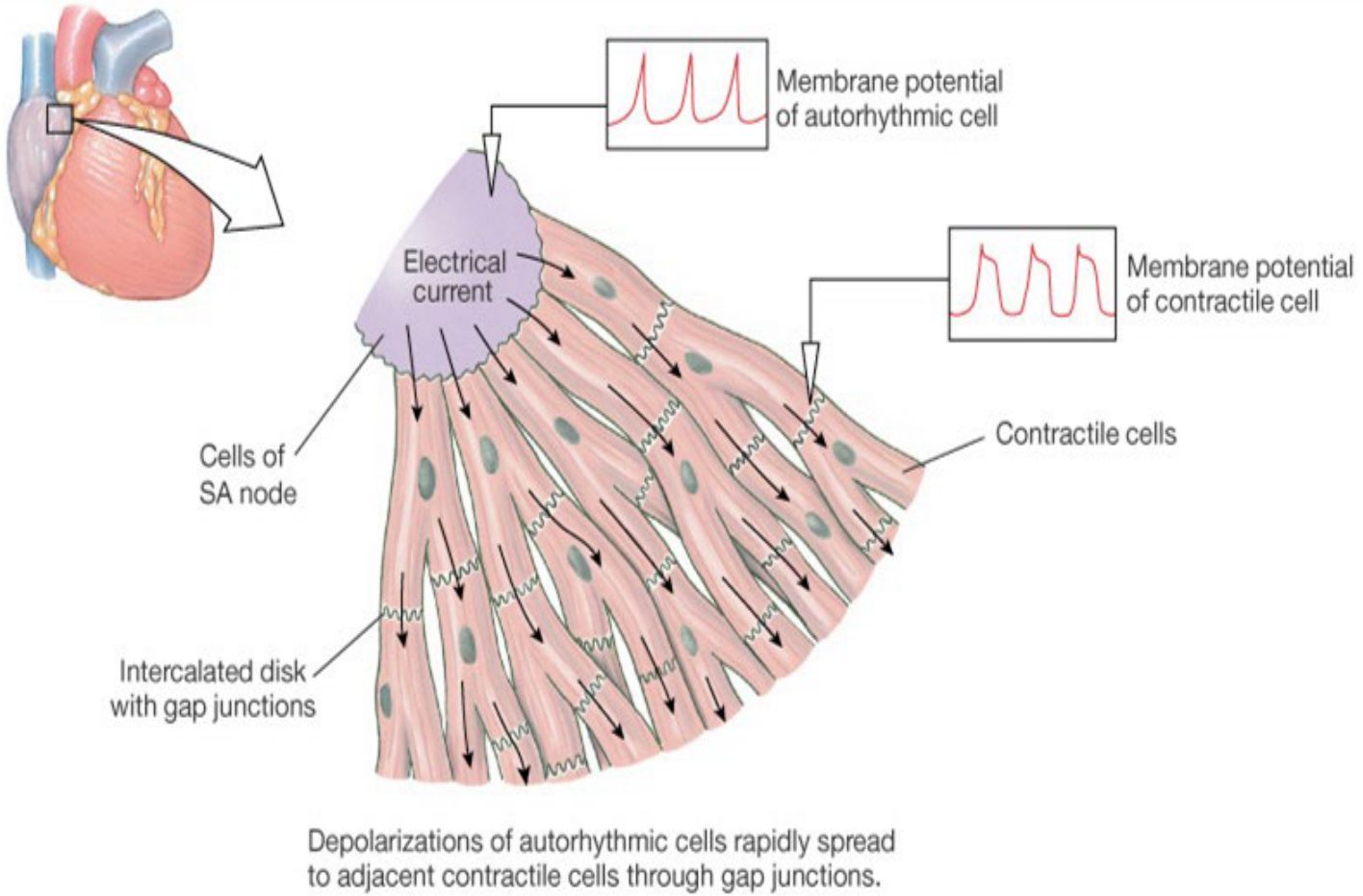
Dr Safa Abdul Ghani

• Heart Cells

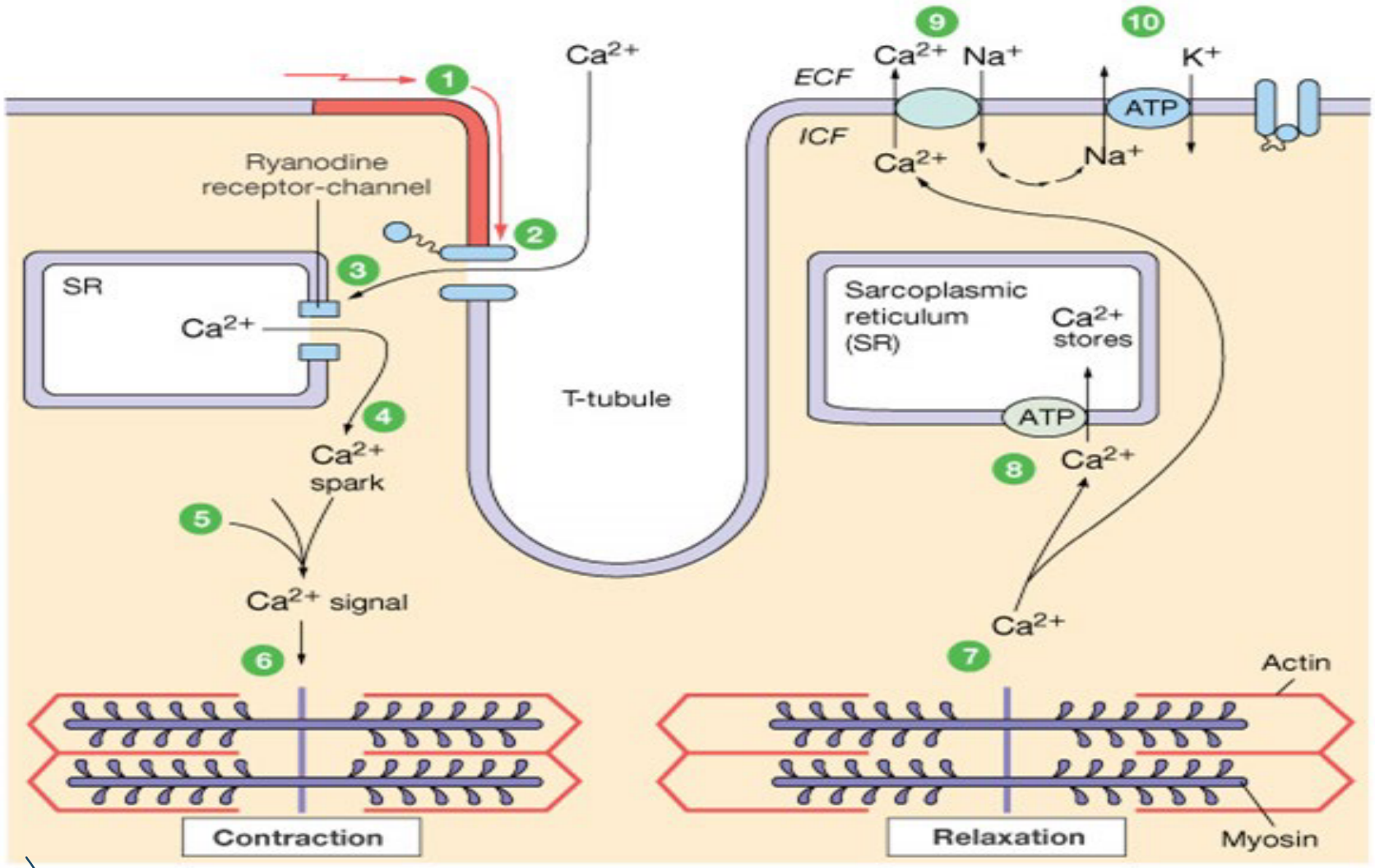
Two types of cells are found in the heart :

1. Mechanical cells (contractile)
2. Electrical cells (Autorhythmic)





Mechanism of Cardiac Muscle Excitation, Contraction & Relaxation



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^{+}.
10. Na^{+} gradient is maintained by the Na^{+}-K^{+}-ATPase.

Figure 14-11: Excitation-contraction coupling and relaxation in cardiac muscle

Approximately 20 % of the calcium required for contraction is supplied by the influx of Ca^{2+} during the plateau phase. The remaining Ca^{2+} for contraction is released from storage in the sarcoplasmic reticulum

Mechanical activity of the heart

- **Cardiac Cycle**
  - V↓ P↑ ~Systole Cont → Ejection blood
  - V↑ P↓ ~Diastole Relax → Filling

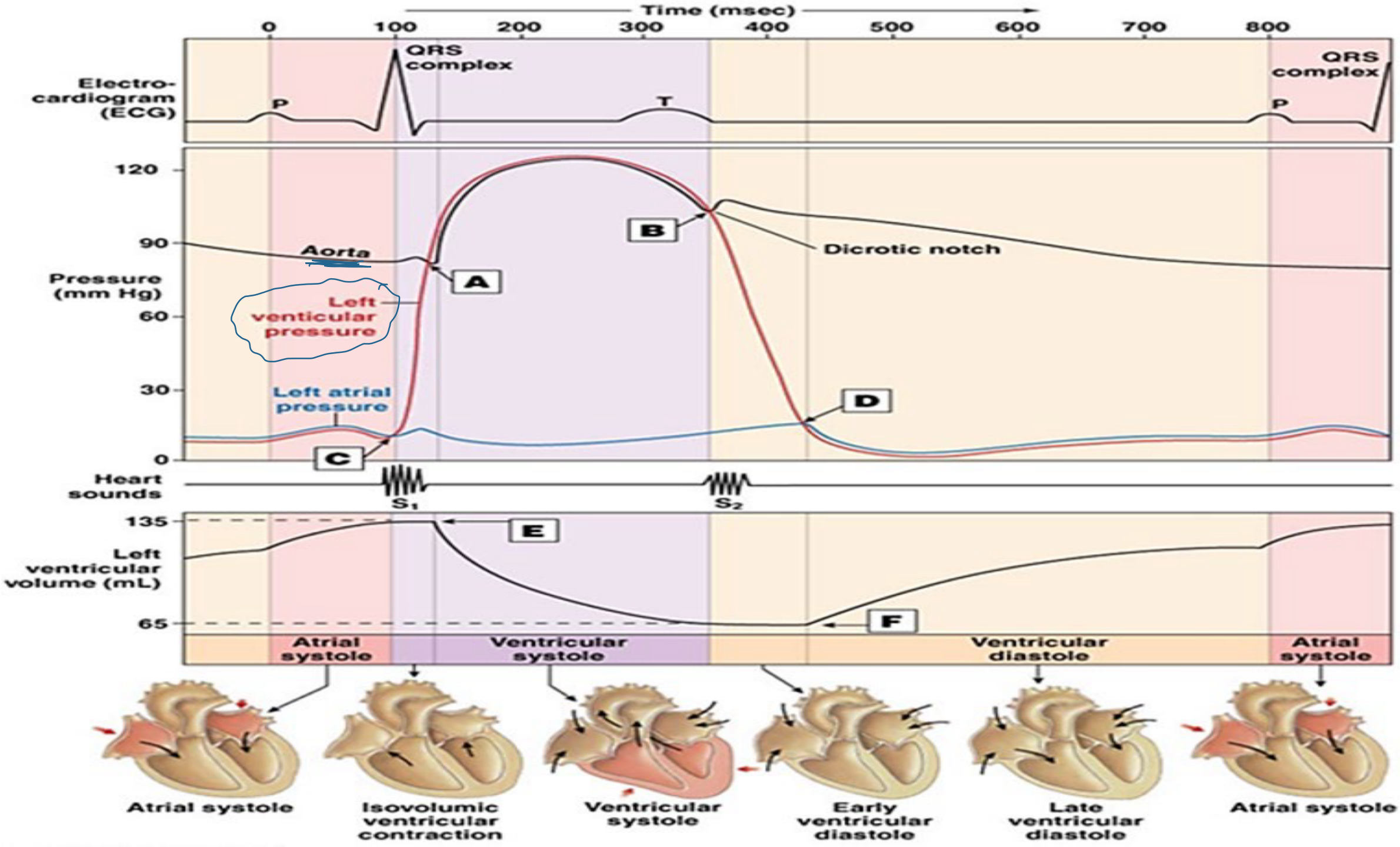
$P \propto \frac{1}{V}$

علاقة عكسية بين ال Volume و ال Pressure

- **Pressure Volume Changes**
- **Heart Sounds** Valves close
- **Cardiac Output** 5 L
- **Venous Return**

CARDIAC CYCLE

1. ELECTRICAL CHANGE
2. MECHANICAL CHANGE
3. HEMODYNAMIC CHANGE
4. HEART SOUNDS


Time (msec)
0
100
200
300
400
500
600
700
800
Electro-cardiogram (ECG)
QRS complex
P
T
QRS complex
P
120
90
Pressure (mm Hg)
60
30
0
Aorta
Left venticular pressure
Left atrial pressure
A
B
C
D
Dicrotic notch
Heart sounds
S1
S2
135
Left ventricular volume (mL)
65
E
F
Atrial systole
Ventricular systole
Ventricular diastole
Atrial systole
Atrial systole
Isovolumic ventricular contraction
Ventricular systole
Early ventricular diastole
Late ventricular diastole
Atrial systole

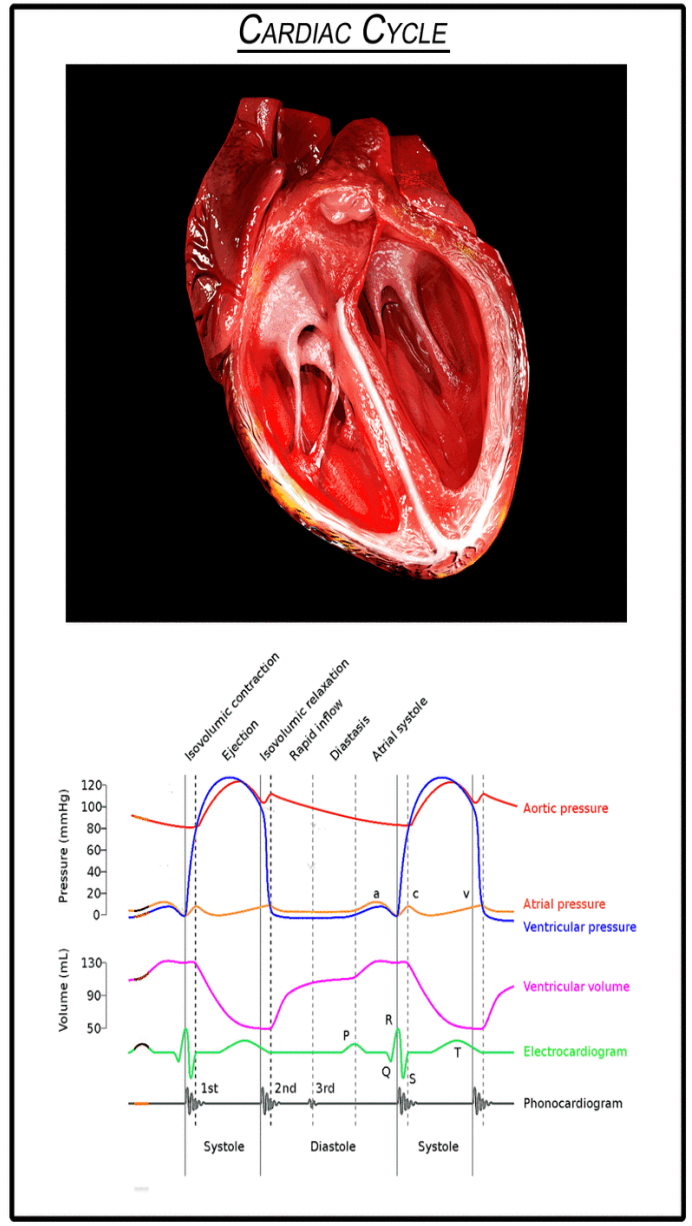
Cardiac Cycle

0.8 second

- The Cardiac Cycle: Cardiac events that occur from beginning of one heart beat to the beginning of next
- Each cycle is initiated by spontaneous generation of action potential in the sinus node (SA node)
- Each cycle lasts about **0.8 second**

- **Cardiac cycle has two phases**:

1. Diastole: time during which cardiac muscle relaxes
2. Systole: time during which the muscle is contracting



	Cardiac Cycle Phase	Atrial state	Ventricular state	State of Atrioventricular AV valves	State of Aortic and pulmonary valves
1	Passive filling ٪80 Blood منفعي هوت	relaxed	relaxed: filling	open	closed
2	Atrial contraction ٪20 Blood	contracting systole	relaxed: filling diastole	open	closed
3	Ventricular isovolumetric contraction * All Valves Close ↑pressure pressure >80 mmHg max 120 mmHg Aorta valve بعد يصير أكتر من 80 بفتح Blood constant	relaxed	isovolumetric contraction	closed *1st sound heart Lub	closed pressure atrial < pressure Vetricle
4	Ejection هوت مندخل لمرحلة ال Ejection	relaxed	contraction: ejection هوت بصير shorting Sacromeres ال	closed	open $P_{ven} > P_{Aortic\ valve}$ semilunar valve هوت بفتح ال
	Ventricular isovolumetric relaxation ↓↓pressure pressure < 80 mmHg Valve بتسكر ال	relaxed	isovolumetric relaxation	closed	closed عشان مايرجع الدم اللي فخيتو للAortic *2nd sound heart Dub

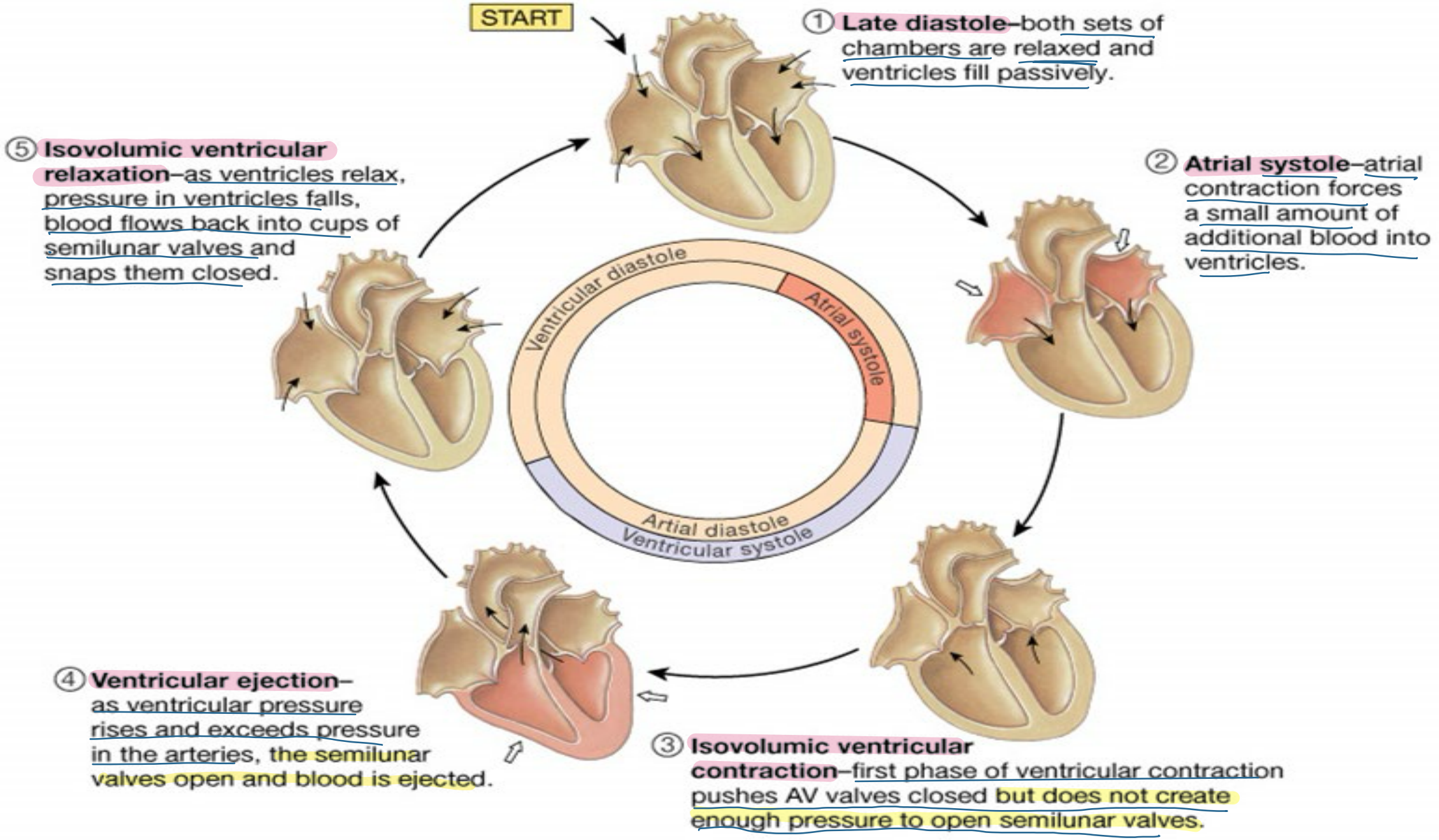
* بطلع sound بس لما يتسكرو ال Valves

After load

	Pressure (mmHg)
Right Atrium	0 – 4
Right Ventricle	25 systolic; 4 diastolic
Pulmonary Artery	25 systolic; 10 diastolic
Left Atrium	8 – 10
Left Ventricle	120 systolic; 10 diastolic
Aorta	120 systolic; 80 diastolic

↳ Hydrostatic pressure

↳ ازا كان فيه Hypertension والضغط 90 بدل 80 هون يعني الـ Ventricle بدو يعمل Contraction أكثر يعني load "After load"


START
① Late diastole–both sets of chambers are relaxed and ventricles fill passively.
② Atrial systole–atrial contraction forces a small amount of additional blood into ventricles.
③ Isovolumic ventricular contraction–first phase of ventricular contraction pushes AV valves closed but does not create enough pressure to open semilunar valves.
④ Ventricular ejection–as ventricular pressure rises and exceeds pressure in the arteries, the semilunar valves open and blood is ejected.
⑤ Isovolumic ventricular relaxation–as ventricles relax, pressure in ventricles falls, blood flows back into cups of semilunar valves and snaps them closed.
Ventricular diastole
Atrial systole
Artial diastole
Ventricular systole

Late diastole (passive filling)

- **The heart at rest: atrial and ventricular diastole**

Both the atria and the ventricles are relaxing.

The atria are filling with blood from the veins, and the ventricles have just completed a contraction (relaxation). Moderately increased pressure in atria (during ventricle systole) will push the AV valves open

Allow rapid blood flow into ventricle **(Rapid filling of ventricles)**

In passive filling

About 80% of blood flows directly into ventricles even before atrial contraction (Rapid in flow/ 0.11sec)

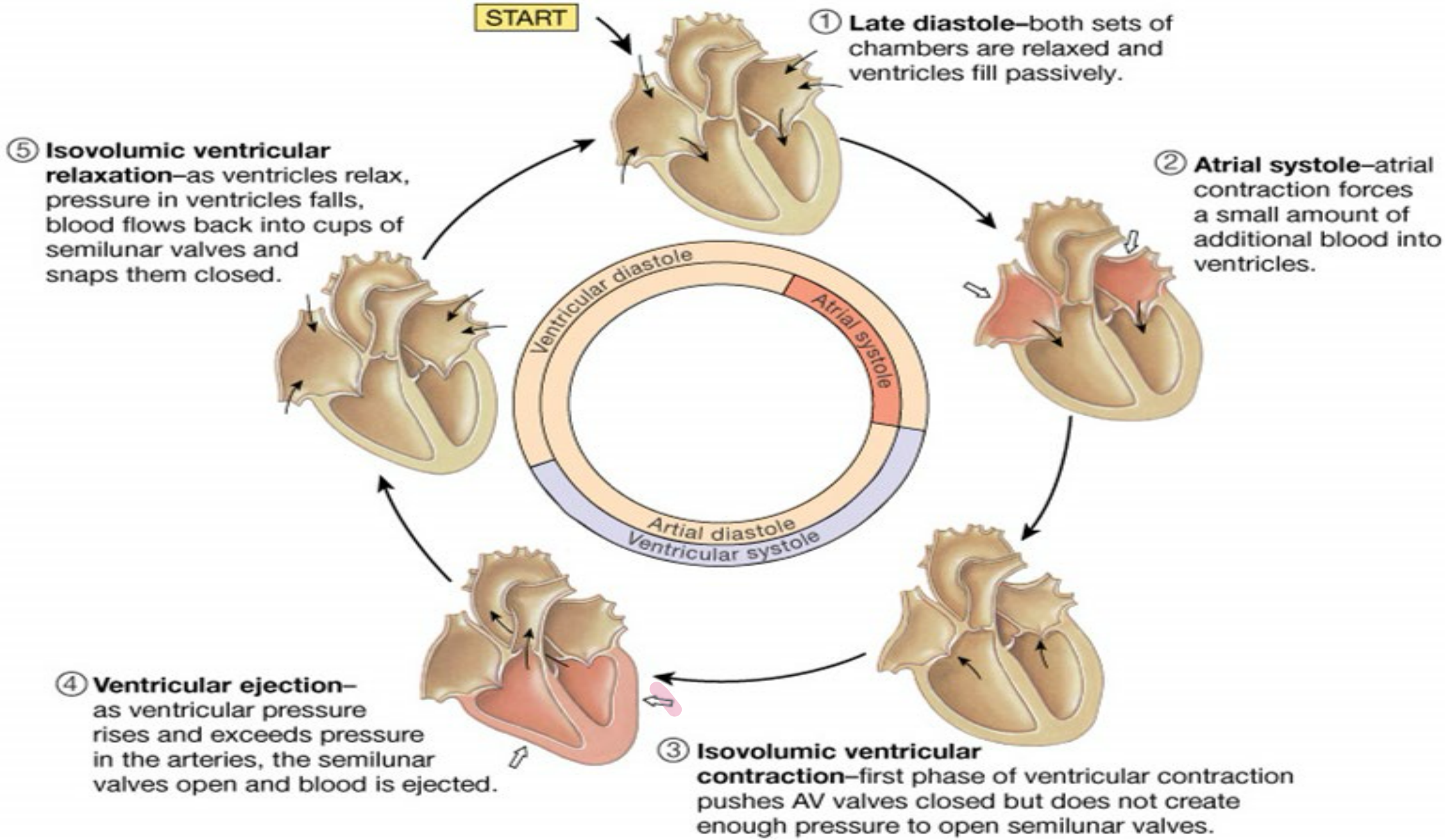
Then only a small amount of blood normally flows into ventricles, blood from veins & passes through atria into ventricles (Diastasis/ 0.19sec)

Atrial contraction causes an additional 20% ventricular filling

Phases of the Cardiac Cycle

Atrial systole

- Completion of ventricular filling: Ventricular filling – mid-to-late diastole
  - Atrial pressure is low as blood enters atria and flows into ventricles
  - AV valves are open, then atrial systole occurs
  - Although most blood enters the ventricles while the atria are relaxed, the last 20% of filling is accomplished when the atria contract and push blood into the ventricles. (This applies to a normal person at rest)


START
① Late diastole–both sets of chambers are relaxed and ventricles fill passively.
② Atrial systole–atrial contraction forces a small amount of additional blood into ventricles.
③ Isovolumic ventricular contraction–first phase of ventricular contraction pushes AV valves closed but does not create enough pressure to open semilunar valves.
④ Ventricular ejection–as ventricular pressure rises and exceeds pressure in the arteries, the semilunar valves open and blood is ejected.
⑤ Isovolumic ventricular relaxation–as ventricles relax, pressure in ventricles falls, blood flows back into cups of semilunar valves and snaps them closed.
Ventricular diastole
Atrial systole
Artial diastole
Ventricular systole

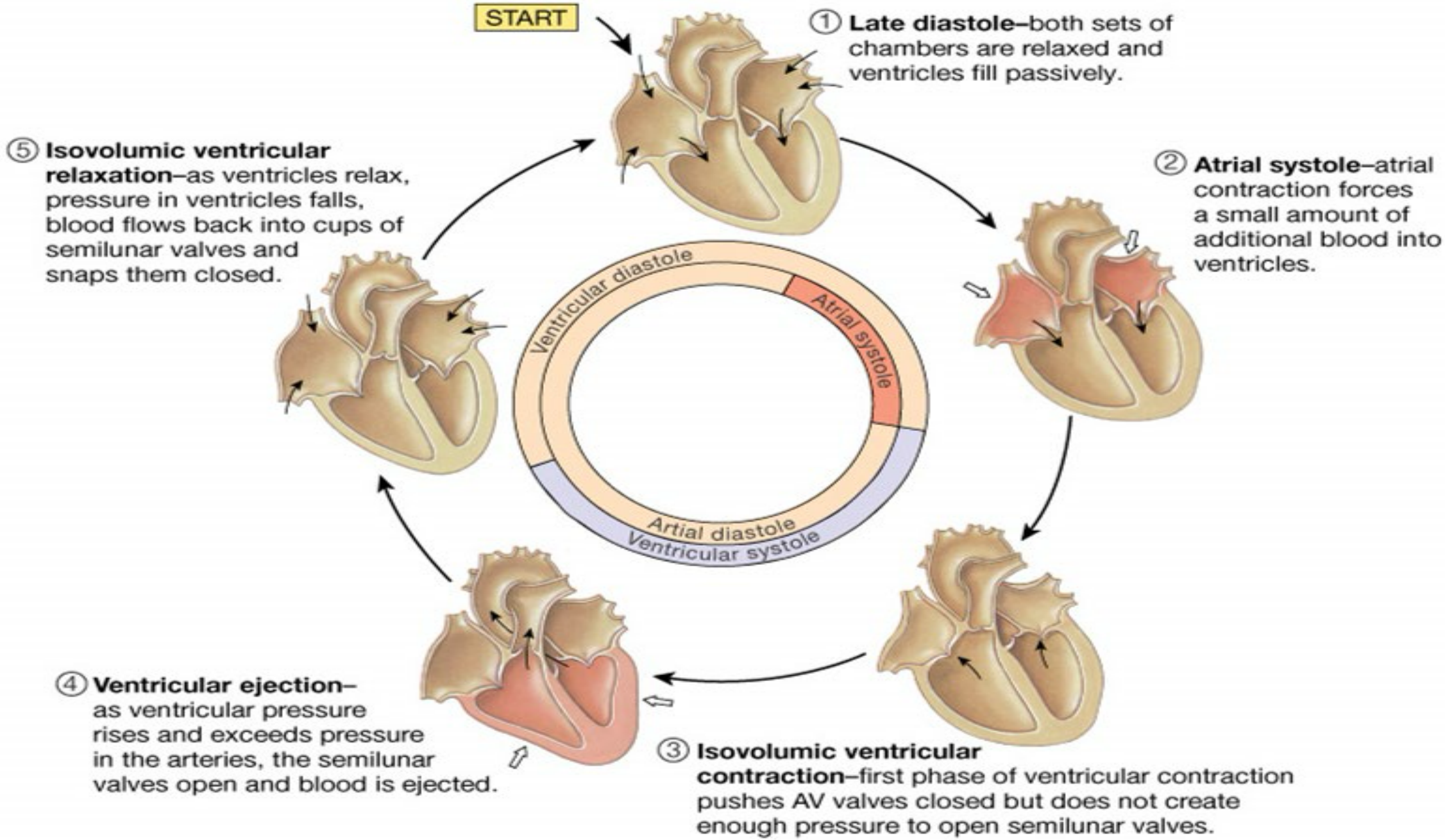
Ventricular systole

Isovolumetric contraction phase (0.05sec)

- Atria relax
- **Rising ventricular pressure results in closing of AV valves**
- **All valves are closed**
- Additional 0.02-0.03 sec is required for the ventricle **to build up sufficient pressure** to push Semilunar valve to open. During this period contraction is occurring in ventricles but there is no emptying
- Tension is increasing in muscle but little or no shortening of muscle fiber is occurring

Ventricular Ejection phase

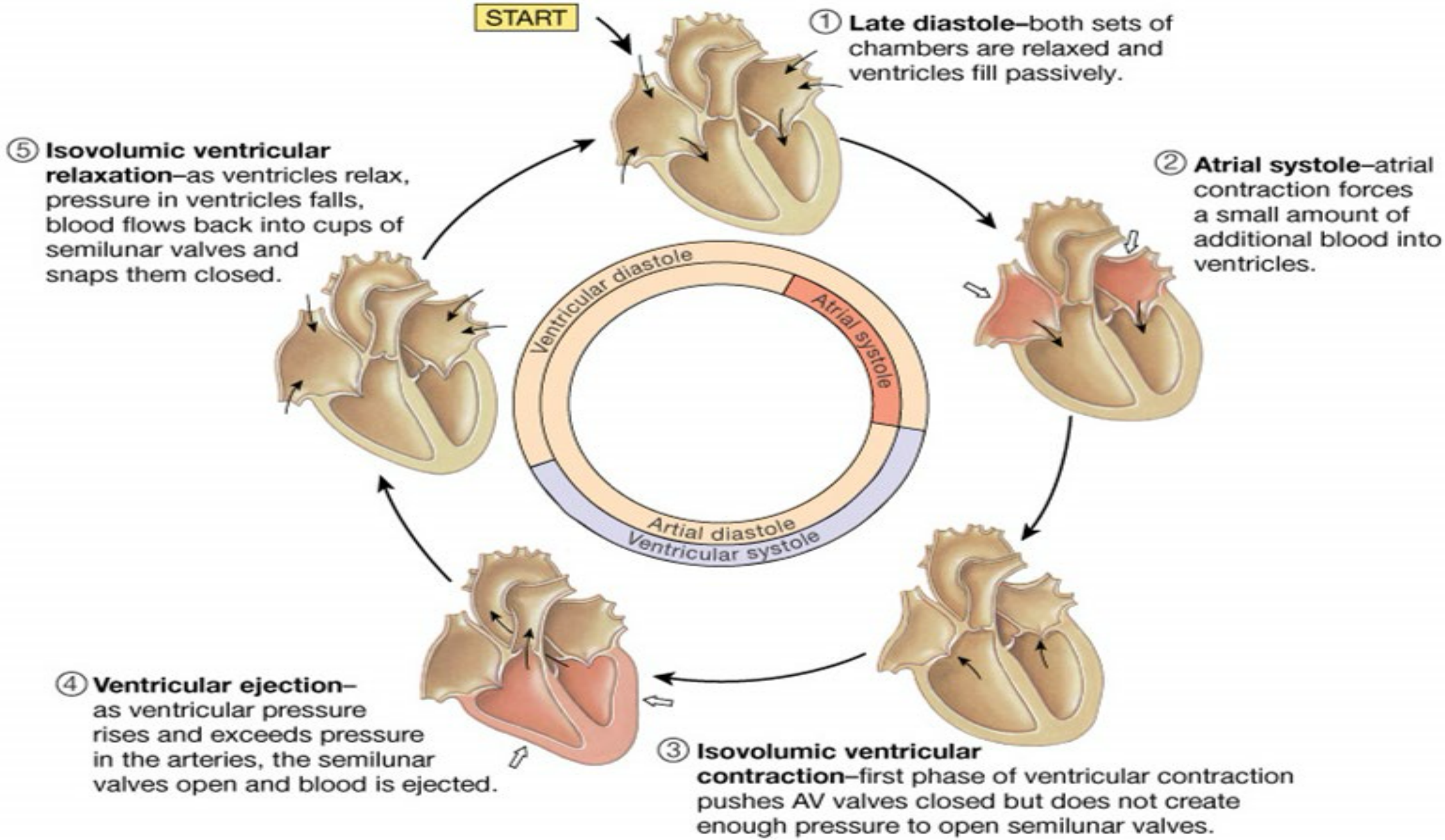
- When left ventricle pressure rise **above 80 mmHg** (right ventricle above 8 mmHg)
  - Ventricular ejection phase opens semilunar valves
- 70% of blood emptying occur during 1st third of period of ejection (rapid ejection/0.09sec)
- 30% emptying during next 2/3 (slow ejection/0.13sec)


START
① Late diastole–both sets of chambers are relaxed and ventricles fill passively.
② Atrial systole–atrial contraction forces a small amount of additional blood into ventricles.
③ Isovolumic ventricular contraction–first phase of ventricular contraction pushes AV valves closed but does not create enough pressure to open semilunar valves.
④ Ventricular ejection–as ventricular pressure rises and exceeds pressure in the arteries, the semilunar valves open and blood is ejected.
⑤ Isovolumic ventricular relaxation–as ventricles relax, pressure in ventricles falls, blood flows back into cups of semilunar valves and snaps them closed.
Ventricular diastole
Atrial systole
Artial diastole
Ventricular systole

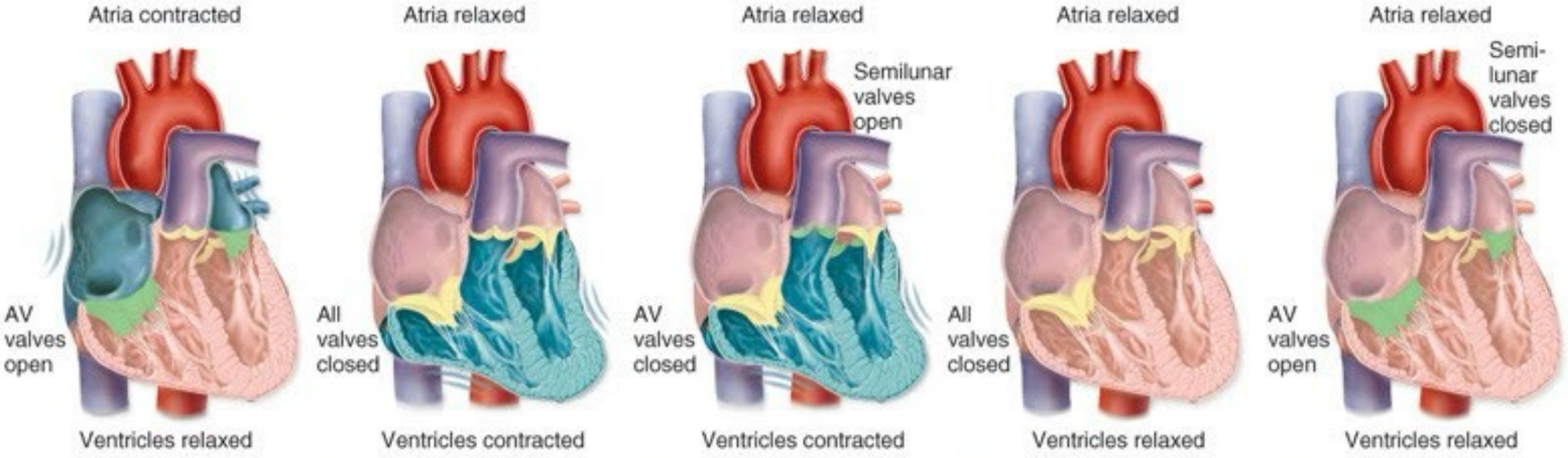
Diastole

- Isovolumetric relaxation (0.12sec)– early diastole
  - Ventricles relax
  - Intraventricle pressure to decrease rapidly.
  - Backflow of blood in aorta and pulmonary trunk closes semilunar valves
  - All valves are closed Dub sound

- **Dicrotic notch** – brief rise in *aortic pressure* caused by backflow of blood rebounding off semilunar valves Aortic valve close → Backflow blood → يتجمع
- For another 0.03-0.06 sec ventr. Continue to relax. Volume do not change (isovolumic relaxation)
- Pressure decrease rapidly back to their low diastolic levels.
- Then AV valves open to begin new cycle----- rapid inflow.

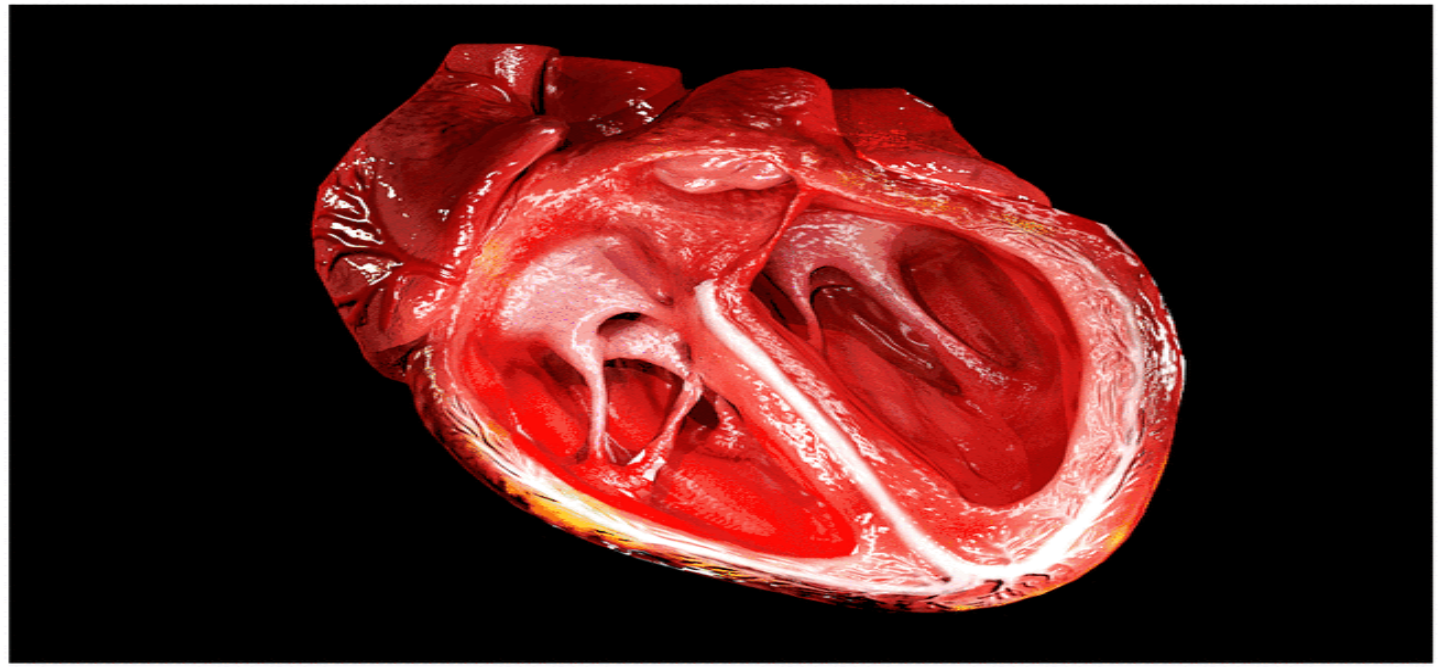

START
① Late diastole–both sets of chambers are relaxed and ventricles fill passively.
② Atrial systole–atrial contraction forces a small amount of additional blood into ventricles.
③ Isovolumic ventricular contraction–first phase of ventricular contraction pushes AV valves closed but does not create enough pressure to open semilunar valves.
④ Ventricular ejection–as ventricular pressure rises and exceeds pressure in the arteries, the semilunar valves open and blood is ejected.
⑤ Isovolumic ventricular relaxation–as ventricles relax, pressure in ventricles falls, blood flows back into cups of semilunar valves and snaps them closed.
Ventricular diastole
Atrial systole
Artial diastole
Ventricular systole

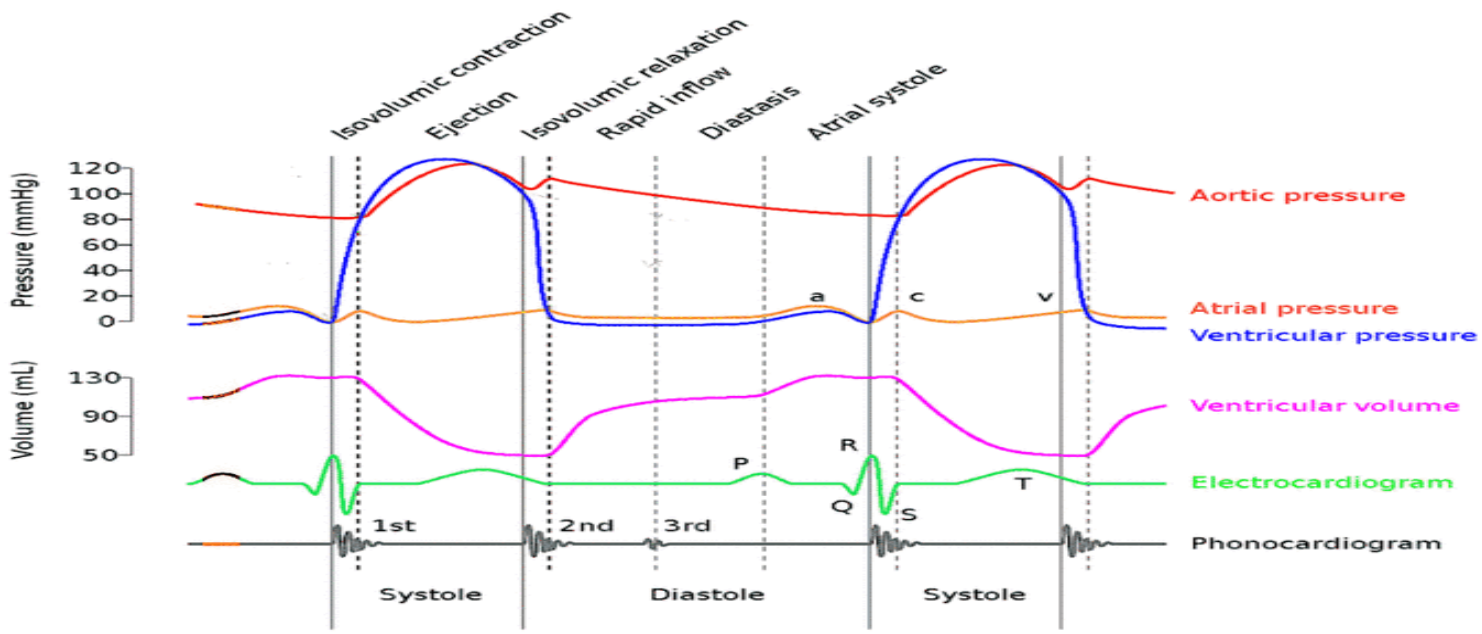
Structure \ Phase	Atrial systole	Early ventricular systole ⟷ Late ventricular systole	Early ventricular diastole ⟷ Late ventricular diastole
Atria	Contract	Relax	Relax
Ventricles	Relax	Contract	Relax
AV valves	Open	Closed	Open
Semilunar valves	Closed	Open	Closed

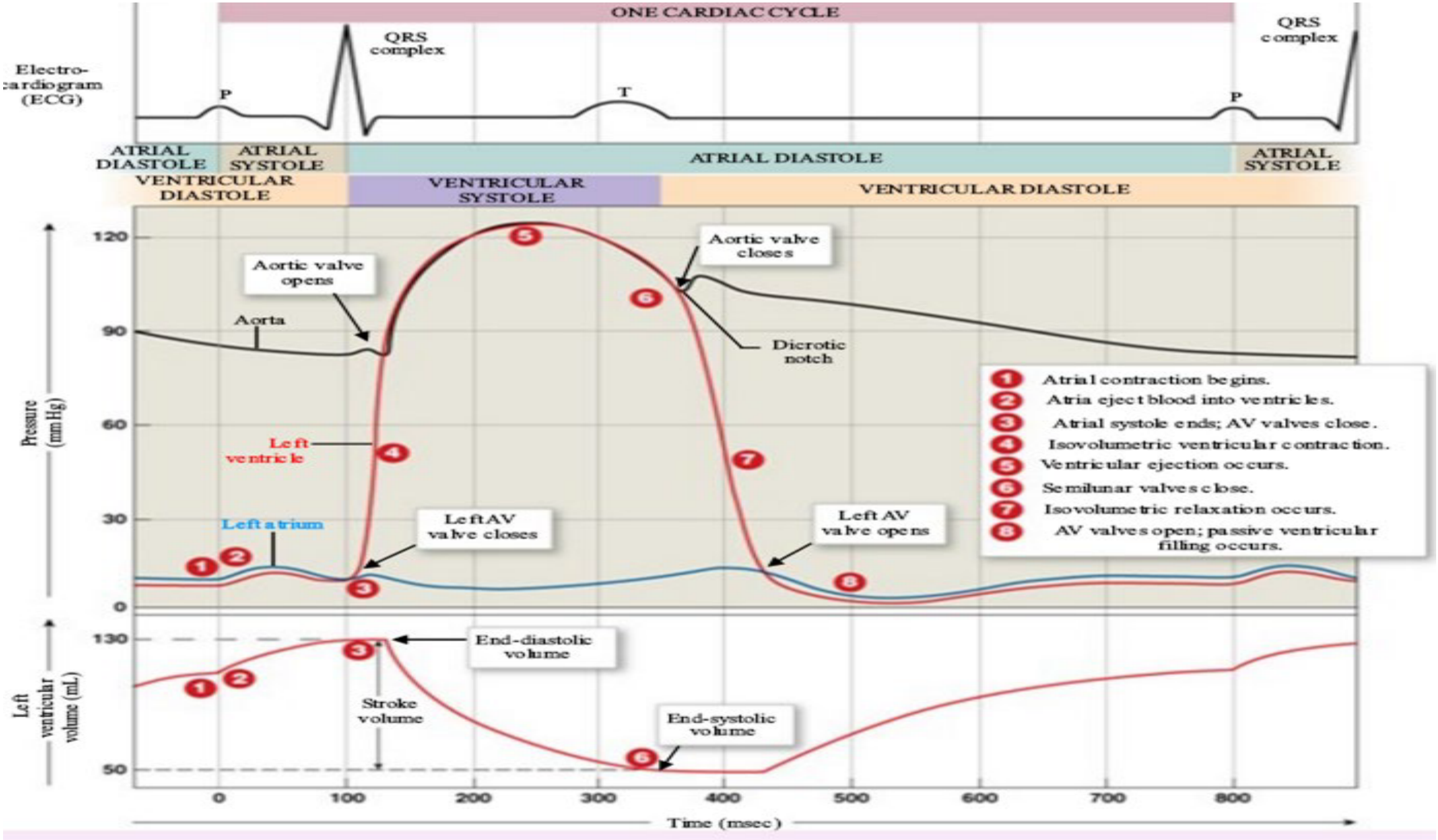


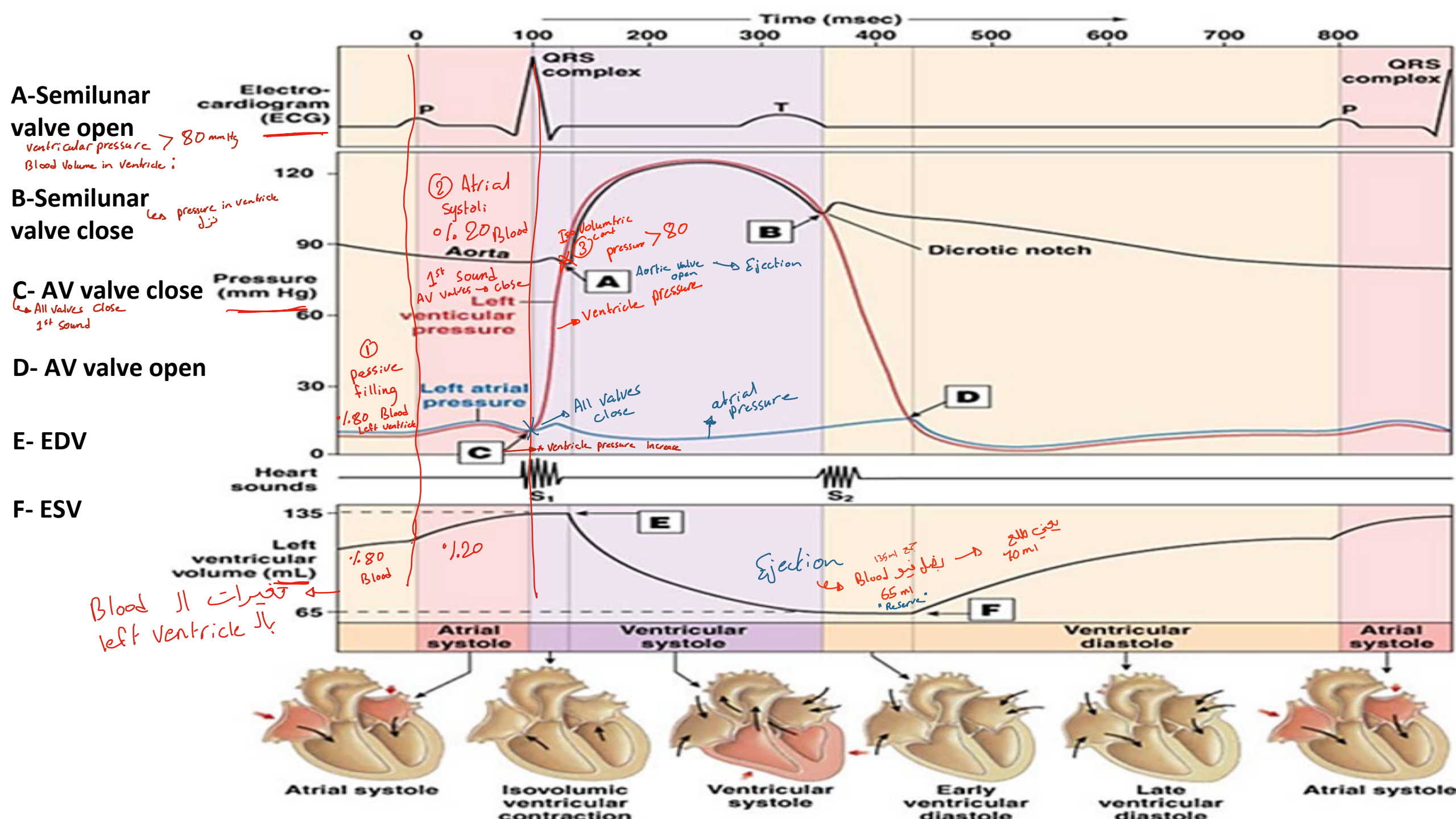
1. **Atrial systole**
   Atria contract, AV valves open, semilunar valves closed
2. **Early ventricular systole**
   Atria relax, ventricles contract, AV valves forced closed, semilunar valves still closed
3. **Late ventricular systole**
   Atria relax, ventricles contract, AV valves remain closed, semilunar 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

Cardiac Cycle





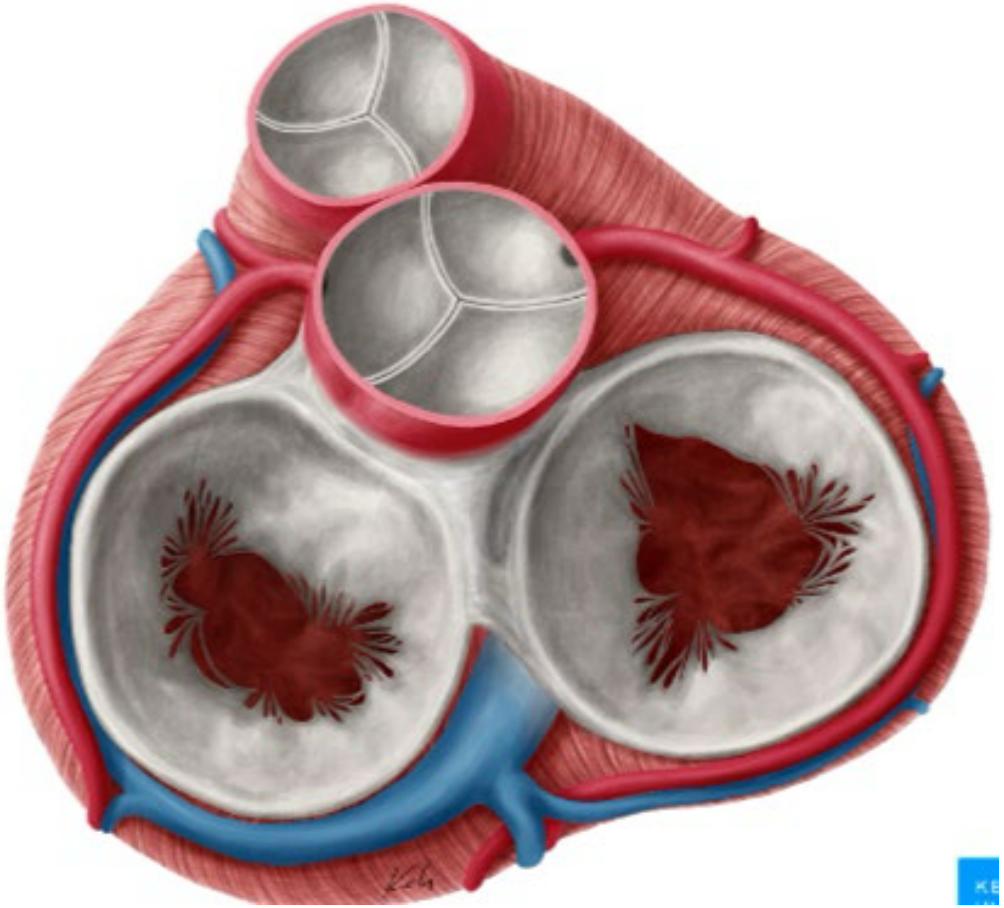

ONE CARDIAC CYCLE
Electro-cardiogram (ECG)
QRS complex
P
T
P
QRS complex
ATRIAL DIASTOLE
ATRIAL SYSTOLE
ATRIAL DIASTOLE
ATRIAL SYSTOLE
VENTRICULAR DIASTOLE
VENTRICULAR SYSTOLE
VENTRICULAR DIASTOLE
Pressure (mm Hg)
120
90
60
30
0
Aortic valve opens
Aorta
Aortic valve closes
Dicrotic notch
Left ventricle
Left atrium
Left AV valve closes
Left AV valve opens
1 Atrial contraction begins.
2 Atria eject blood into ventricles.
3 Atrial systole ends; AV valves close.
4 Isovolumetric ventricular contraction.
5 Ventricular ejection occurs.
6 Semilunar valves close.
7 Isovolumetric relaxation occurs.
8 AV valves open; passive ventricular filling occurs.
Left ventricular volume (mL)
130
50
End-diastolic volume
Stroke volume
End-systolic volume
0
100
200
300
400
500
600
700
800
Time (msec)

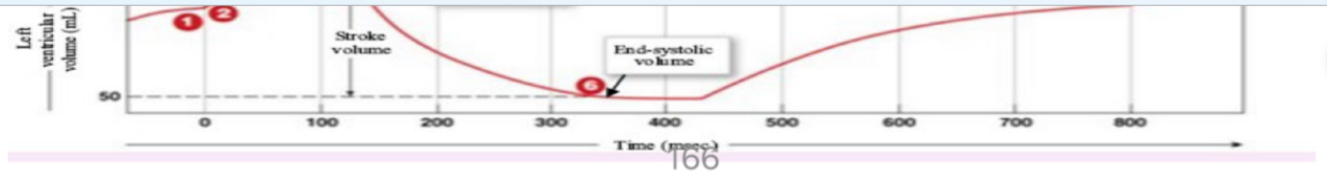

A-Semilunar valve open
ventricular pressure > 80 mmHg
Blood Volume in Ventricle :
B-Semilunar valve close
less pressure in ventricle
C- AV valve close
All valves close
1st sound
D- AV valve open
E- EDV
F- ESV
Time (msec)
0
100
200
300
400
500
600
700
800
Electro-cardiogram (ECG)
QRS complex
P
T
QRS complex
P
120
90
60
30
0
Pressure (mm Hg)
Aorta
Left ventricular pressure
Left atrial pressure
Dicrotic notch
A
B
C
D
② Atrial Systoli
٪20 Blood
③ Isovolumetric cont
pressure > 80
Aortic valve open
Ejection
1st sound
AV valves close
Ventricle pressure
① passive filling
٪80 Blood Left ventricle
All valves close
atrial pressure
Ventricle pressure increase
Heart sounds
S1
S2
135
65
Left ventricular volume (mL)
E
F
٪80 Blood
٪20
Ejection
Blood 135ml
65 ml Reserve
70 ml
Blood تغيرات ال left ventricle بال
Atrial systole
Ventricular systole
Ventricular diastole
Atrial systole
Atrial systole
Isovolumic ventricular contraction
Ventricular systole
Early ventricular diastole
Late ventricular diastole
Atrial systole

* ESV = 65 ml "End Systole Volume"

* EDV = 135 ml "End dystole Volume"

* SV = EDV − ESV
= 70 ml





166

A-Semilunar valve open

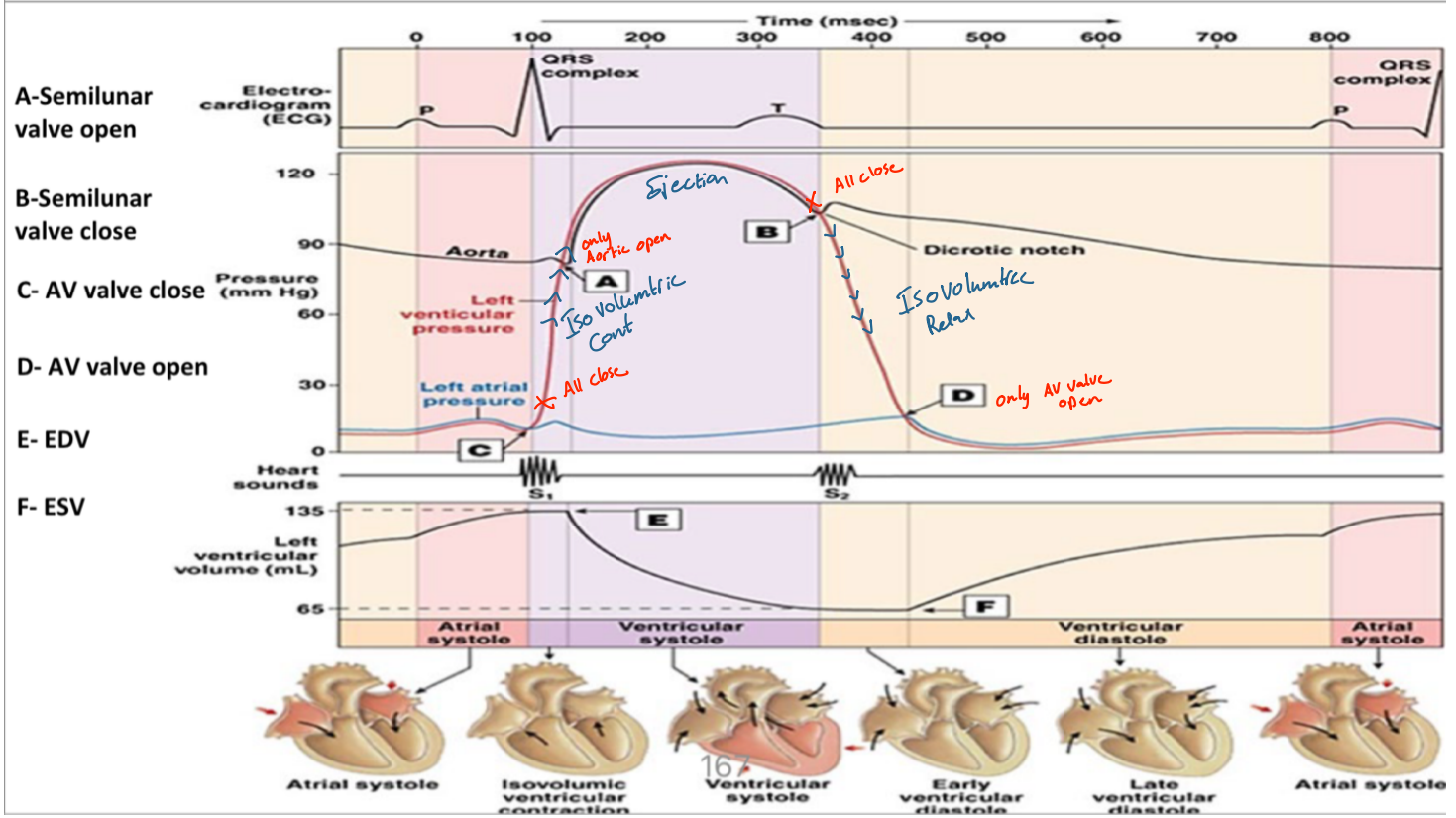
B-Semilunar valve close

C- AV valve close

D- AV valve open

E- EDV

F- ESV

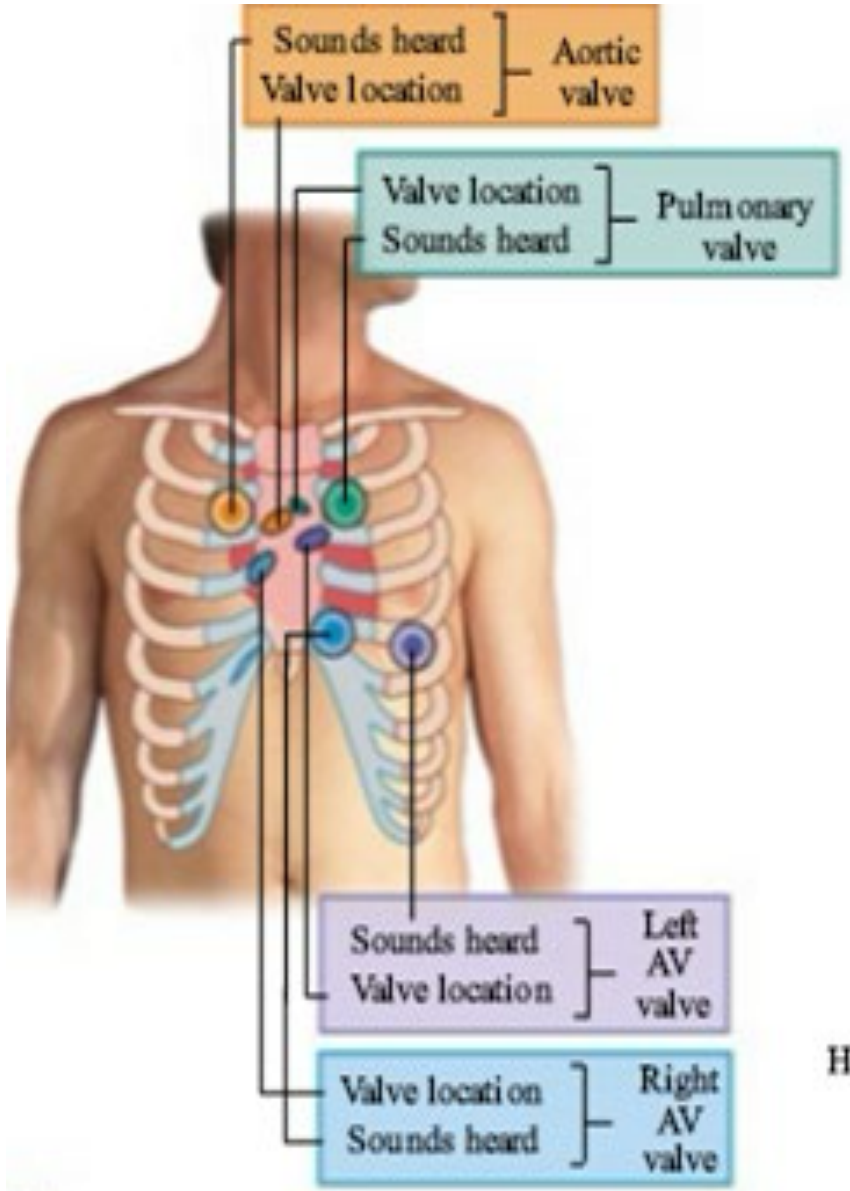


167

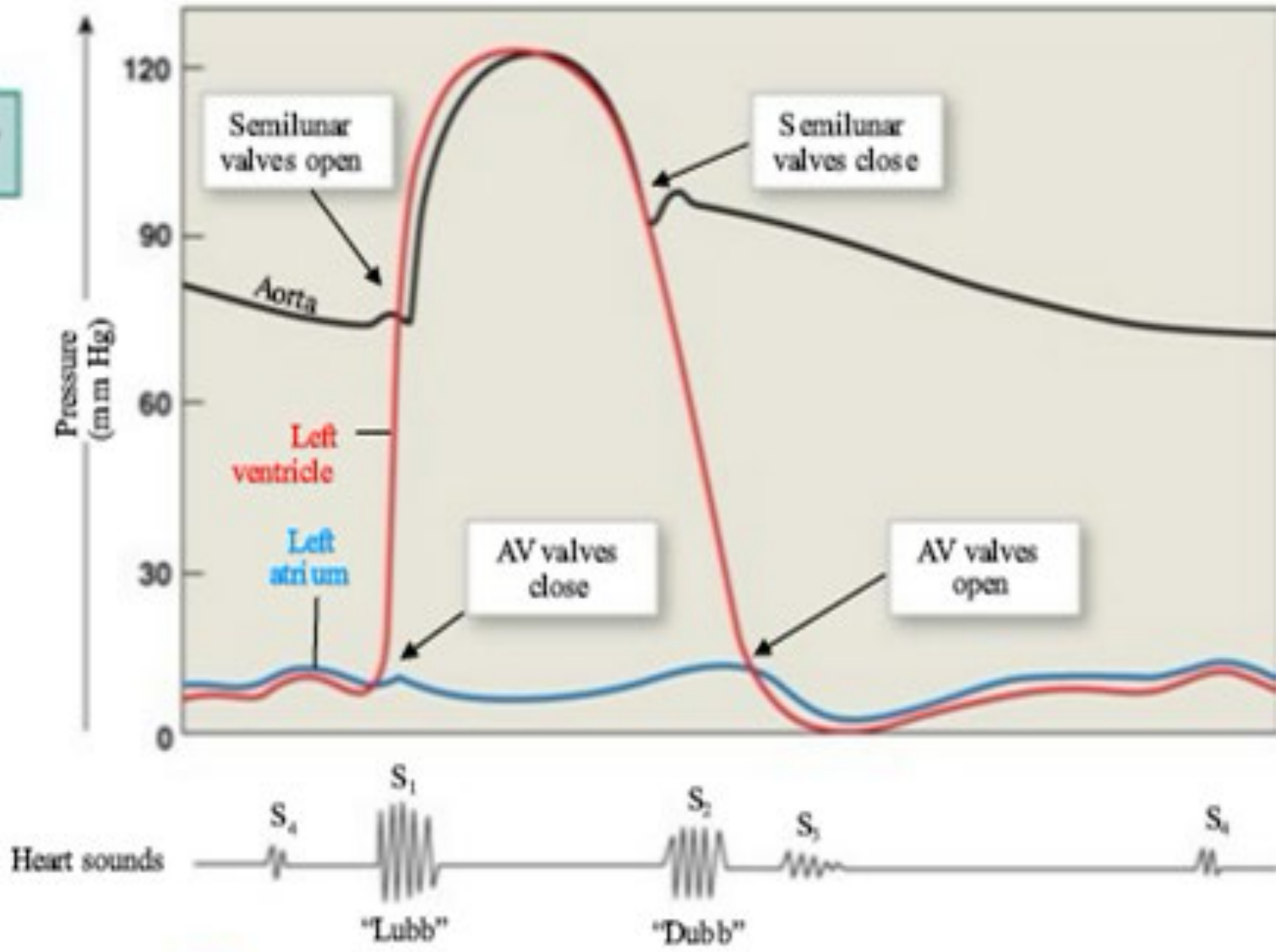
	Pressure (mmHg)
Right Atrium	0 – 4
Right Ventricle	25 systolic; 4 diastolic
Pulmonary Artery	25 systolic; 10 diastolic
Left Atrium	8 – 10
Left Ventricle	120 systolic; 10 diastolic
Aorta	120 systolic; 80 diastolic

Heart Sounds

- Closing of valves and rushing of blood through heart → characteristic heart sounds heard during auscultation with stethoscope
  - AV valves close = "lubb" **(S1)**
  - Semilunar valves close = "dubb" **(S2)**
  - S3 and S4 are sounds of blood flowing through heart



a Placements of a stethoscope for listening to the different sounds produced by individual valves



b The relationship between heart sounds and key events in the cardiac cycle

First heart sound:

- It is produced during isometric contraction and earlier part of ejection period.
- It resembles spoken word 'LUBB'.

Characteristics:

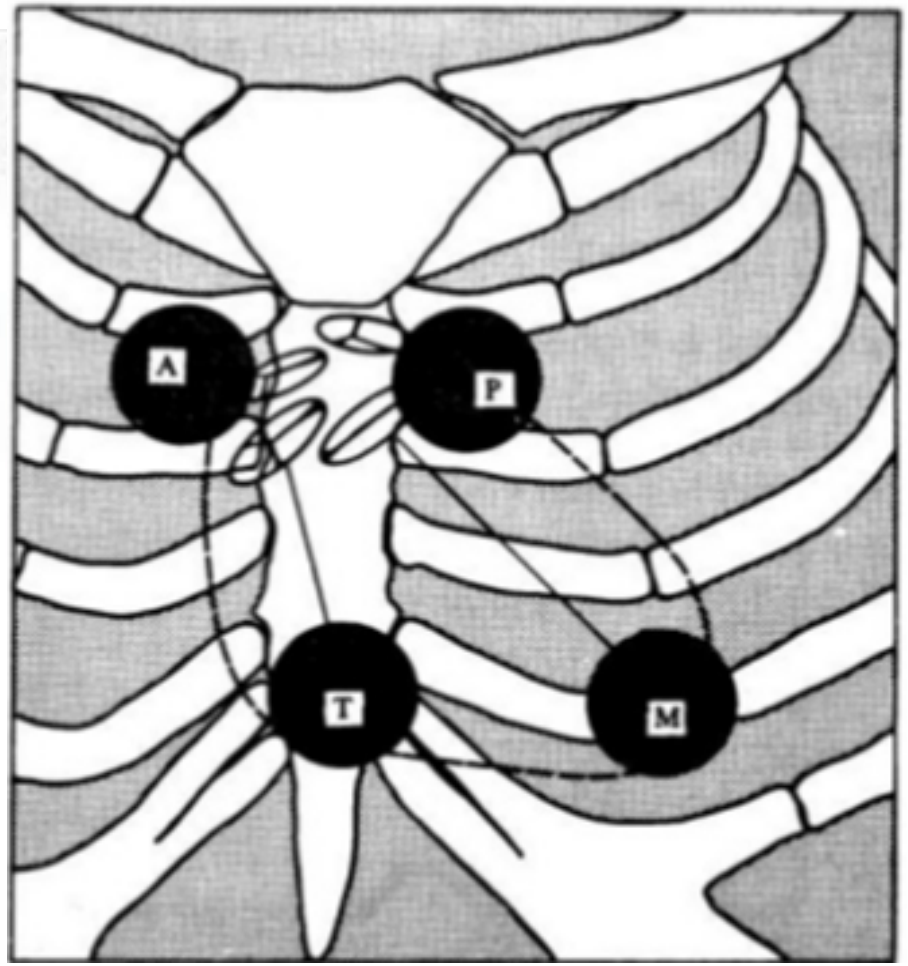
- It is long, soft, low pitched sound.
- Duration of this sound is 0.10 – 0.17 sec

Causes:

- It mainly occurs due to sudden closure of atrioventricular valves.

First heart sound and ECG:

- It coincides with peak of 'R' wave of ECG



Second heart sound:

- It produces during the onset of diastole.
- It resembles the spoken word 'DUBB'

Characteristics:

- It is short, sharp and high pitched sound.
- Duration of this sound is 0.10 – 0.14 seconds.

Causes:

- It mainly produces during sudden closure of the semilunar valves.

Second heart sound and ECG:

- It coincides with the 'T' wave of ECG.

Third heart sound:

- It is produced during rapid filling period of the cardiac cycle.

Characteristics:

- It is short and low pitched sound.
- Duration of this sound is 0.07 – 0.10 seconds.

Causes:

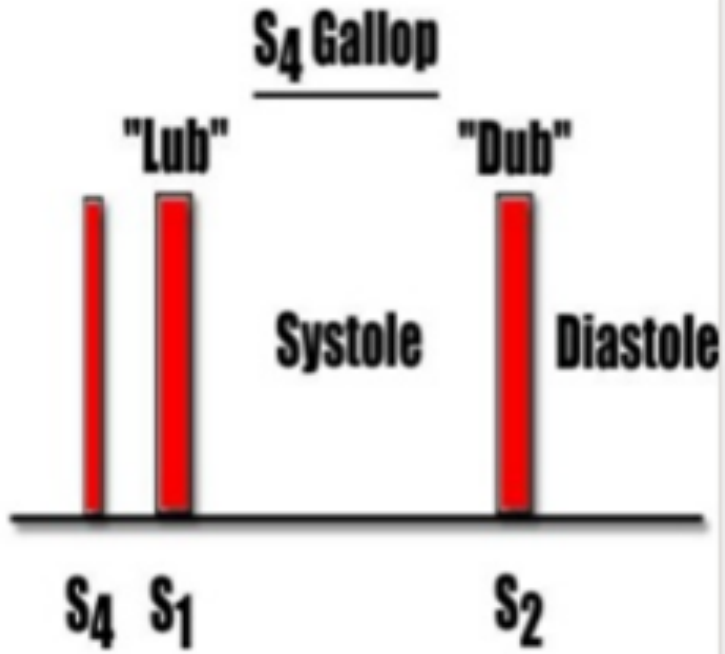
- It is produced due to the vibrations which set up in ventricular wall, due to rushing of blood in to ventricles during rapid filling phase.

Third heart sound and ECG:

- It appears between ‘T’ and ‘P’ waves of ECG.

Triple heart sound:

- In some conditions like myocardial infarction and severe hypertension, the intensity of third and fourth heart sounds increases and they could be heard as a single sound along with the first and second heart sound. This is known as triple heart sound.



Importance of the heart sounds:

- Heart sound generally alters during cardiac diseases involving the valves of the heart. That's why heart sounds are having important diagnostic value.

Cardiac Output (CO) and Reserve

- CO is the amount of blood pumped by each ventricle in one minute
- CO is the product of heart rate (HR) and stroke volume (SV)
- HR is the number of heart beats per minute
- SV is the amount of blood pumped out by a ventricle with each beat
- Cardiac reserve is the difference between resting and maximal CO (60ml)

$SV = 70\ ml/Beat$

$CO = SV \times HR$

(EDV - ESV) — Heart rate

ml/Beat — 5 l/minute

$= ml/min$

5000 ml/min

كمية الدم اللي بتطلع بالدقيقة

ESV: نهاية الدم اللي فلوصل بعد الـ systolic

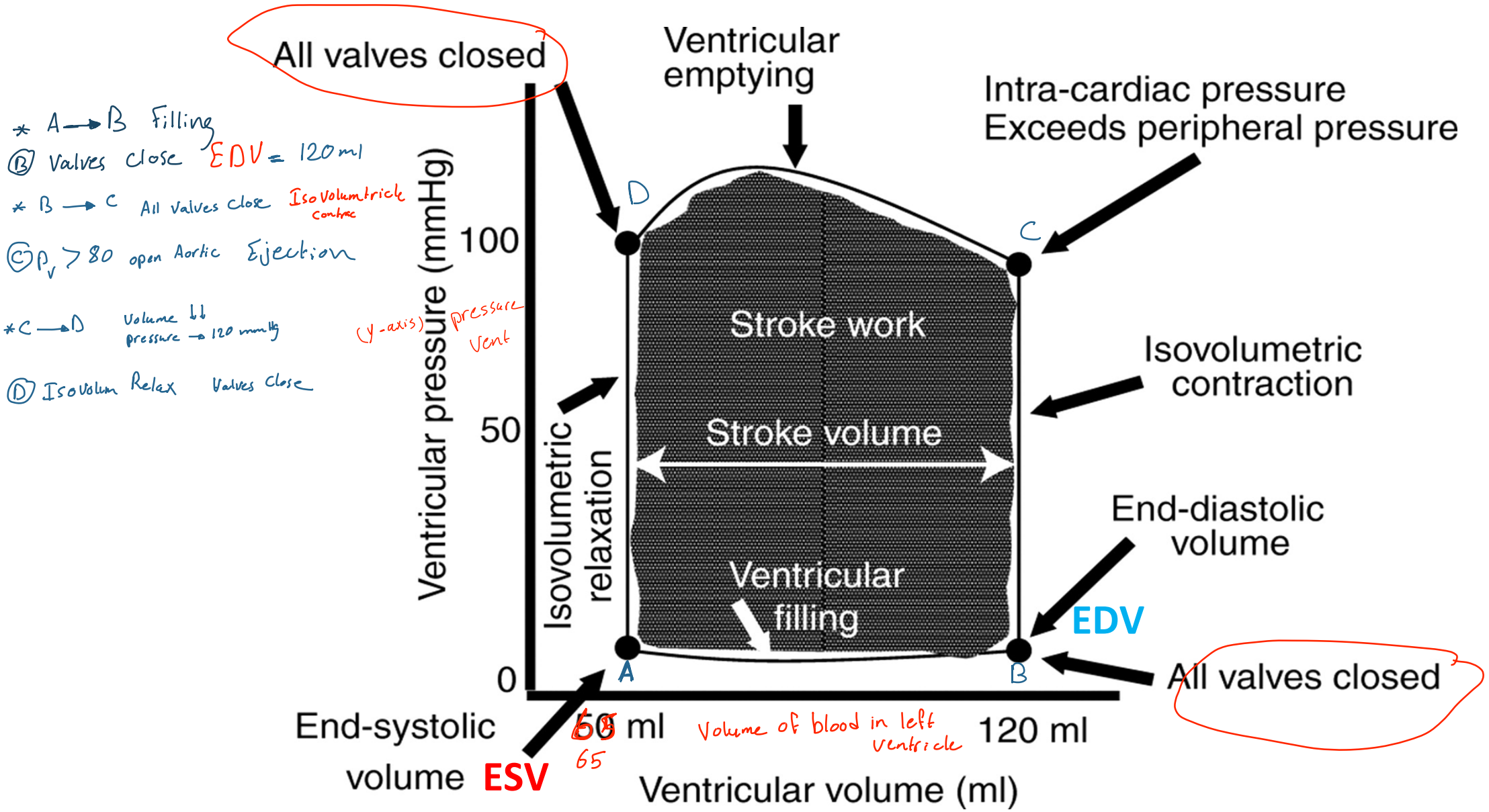
Regulation of Stroke Volume

- SV = end diastolic volume (EDV) minus end systolic volume (ESV) 70 ml
- EDV = amount of blood collected in a ventricle during diastole 135 ml
- ESV = amount of blood remaining in a ventricle after contraction 65 ml

Cardiac Output: Heart Rate X Stroke Volume

- The volume of blood pumped by the heart per unit time.
- Around 5L :
  (72 beats/min × 70 ml/beat = 5040 ml)
- Rate: beats per minute (bpm)
- Stroke volume: ml per beat
  - EDV – ESV

left ventricular pressure volume changes



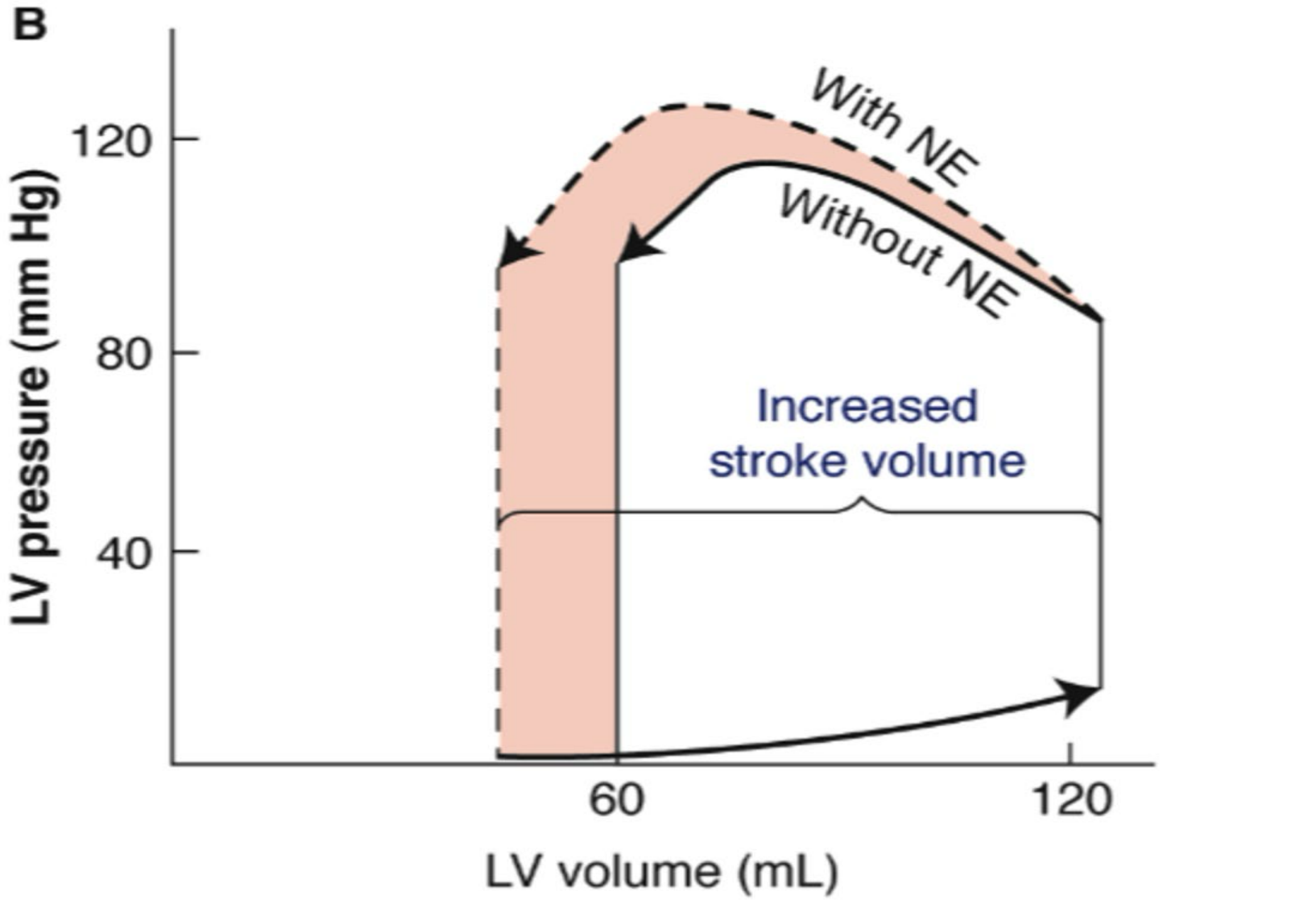
- **End –Diastolic volume** during diastole, normal ventricular filling increases the volume of each ventricle to about **110 to 120 ml**
- **End- Systolic volume** Remaining volume in each ventricle ~50 ml
- **Stroke volume output** As ventricles empty during systole, volume decreases about 70 ml, which is called stroke volume output
- **Ejection Fraction** fraction of end diastolic volume that is ejected is called ejection fraction, usually equal to about 60%

$$\text{EJECTION FRACTION} = \frac{\text{STROKE VOLUME (END DIASTOLIC VOLUME-END SYSTOLIC VOLUME)}}{\text{END-DIASTOLIC VOLUME}} = \frac{SV}{EDV} \approx \%60$$

➢ **When heart contracts strongly**, **ESV** can be decreased to as little as 10 to 20 ml. conversely, when large amount of blood flows into ventricles during diastole, ventr. **EDV** can become as great as 150 to 180 ml ≈

* when Exersice
ESV ↓ decrease

SV & CO ↑ Increase



Regulation of the heart

Dr Safa Abdul Ghani

Regulators of the Heart: Factors Influencing Stroke Volume

- Stroke volume: the volume of blood pumped by the ventricle per contraction and is directly proportional to the force generated by cardiac muscle during contraction.
- The force of ventricular contraction depends on two parameters: the length of muscle fibres at the beginning of contraction and the contractility of the heart
- Venous return:
  - Skeletal pumping.
  - Pressure changes in the abdomen and thorax during breathing.
  - Sympathetic innervation of the veins.

VR ↑ → EDV ↑ → SV ↑

Frank-Starling law of the heart:

the heart pumps all the blood that returns to it

According to Frank-Starling law, stroke volume increases as EDV increases.

EDV is determined by venous return, which is the amount of blood that enters the heart from the venous circulation.

↑SV ↑VR "Venous return"

Venous return depends on 3 factors:

1. Skeletal muscle pump
2. Respiratory pump
3. Sympathetic innervation of veins

* كل ما تنفس منساعد نفع دم القلب

↑CO = ml/min

= ↑SV x ↑HR

= (EDV - ESV) x HR = 5000 ml/min

↑SV ⟹ ↑VR

Frank-Starling Law of the Heart

- Preload, or degree of stretch, of cardiac muscle cells before they contract is the critical factor controlling stroke volume
- exercise increase venous return to the heart, increasing SV
- Blood loss and extremely rapid heartbeat decrease SV and venous return

- Preload – amount ventricles are stretched by contained blood

The degree of myocardial stretch before contraction begins is called the preload

- Afterload – back pressure exerted by blood in the large arteries leaving the heart

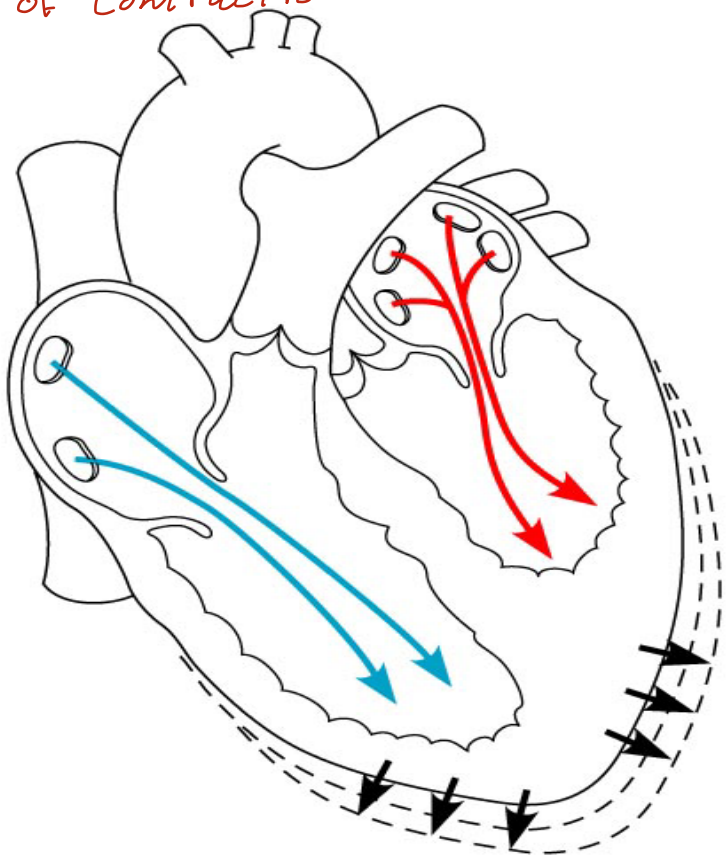
↳ Increas Force of Contraction

↑ preload "Stretch"

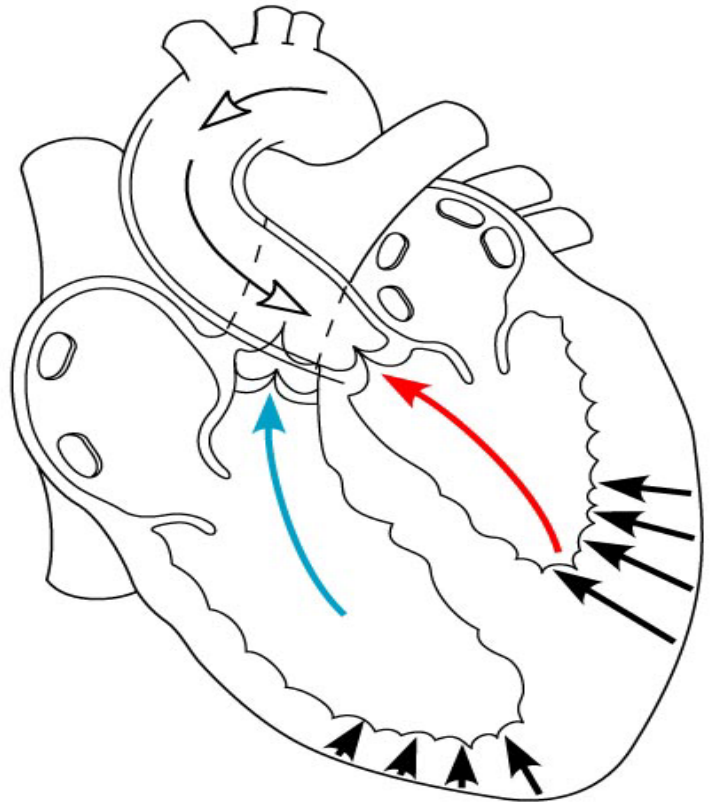
↑ EDV

↑ SV

↑ CO



(a) Preload



(b) Afterload

EJECTION FRACTION

EJECTION FRACTION = **STROKE VOLUME (END DIASTOLIC VOLUME-END SYSTOLIC VOLUME)** / **END-DIASTOLIC VOLUME**

LR
↓ Ventricle compliance
↓ pericardial compliance
↓ W
. Knee

PRELOAD

Venous Return
Ventricular Compliance
Pericardial Compliance
Valvular Disease
Atrial Systole
Wall thickness

AFTERLOAD

Wall stress
Ventricular transmural pressure
Ventricular chamber radius
Ventricular Wall Thickness

Please measure BP

CONTRACTILITY

ESV AFFECTED BY

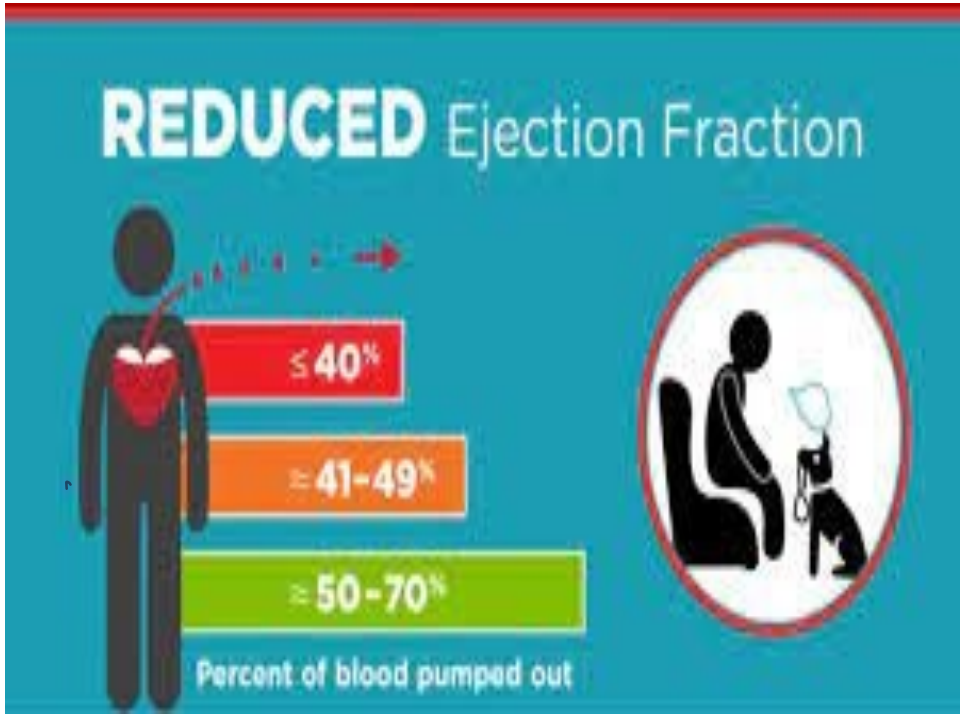
↓

AFTERLOAD
CONRACTILITY

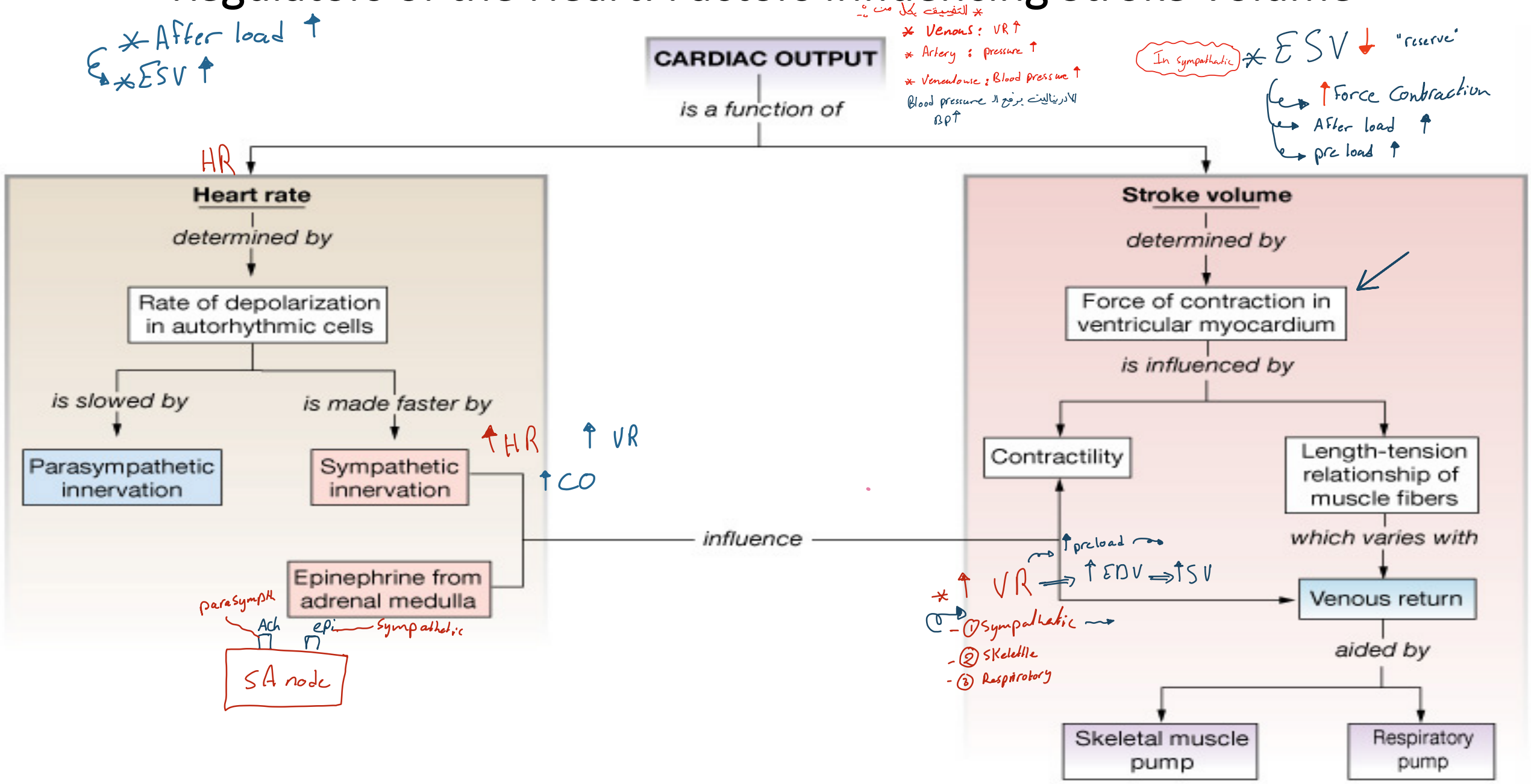
EDV AFFECTED BY

↓

PRELOAD
CONRACTILITY



Regulators of the Heart: Factors Influencing Stroke Volume

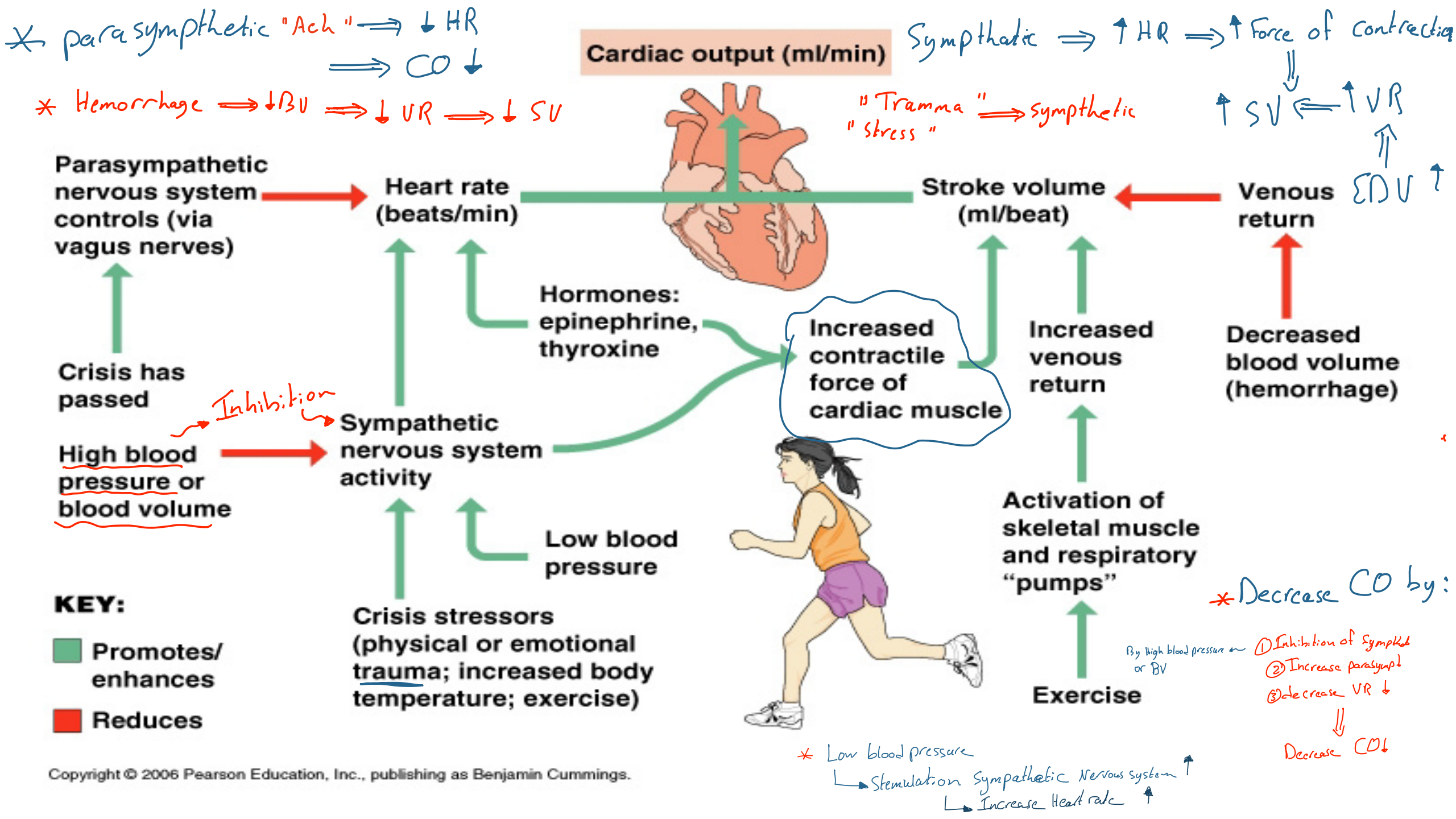


* parasympthetic "Ach" ⟹ ↓ HR ⟹ CO ↓

* Hemorrhage ⟹ ↓BV ⟹ ↓ VR ⟹ ↓ SV

Sympthatic ⟹ ↑ HR ⟹ ↑ Force of contractio ⟹ ↑ SV ⟸ ↑ VR ⟸ ↑ EDV

" Tramma " ⟹ sympthetic
" Stress "



* Decrease CO by:

By High blood pressure or BV
① Inhibition of Sympath
② Increase parasympt
③ decrease VR ↓
⇓
Decrease CO↓

* Low blood pressure
↳ Stemulation Sympathetic Nervous system ↑
↳ Increase Heart rate ↑

* High blood pressure
  - Inhibition Sympathetic N s ↓
    - Decrease Heart rate ↓

Extrinsic Innervation of the Heart

- Heart is stimulated by the sympathetic cardioacceleratory center
- Heart is inhibited by the parasympathetic cardioinhibitory center

Vagus nerve ⟹ هو المسيطر على القلب اكثر من ال Sympathetic

CVS

In brain Steam
- Medulla oblingata

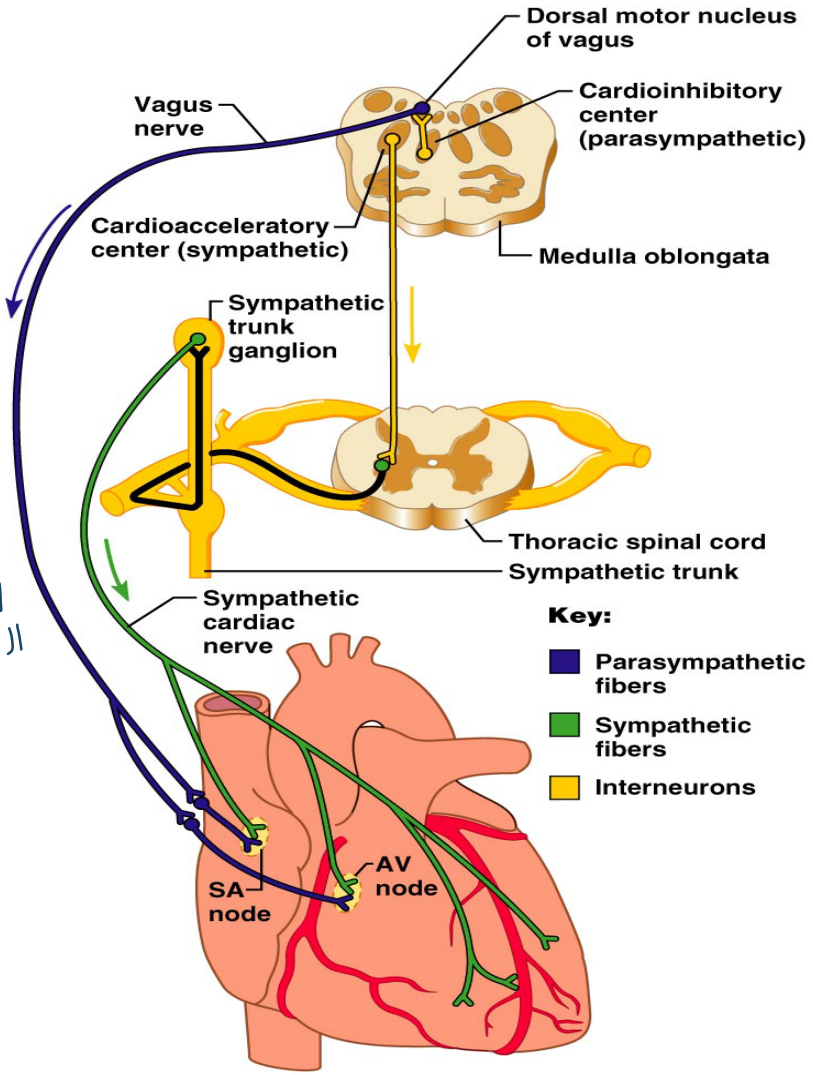


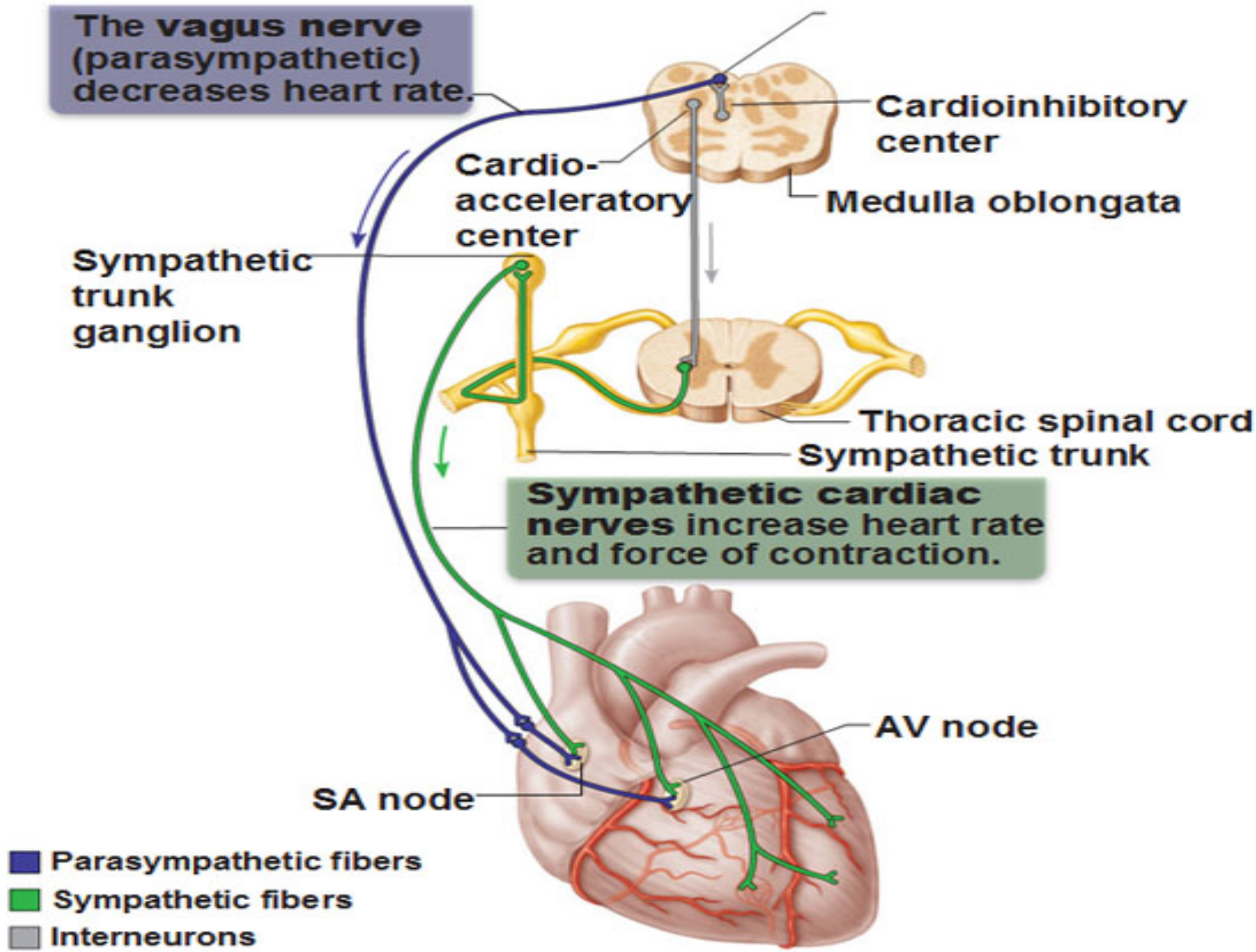
Figure 18.15

Regulation of Heart Rate: Autonomic Nervous System

- Sympathetic nervous system (SNS) stimulation is activated by stress, anxiety, excitement, or exercise
- Parasympathetic nervous system (PNS) stimulation is mediated by acetylcholine
- PNS dominates the autonomic stimulation, slowing heart rate and causing vagal tone

Vagus nerve

External Innervation



Cardio-vascular regulation

- Middle Group of Neurons (MGN)

(hypothalamus)

بتأثر على الـ CIC وهما على Medull oblins

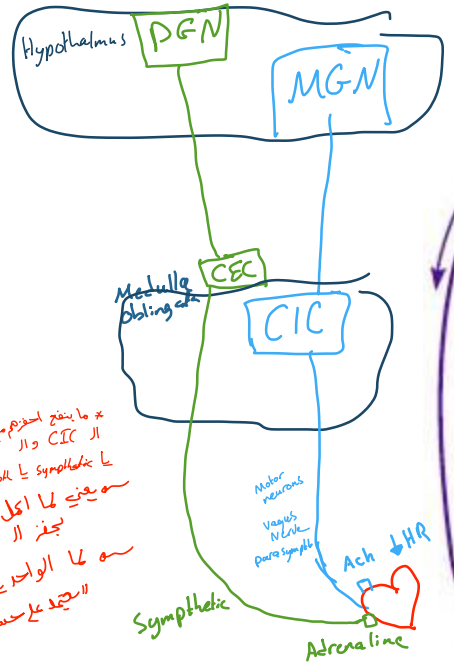
Cardio-inhibitory centres (CIC)

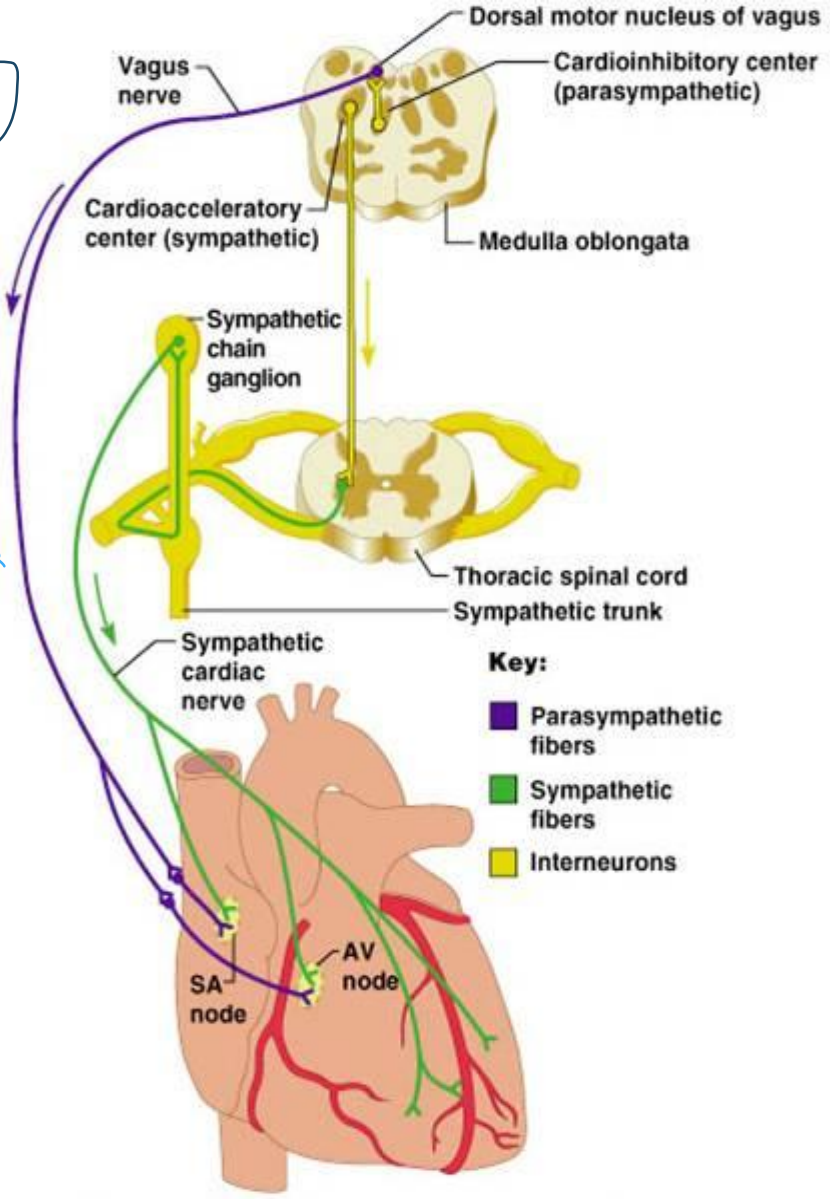
(Medulla Oblongata)

Connected to Parasympathetic nerve through Efferent Vagus (release of Ach neurotransmitter)

Muscarinic receptors on SA node

Stimulation = ↓ HR & ↓ BP





Posterior Group of Neurons (PGN)

(hypothalamus)

Cardio-acceleratory centres (CEC)

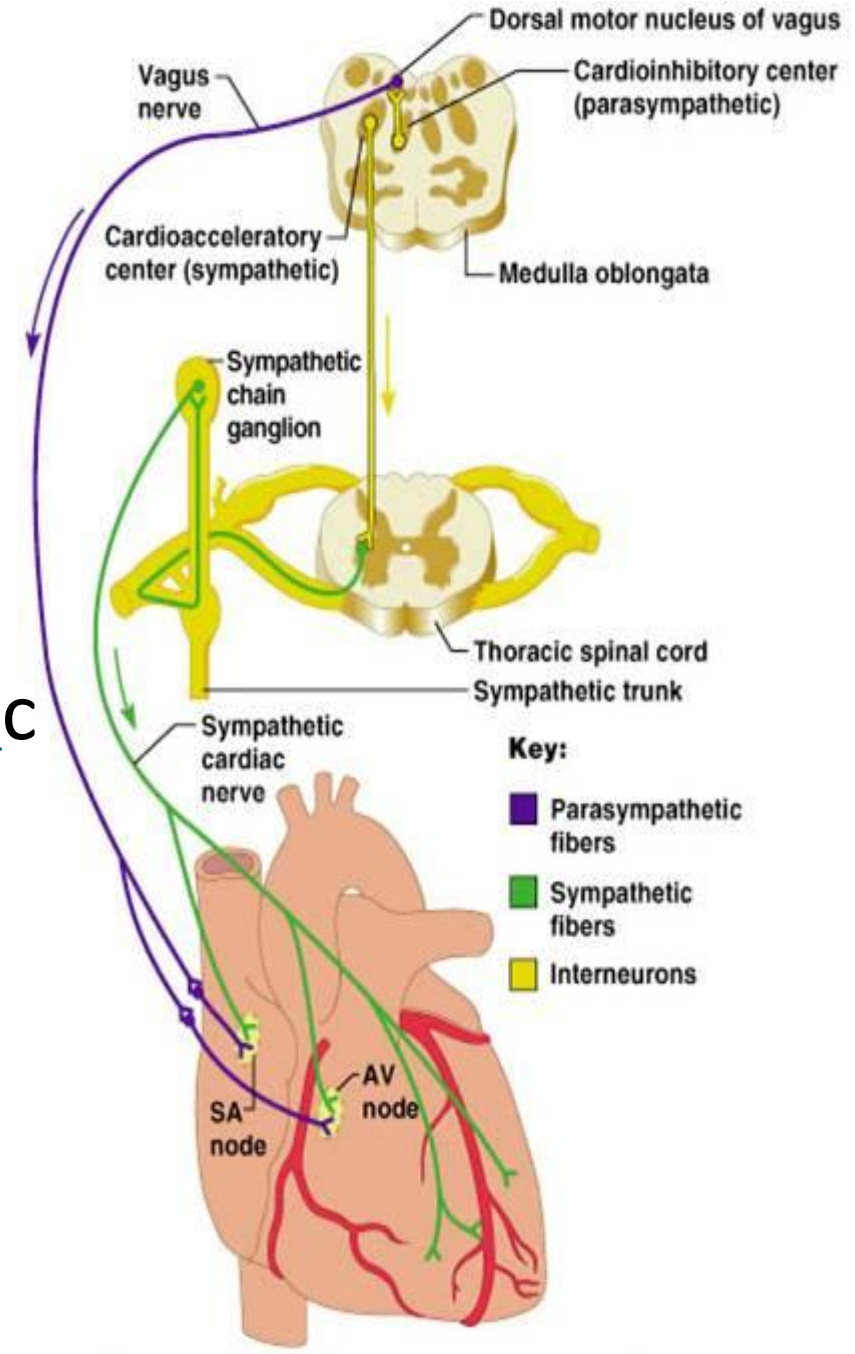
(Medulla Oblongata)

Connected to Sympathetic nerve through cardiac plexus (release of adrenaline neurotransmitter)

OR Epinphrene / Norepinphrene

Beta receptors on SA node

Stimulation = ⬆HR & ⬆BP



Cardio-acceleratory Reflex (Bainbridge)

1) Stimuli: initiated by increased blood in the atria (increase venous return)
2) (stretch receptors) in the right atrium and inferior Vena cava.
3) Sensory nerve: Afferent vagus from right atrium
4) Center: Stim. Of CEC & inhib. CIC
5) Motor nerves: Stim. Of symp nerve to the heart

   Inhib. Of Parasympathetic

1) Organ: Cardiac muscle depolarization
2) Response: Cardiac muscle contraction ---------increase HR

Cardio-Inhibitory Reflex

1) Stimuli: initiated by increased aortic blood pressure
2) Receptor: stretch receptors in aorta (aortic sinus)
3) Sensory nerve: Afferent vagus from Aorta
4) Center: Stim. Of CIC & inhib. CEC
5) Motor nerves: Stim. Of parasymp nerve to the heart

   Inhib. Of sympathetic

1) Organ: Cardiac muscle hyperpolarization
2) Response: Cardiac muscle relaxation ---------decrease HR

Baroreceptor
↳ In Aortic arch
& carotid sinus

Chemical Regulation of the Heart

From Adrenal gland

Thyroid gland بفرزو ال

- The hormones epinephrine and thyroxine increase heart rate

↳ ↑ HR

- Intra- and extracellular ion concentrations must be maintained for normal heart function

* يعني ال Epinphrine

ممكن يجينا كـ Neurotransmitter

من ال Sympthetic neurones

وممكن يجينا كـ Hormones

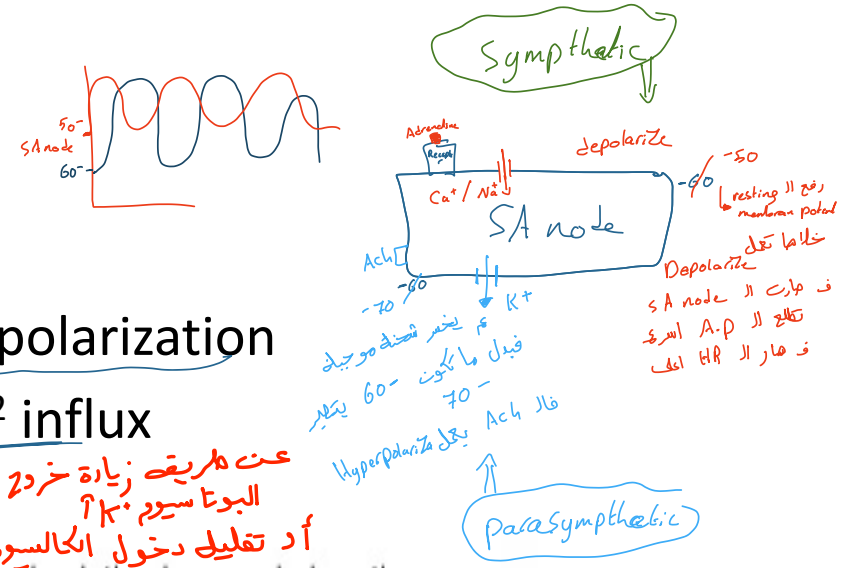
من ال Gland

Adrenal gland تفرز Hormones epinphrine

↳ بروح في ال blood

بوصل القلب وبعمل نفس ال effect اللي بعمله ال Epinphrine اللي بيجي من الأعصاب

Sympathetic and Parasympathetic



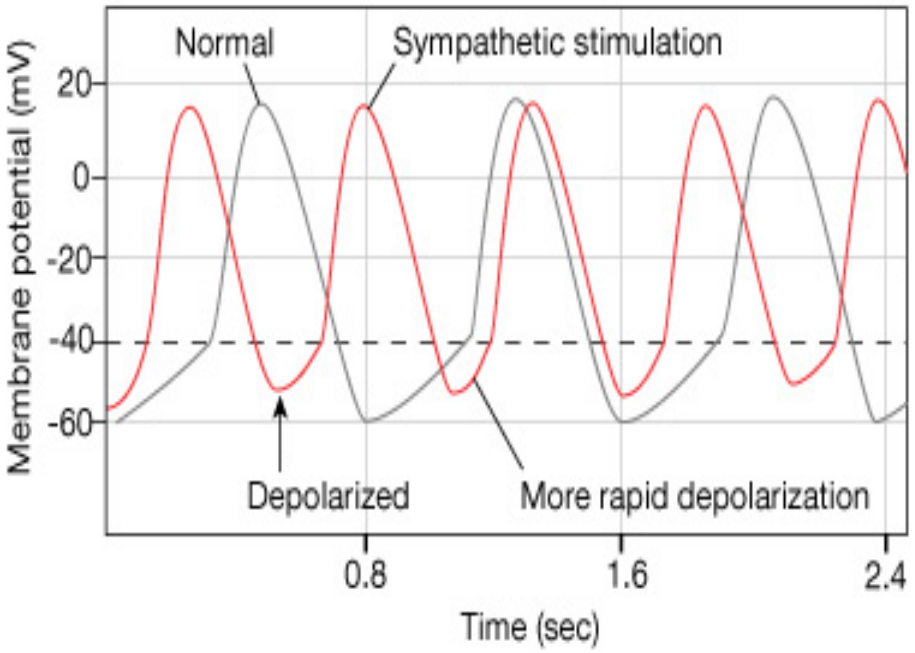
- Sympathetic – speeds heart rate by ↑ Ca^{+2}

Beta adrenergic receptors effect (Ca/ Na channels) /depolarization

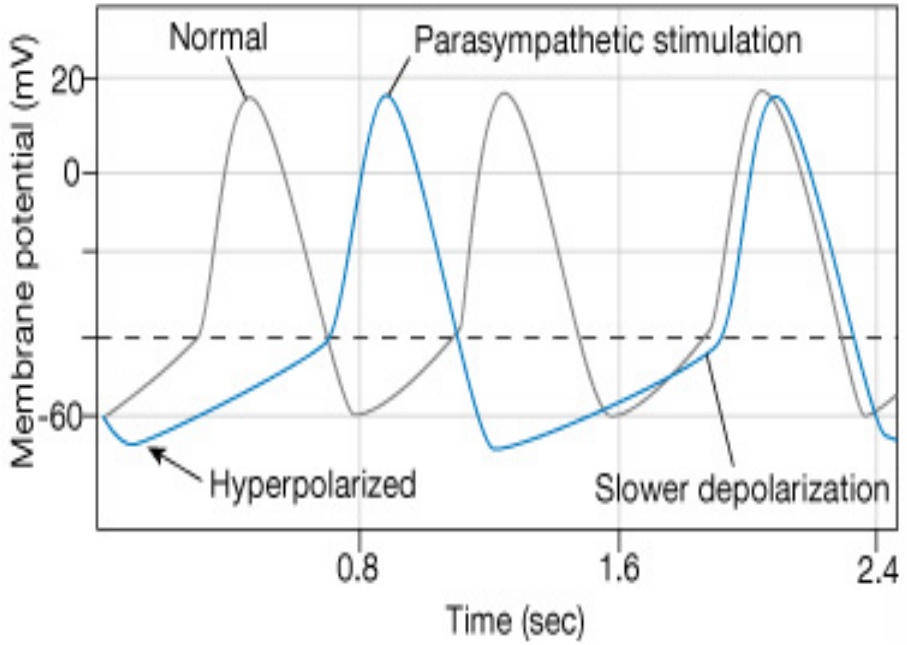
- Parasympathetic – slows rate by ↑ K+ efflux & ↓ Ca^{+2} influx

Ach receptors (opens K channels)/ hyperpolarization

(a) Sympathetic stimulation and epinephrine depolarize the autorhythmic cell and speed up the depolarization rate, increasing the heart rate.



(b) Parasympathetic stimulation hyperpolarizes the membrane potential of the autorhythmic cell and slows depolarization, slowing down the heart rate.



* Adrenaline ⟹ Depolarization
* Ach ⟹ Hyperpolarization

Heart Contractility and Norepinephrine

In Contractile Cell

GPCR → B_1 receptor

- Sympathetic stimulation releases norepinephrine and initiates a cyclic AMP second-messenger system

Adrenaline

* when norepinphrine bind in B receptor:

↑cAMP → ↑PKA → phosphorilation

Second messenger

↳ Ca^{+2} Release

↳ Force of contraction ↑ → SV ↑

↳ CO ↑

يروح على مخازن ال Ca^{+2} SR

ويعمل phosphorilation ويحفز ال Release of Ca^{+2}

ويساعد على زيادة ال Influx Ca^{+2}

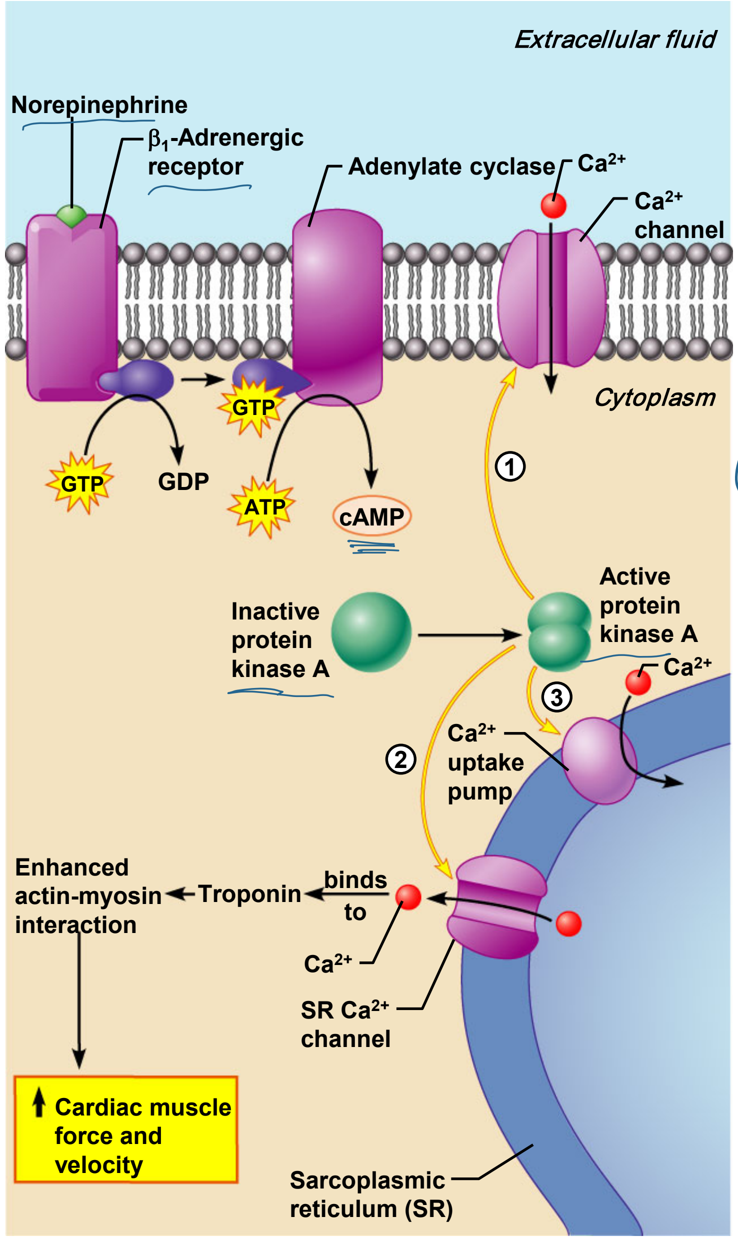


Figure 18.22

* ال Adrenaline بزيد ال CO ↑ بطريقتين :-

In SA node : CO ↑ = HR ↑

* In Contractile Cell

CO ↑ = Ca^{+2} Relase

⇓ ↑ Force of contraction

⇓ ↑ SV

⇓ ↑ CO

Heart Contractility and Norepinephrine

- Sympathetic stimulation releases norepinephrine and initiates a cyclic AMP second-messenger system

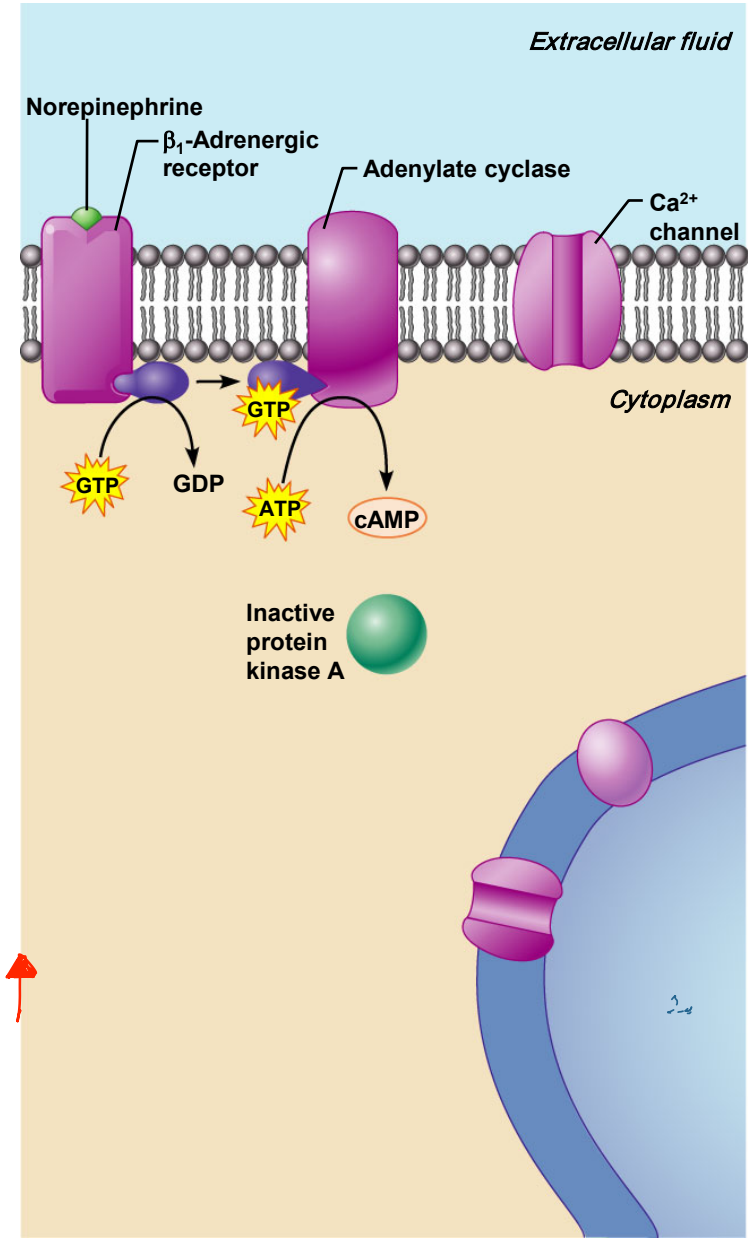


Figure 18.22

* Adrenaline ⟹ Increase preload ↑
"degree of streching"
↳ ↑ After load كمان بزيد ال *
Artery الموجود بال pressure ال " يعني بزيد

Heart Contractility and Norepinephrine

- Sympathetic stimulation releases norepinephrine and initiates a cyclic AMP second-messenger system

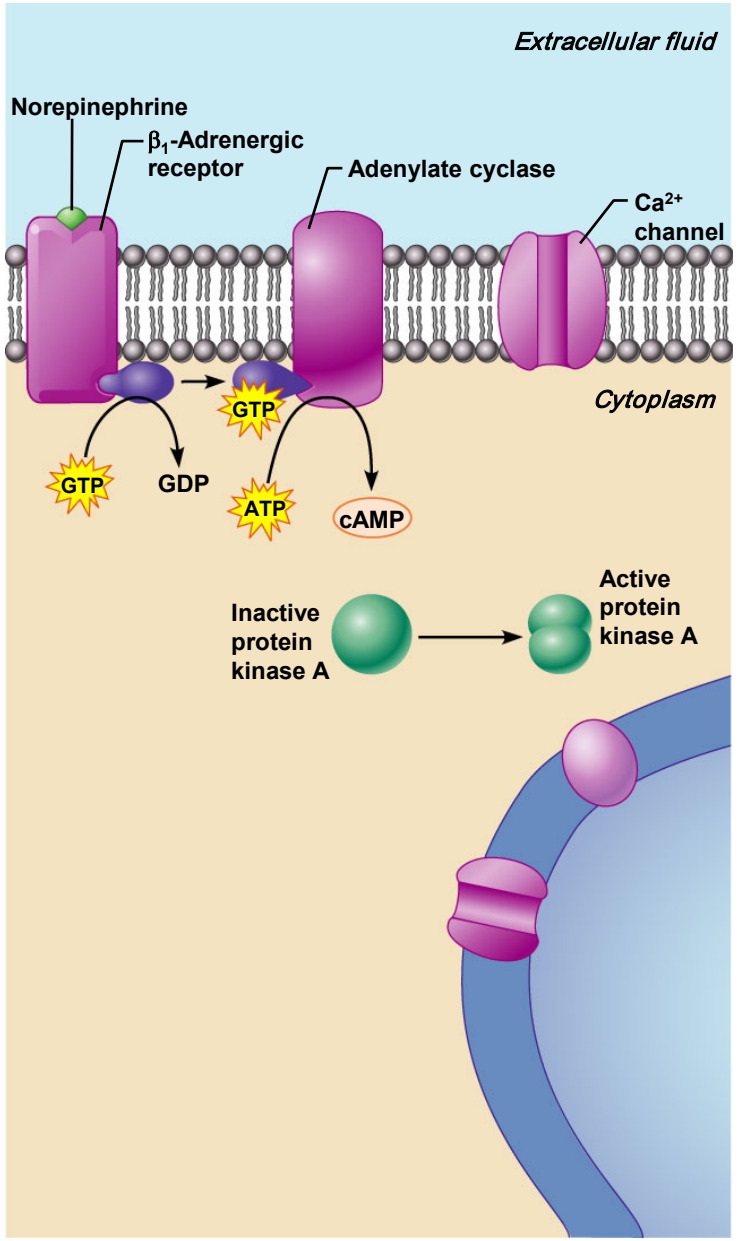


Figure 18.22

Heart Contractility and Norepinephrine

- Sympathetic stimulation releases norepinephrine and initiates a cyclic AMP second-messenger system

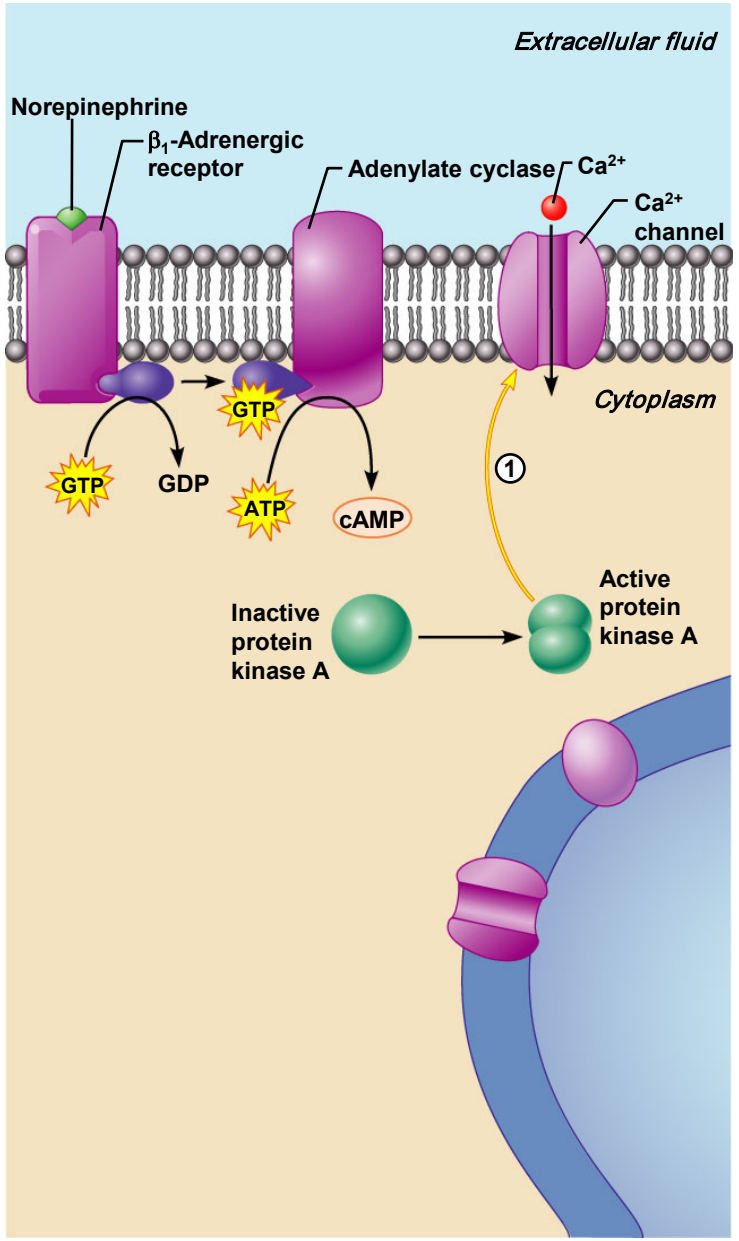


Figure 18.22

Heart Contractility and Norepinephrine

- Sympathetic stimulation releases norepinephrine and initiates a cyclic AMP second-messenger system

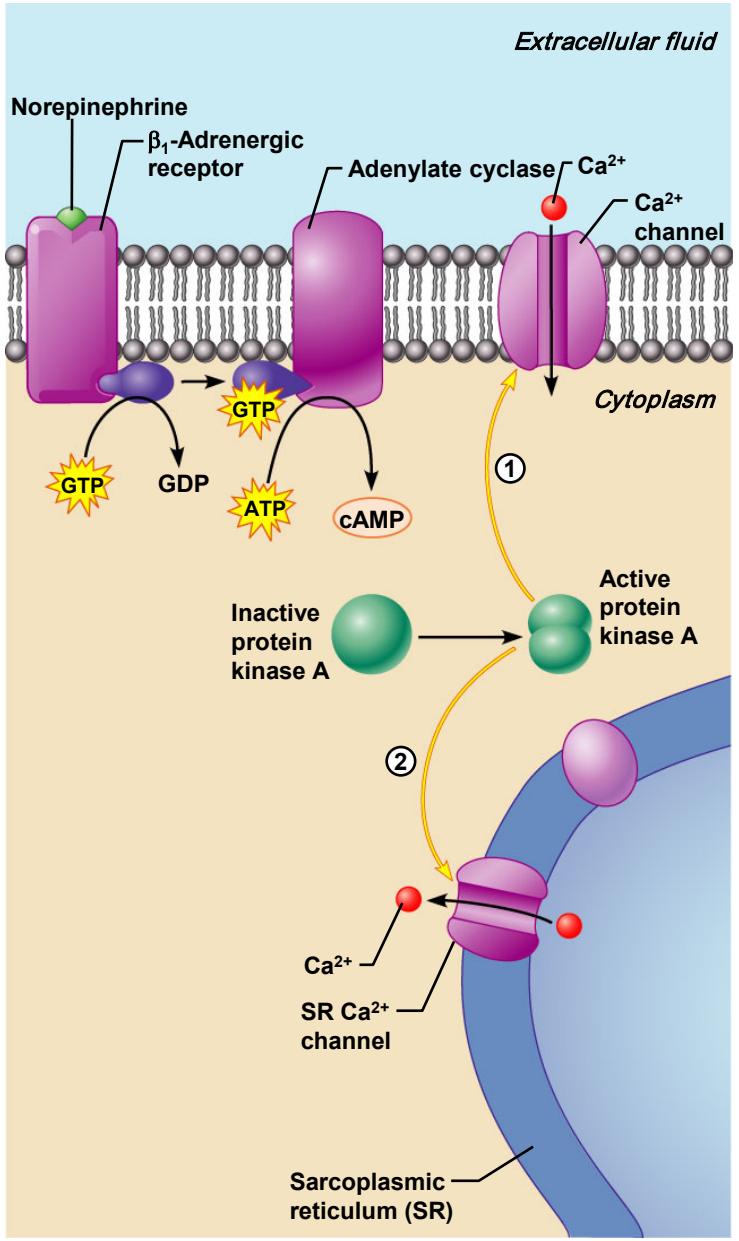


Figure 18.22

Heart Contractility and Norepinephrine

- Sympathetic stimulation releases norepinephrine and initiates a cyclic AMP second-messenger system

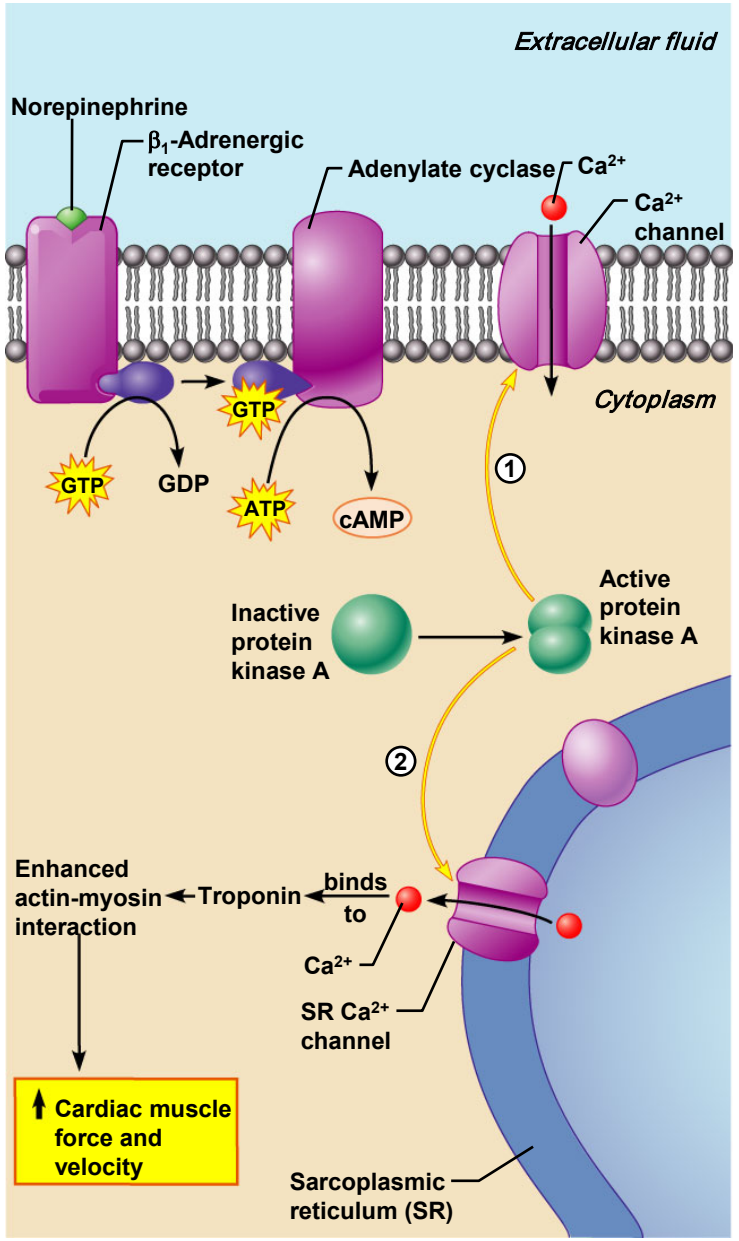


Figure 18.22

Heart Contractility and Norepinephrine

- Sympathetic stimulation releases norepinephrine and initiates a cyclic AMP second-messenger system

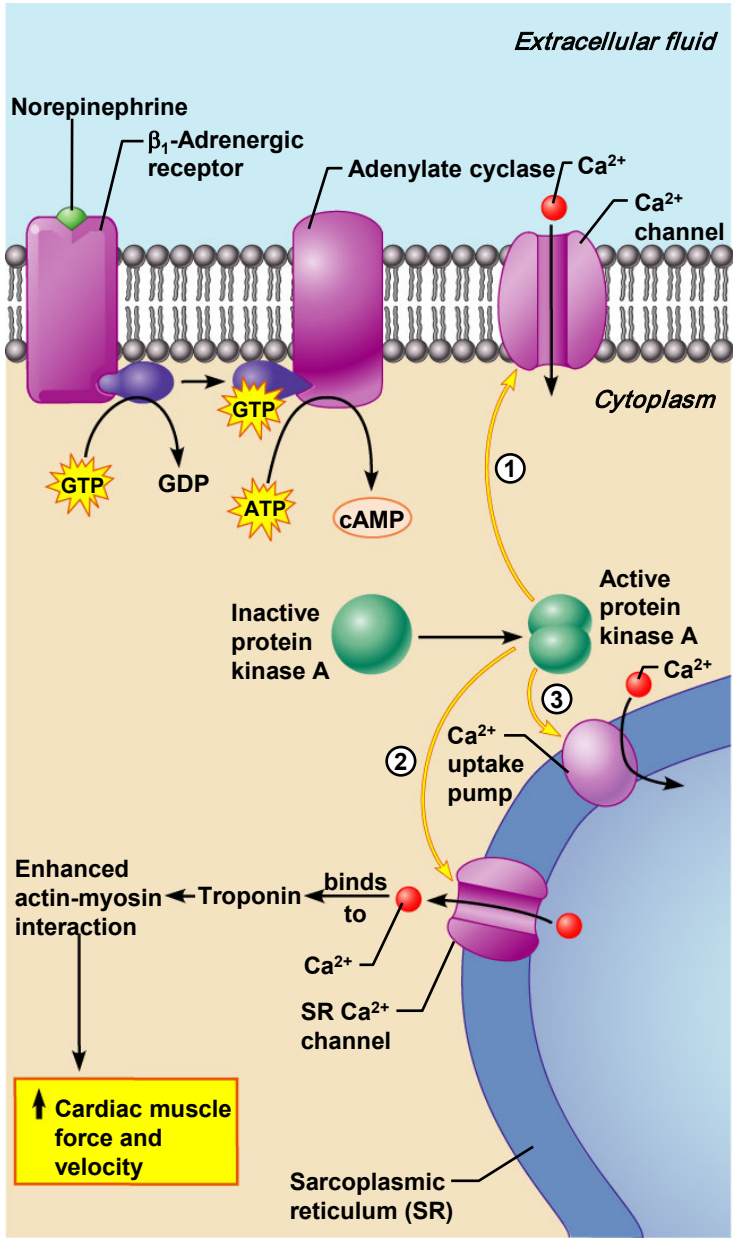


Figure 18.22

Vascular Physiology

Dr Safa Abdul Ghani

Vascular Physiology

Physiology of systemic circulation determined by

1. Anatomy of circulatory system
2. Dynamics of blood flow
3. Regulatory mechanisms that control heart and blood vessels

Perfusion = blood flow through tissues or organs

Blood Vessels

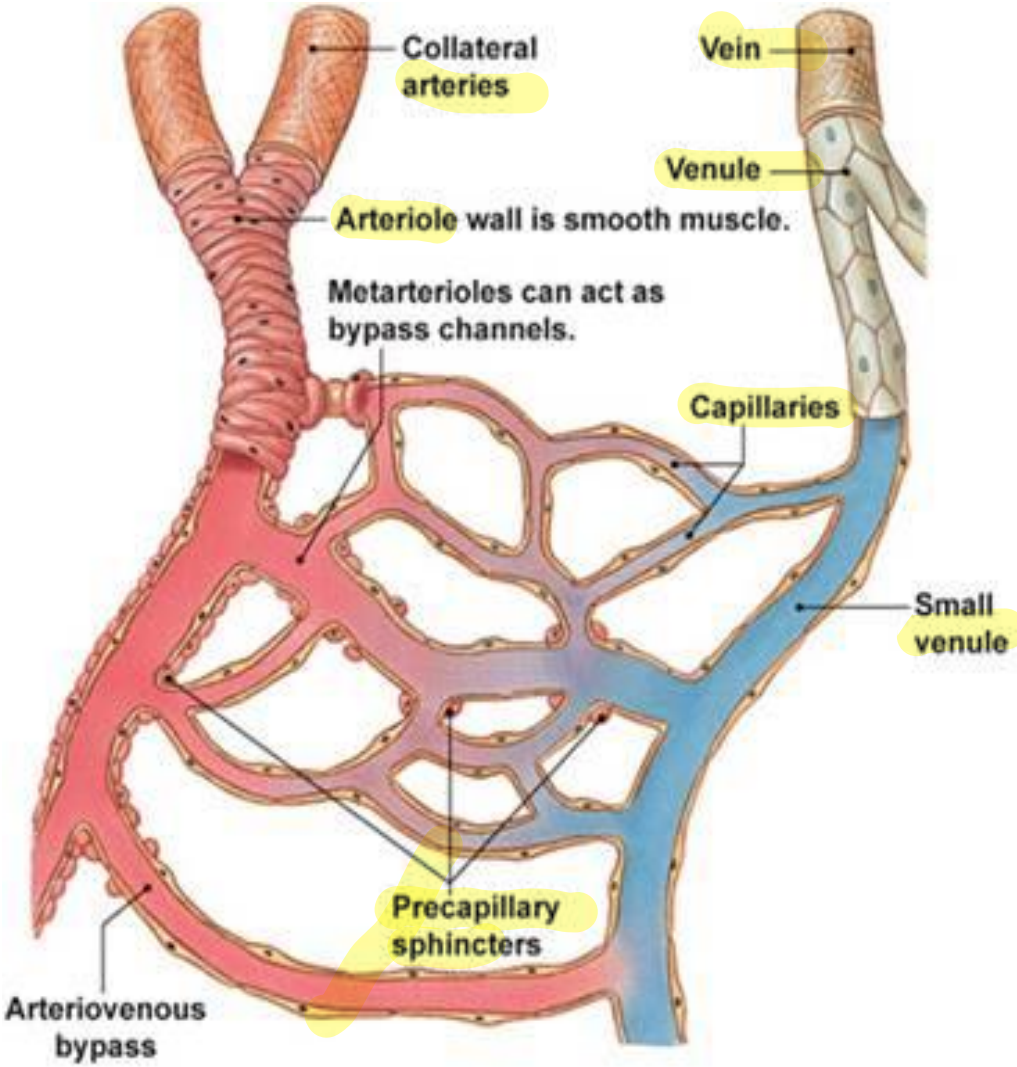
- Blood is carried in a closed system of vessels that begins and ends at the heart
- The three major types of vessels are: Arteries, Capillaries, and Veins

1) Arteries: carry blood away from the heart
2) Veins: carry blood toward the heart
3) Capillaries: contact tissue cells and directly serve cellular needs

عندو المواد بعيرلها ← Exchang

Vascular Tree

- **Arteries** - carry blood away from heart to tissues
- **Arterioles** - smaller branches of arteries
- **Capillaries**
  - Smaller branches of arterioles
  - Smallest of vessels across which all exchanges are made with surrounding cells
- **Venules**
  - Formed when capillaries rejoin
  - Return blood to heart
- **Veins**
  - Formed when venules merge
  - Return deoxygenated blood to heart



* كل ما زاد الـ Length بقل الـ pressure
← يعني بس يوصل الـ Capillaries بكون الـ pressure تقريبًا 50 بعدها بوصل الـ veins 30/40
لحد ميرجع القلب لـ R.atrium بكون

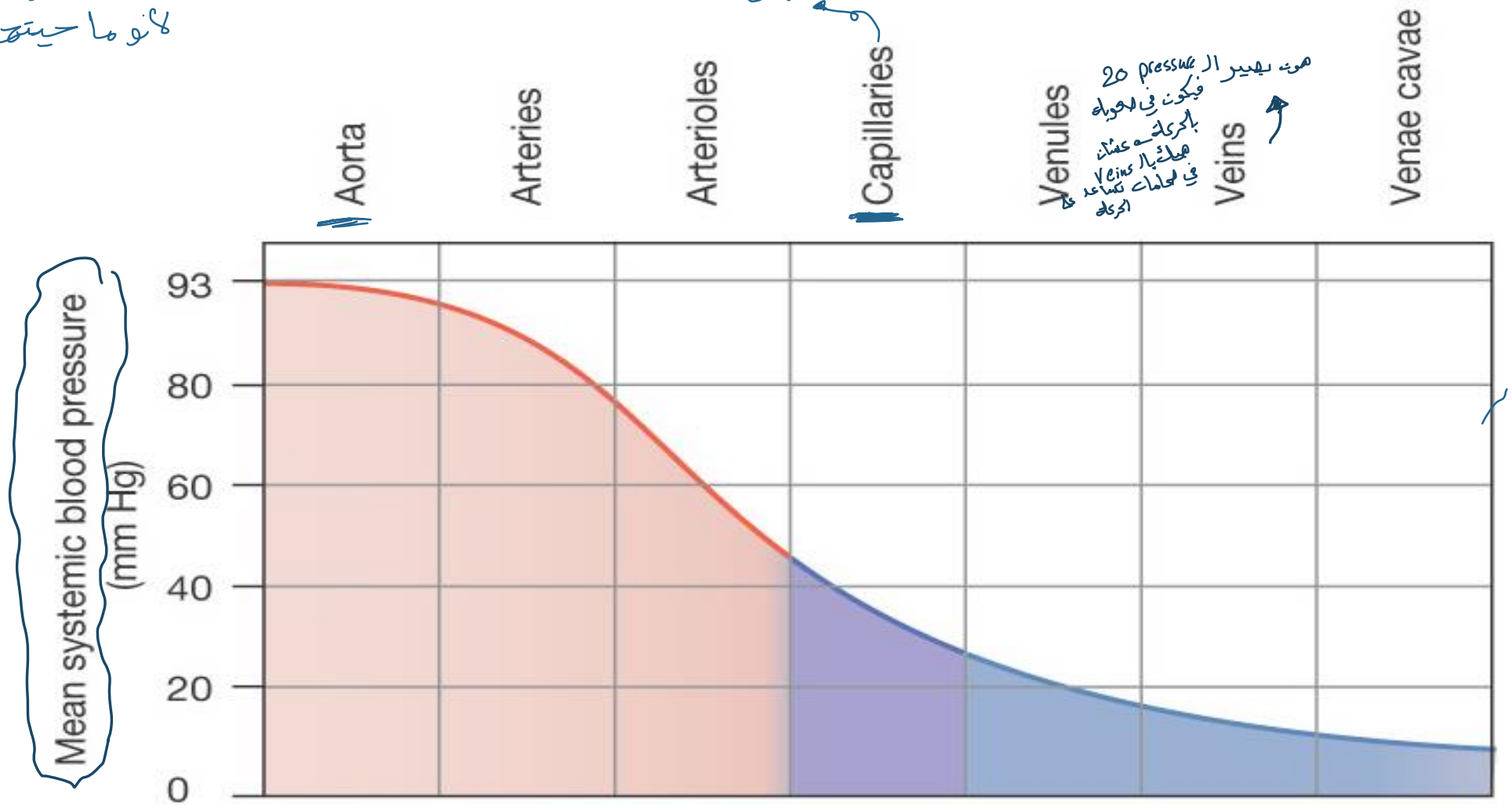
← فرق الـ pressure هو اللي بمشي الدم

Blood Flow: Pressure Changes

- Flows down a pressure gradient
- Highest at the heart (driving P), decreases over distance
- Hydrostatic pressure in vessels (pressure of the blood against the wall)
- Decreases 90% from aorta to vena cava

Blood Flow: Pressure Changes

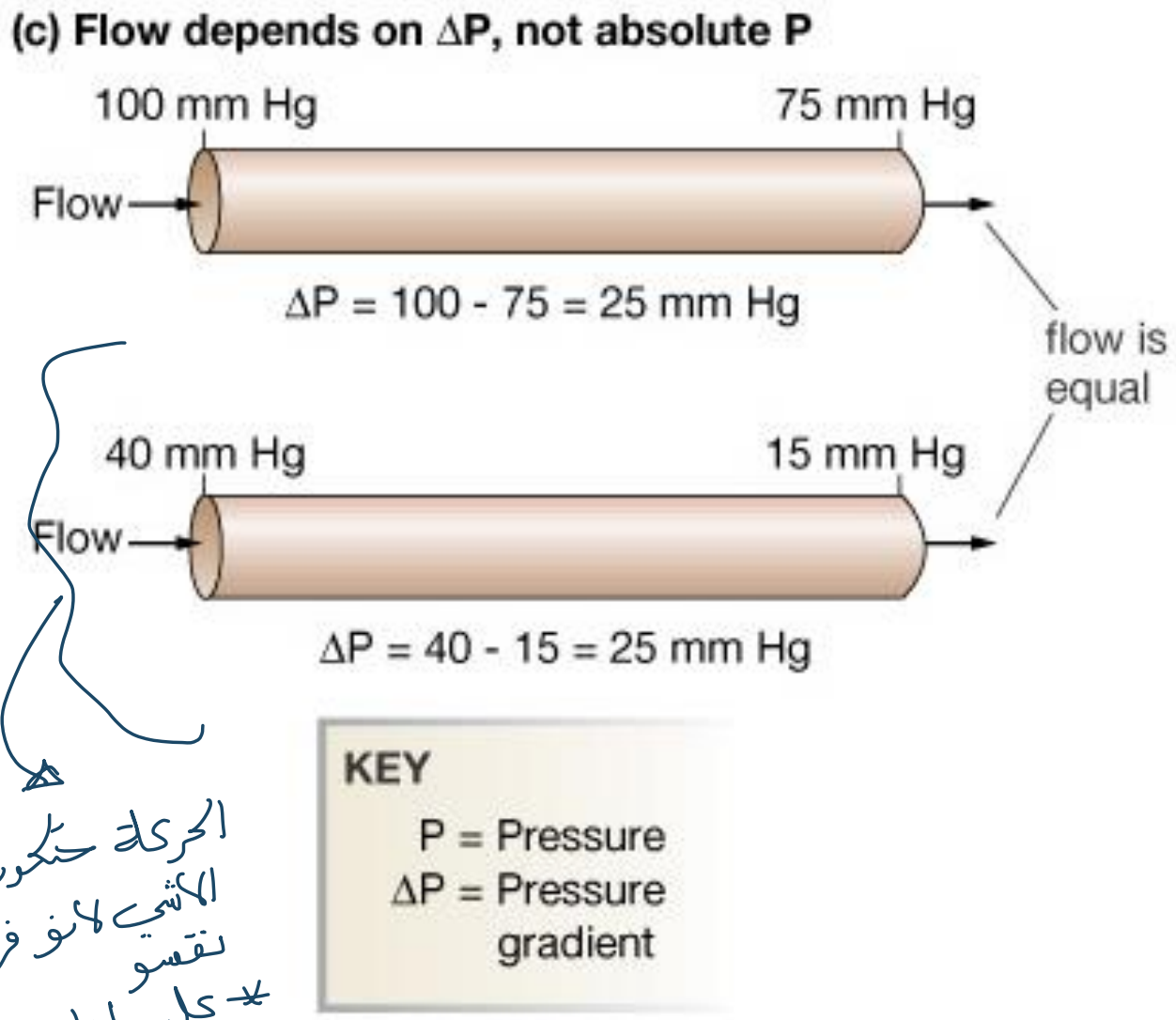
مكون من طبقة وحدة كتير رقيقة عشان هيك الضغط بيت يوصلو يكون قليل
لأنو ما حيتحمل الضغط العالي



هون بيصير الـ pressure
فيكون في لحويلة
بالحركة عشان
هيك بالـ veins
في لحاجات تساعد ع
الحركة

Blood Flow

- Blood flows if a pressure gradient (ΔP) is present
- Blood flows from areas of higher pressure to areas of lower pressure
- Flow is usually expressed in either (L) or (ml) per minute
  - Velocity of flow is usually expressed in either (cm/min) or (mm/sec).
  - The primary determinant of velocity is the cross-sectional area of the vessel



Some Physic of Fluid Movement: Blood Flow

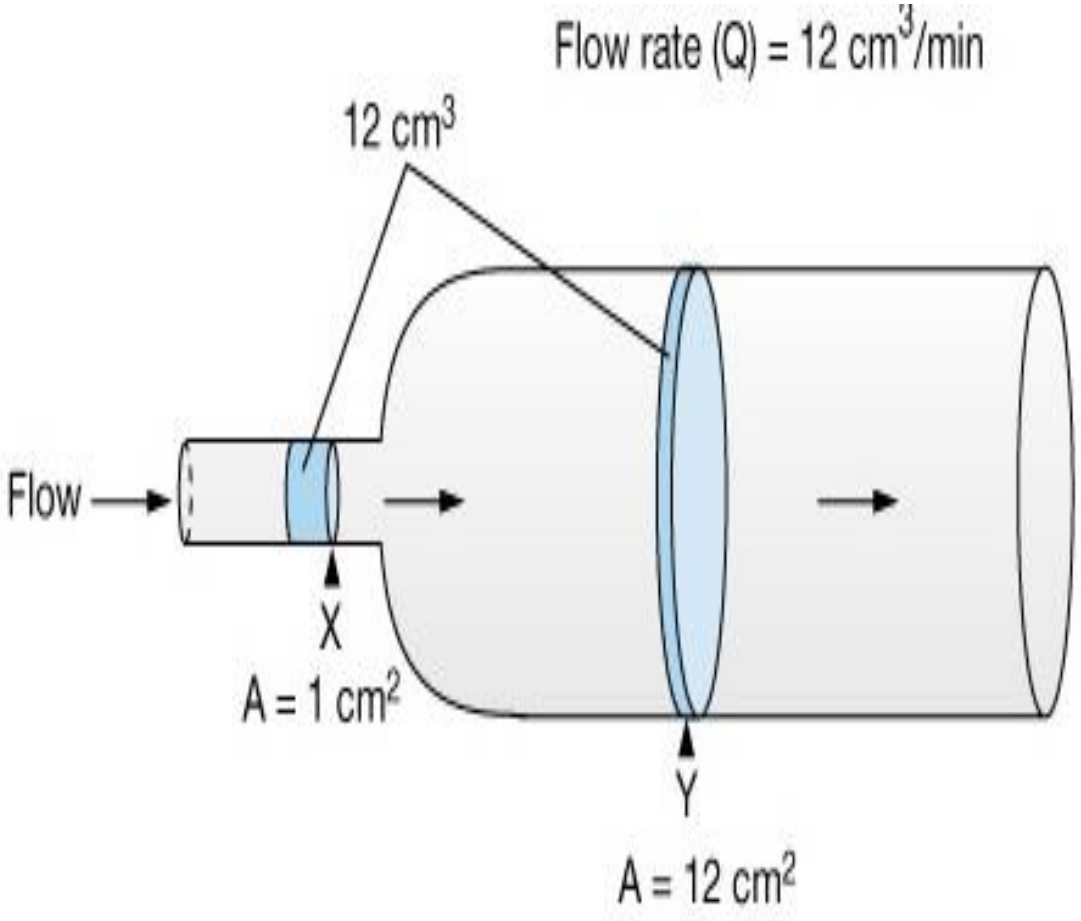
- **Flow rate**: is the volume of blood that passes one point in the system per unit of time (L/min)

- **Flow velocity**: the distance a fixed volume of blood will travel in a given period of time

- **Flow rate** mesures how much blood flow past a point in a given period of time, **flow velocity** mesures how fast blood flows past a point.

Velocity= rate/Cross Section area of vessel

Some Physic of Fluid Movement: Blood Flow

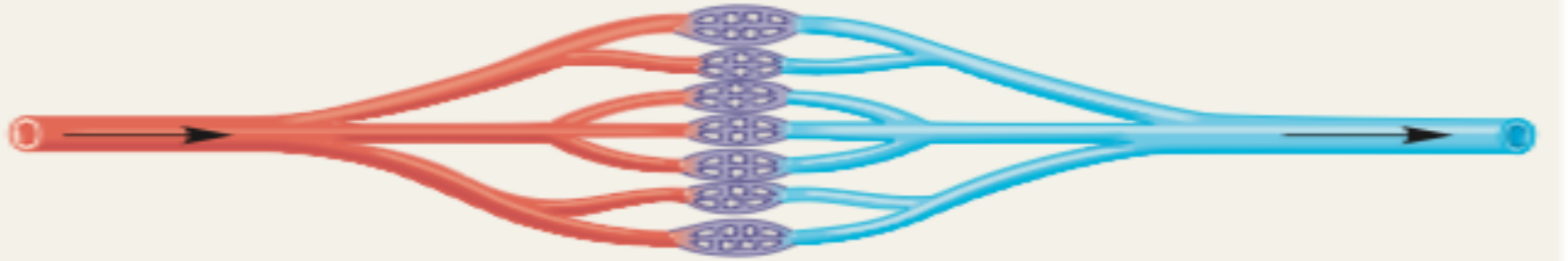


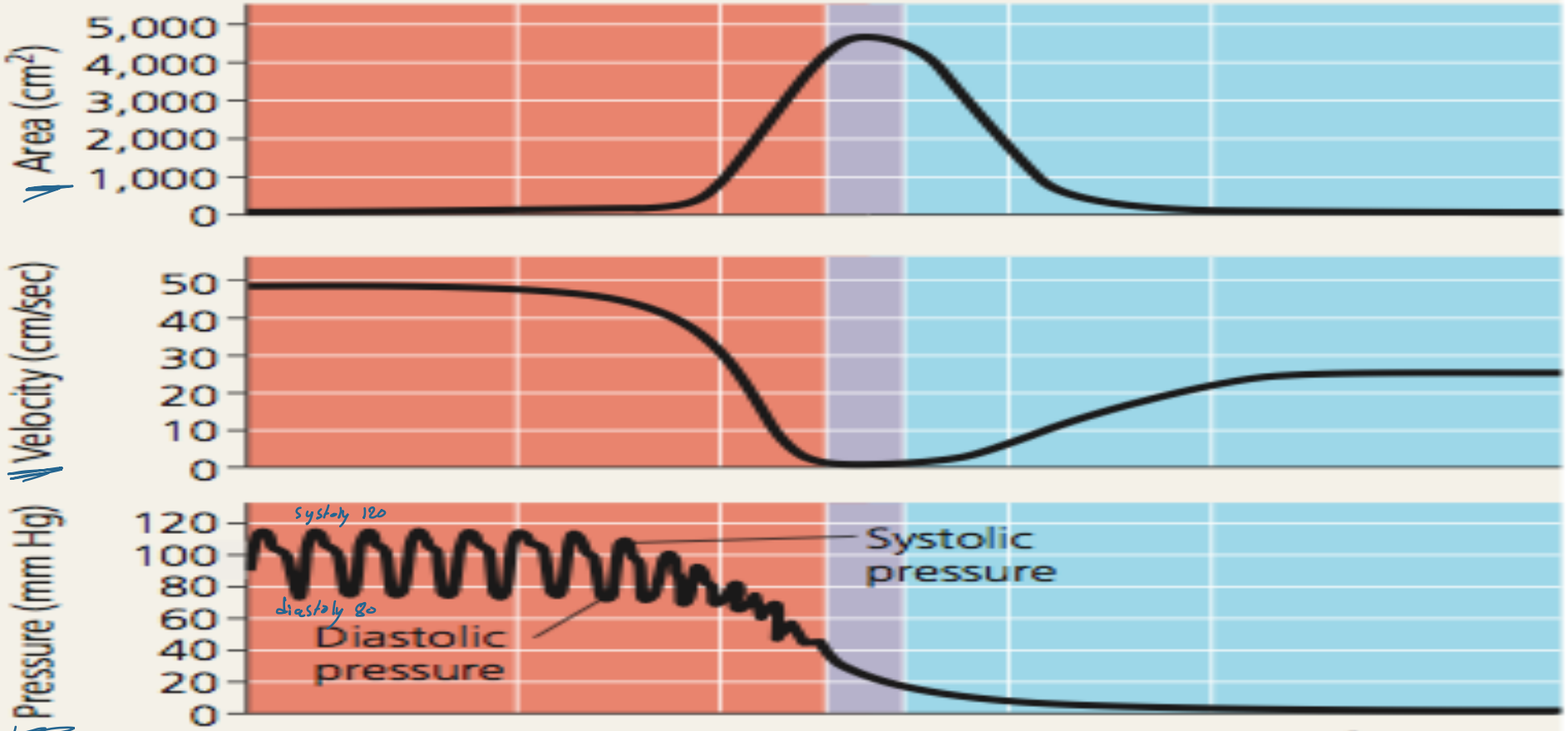
The narrower the vessel, the faster the velocity of flow.

Velocity (v) = $\frac{\text{Flow rate (Q)}}{\text{Cross-sectional area (A)}}$	
At point X	**At point Y**
$v = \frac{12\ cm^3/min}{1\ cm^2}$	$v = \frac{12\ cm^3/min}{12\ cm^2}$
v = 12 cm/min	v = 1 cm/min

*Total Cross section area
Capillaries ال
كتير عاليك
لذلك السرعة عندها اقل
مايمكن

وهاي نحكي بانو
بال Capillary
يصير Exchange
ف معنى منيح تكون
Volecity ال
عاليك





كل ما منشنا بارتفع
عنا احتكاك أكتر
فبقل ال pressure

Some Physic of Fluid Movement: Blood Flow

* Smooth muscle
↳ Arterioles

- Blood flow is opposed by the resistance of the system

Blood Flow α $\frac{\Delta P}{R}$

فرق الـ pressure وليس الـ pressure

ΔP طردي مع BF
R عكسي BF

- 3 factors affecting resistance :
  - **Vessel diameter (r)** — $R \propto \frac{1}{r^4}$
  - **Blood viscosity (η)** — $R \propto \eta$
  - **Tube length (L)** — $R \propto L$

↑BF
↳ ① ↓ length
② ↓ B viscolnj

↓R ↑BF
↳ ↑ Vasodilation (r)

$$\downarrow R = \frac{8L\eta}{\Pi r^4} \uparrow$$

Resistance varies inversely with the fourth power of vessel radius

Resistance

- Resistance – opposition to flow
  - Measure of the amount of friction blood encounters
  - Referred to as peripheral resistance (PR)

- The three important sources of resistance are blood viscosity, total blood vessel length, and blood vessel diameter

Resistance Factors: Blood Vessel Diameter

- Changes in vessel diameter are frequent and significantly alter peripheral resistance
- Resistance varies inversely with the fourth power of vessel radius
  - For example, if the radius is doubled, the resistance is 1/16 as much

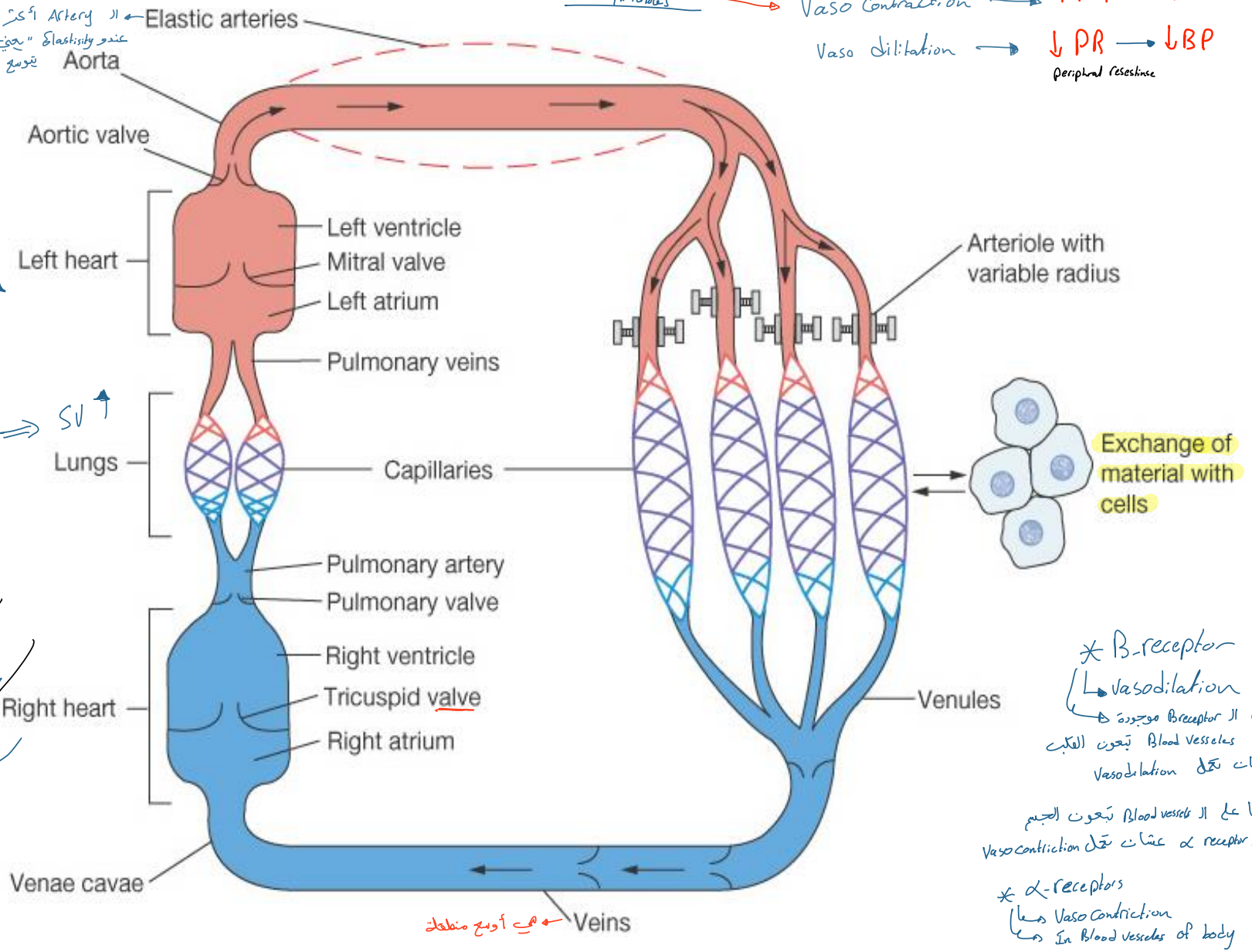
- Small-diameter arterioles are the major determinants of peripheral resistance
- Fatty plaques from atherosclerosis:
  - Cause turbulent blood flow
  - Dramatically increase resistance

لأنها تكون من هـ
Smooth muscle خلايا

* وما اخترنا الـ Artery
لأنها سميكة وتكون
من عدة طبقات

* وما اخترنا الـ Venule
و الـ capillary
لأنو ما عندهم خلايا Smooth muscle

The Blood Vessels and the Cardiovascular System



↓BV ⇒ ↓BP

Exercise ⇒ Adrenaline / epinephrine ⇒ Vaso Contraction

α receptor على عضل الجسم

Arterioles

Vaso Contraction → ↑PR → ↑BP

Vaso dilitation → ↓PR → ↓BP

Peripheral resistance

* Exercise
  - ↳ Epi ↑
  - * Veins : Skeletal pumped & Respiratory pumped ↑
  - ⇓
  - ↑VR ⇒ EDV ↑ ⇒ SV ↑

* Epi ↑
  - ↳ Artery ⇒ ↑ After load

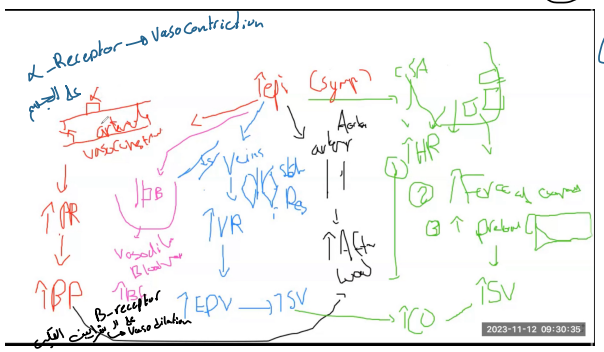
Elastic arteries ← الأكبر اسمي Artery
عندو Elasticity يعني قدرة stretch ، يتوسع بعدها يرجع

* B-receptor
  - ↳ Vasodilation
    - هدول موجودة B receptor ال على Blood Vessels تبعون القلب عشان تعمل Vasodilation

* بينما على Blood vessels ال تبعون الجسم Vasoconstriction عشان تعمل α receptor عليهم

* α-receptors
  - ↳ Vaso Constriction
    - ↳ In Blood vessels of body

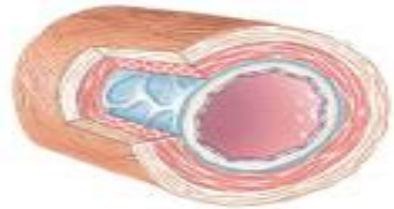
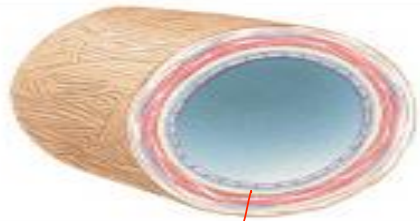
هي أوسع منطقة



Make Up of Blood Vessels: Arteries and Arterioles

- Endothelium
- Elastic tissues
  - Rebounds
  - Evens flow
- Smooth muscles

  vasoconstriction & vasodilation
- Fibrous tissue
  - Tough
  - Resists stretch

	Mean diameter	Mean wall thickness	Endothelium	Elastic tissue	Smooth muscle	Fibrous tissue	
Artery	4.0 mm	1.0 mm					
Arteriole	30.0 µm	6.0 µm					
Capillary	8.0 µm	0.5 µm					
Venule	20.0 µm	1.0 µm					
Vein	5.0 mm	0.5 mm					

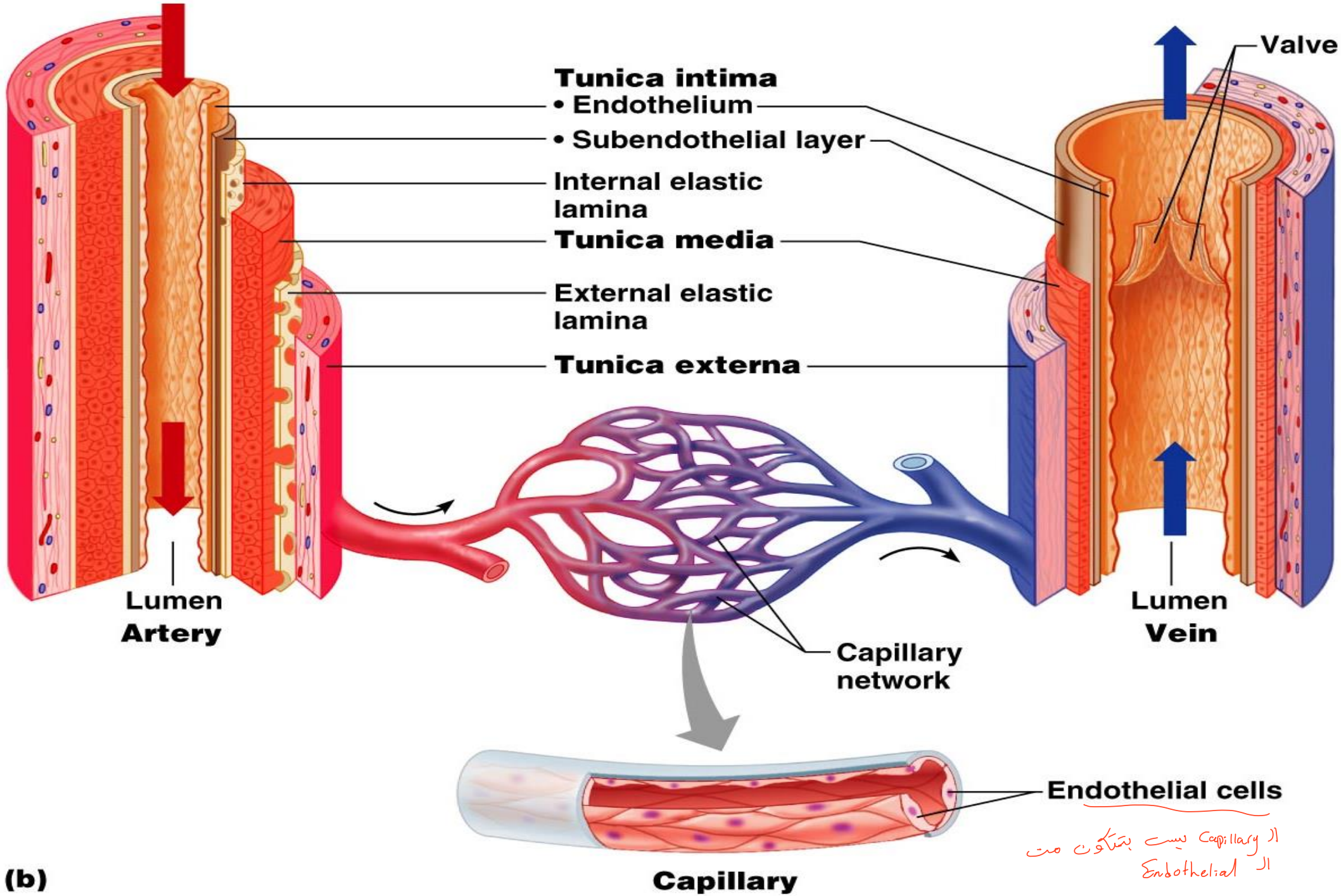
Generalized Structure of Blood Vessels

- Arteries and veins are composed of three tunics – tunica interna, tunica media, and tunica externa
- Lumen – central blood-containing space surrounded by tunics
- Capillaries are composed of endothelium with sparse basal lamina

Tunics

- **Tunica interna (tunica intima)**
  - **Endothelial layer that lines the lumen of all vessels**
  - **In vessels larger than 1 mm, a subendothelial connective tissue basement membrane is present**
- **Tunica media**
  - **Smooth muscle and elastic fiber layer, regulated by sympathetic nervous system**
  - **Controls vasoconstriction/vasodilation of vessels**
- **Tunica externa**
  - **Collagen fibers that protect and reinforce vessels**

Tunica interna
(Endothelial layer)



الـ Capillary بيت بتتكون من الـ Endothelial

1. Role of Arteries

Elastic Recoil

- Elastic or conducting arteries → لانها معرضة لـ P كبير
- Largest diameters, high pressure fluctuations
- **Provides pressure reservoir**
- Elastic recoil drive blood after systole
- smooth muscle allows vessels to regulate blood supply by constricting or dilating

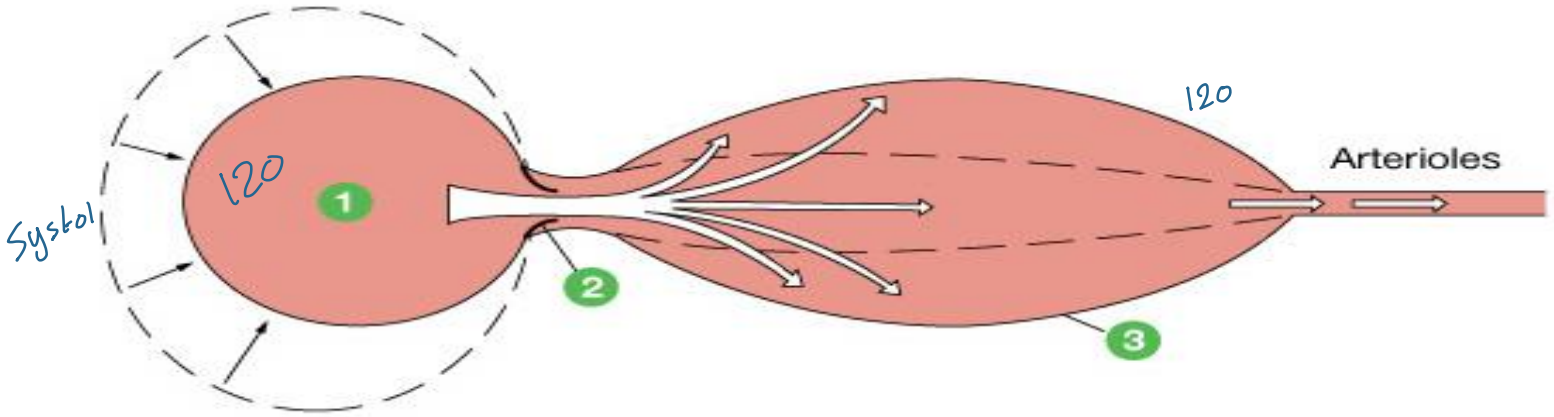
↑ Afterload ↑ 80 P

2. Role of Arterioles

- Transport blood from small arteries to capillaries
- **Controls the amount of resistance**
- Greatest drop in pressure occurs in arterioles which regulate blood flow through tissues
- No large fluctuations in capillaries and veins

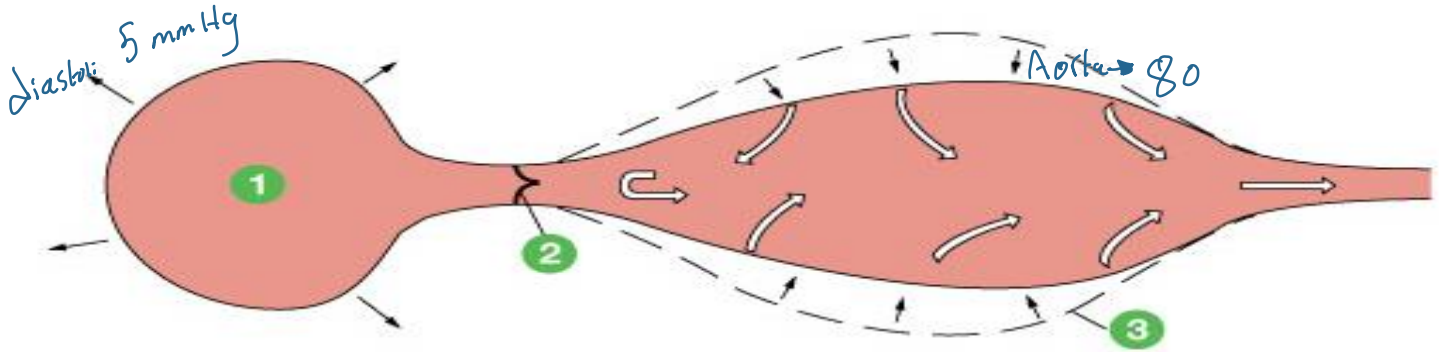
Blood Pressure:
Generated by Ventricular Contraction

(a) Ventricular contraction



1. Ventricle contracts.
2. Semilunar valve opens.
3. Aorta and arteries expand and store pressure in elastic walls.

(b) Ventricular relaxation

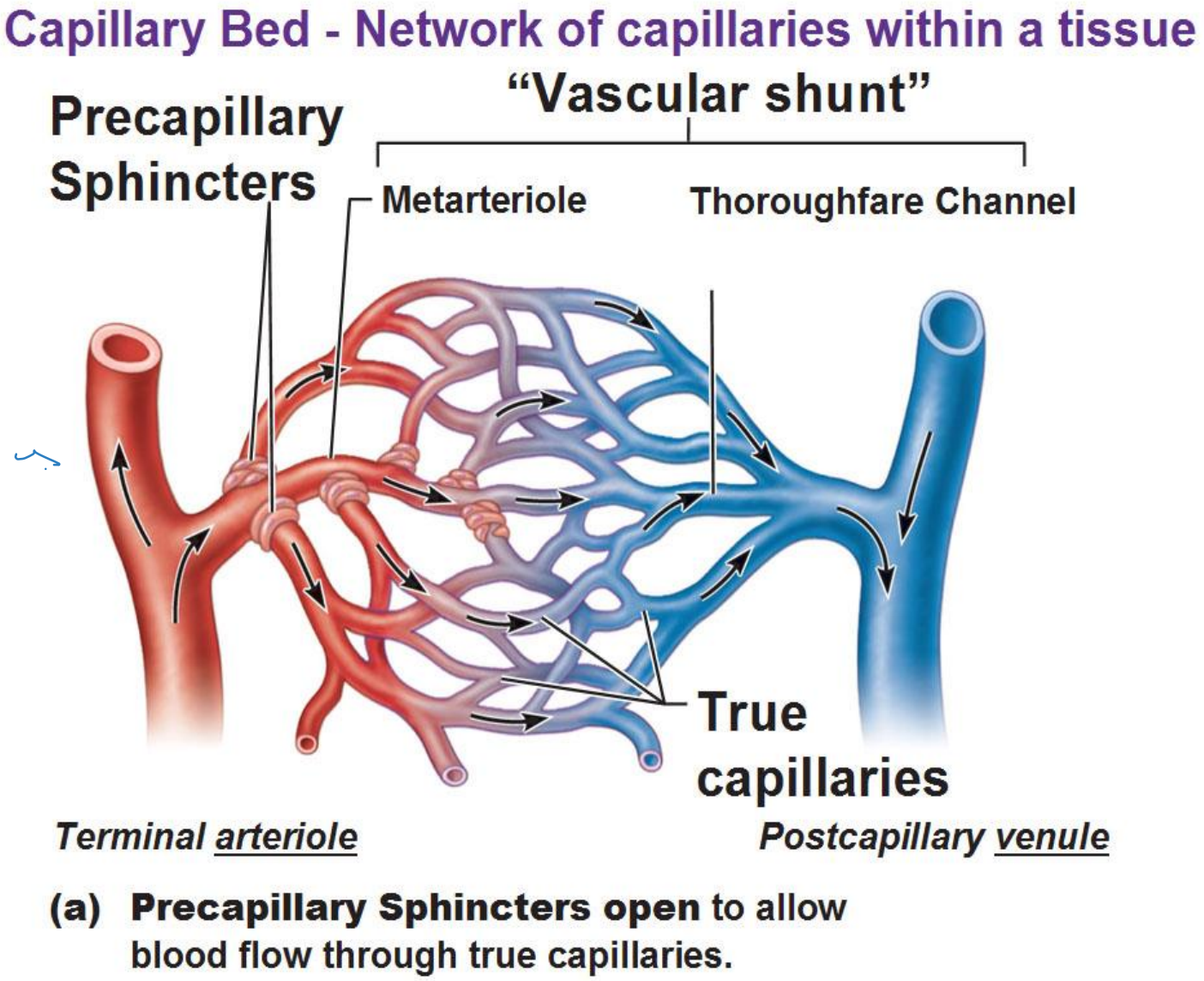


1. Isovolumic ventricular relaxation
2. Semilunar valve shuts.
3. Elastic recoil of arteries sends blood forward into rest of circulatory system.

Metarterioles

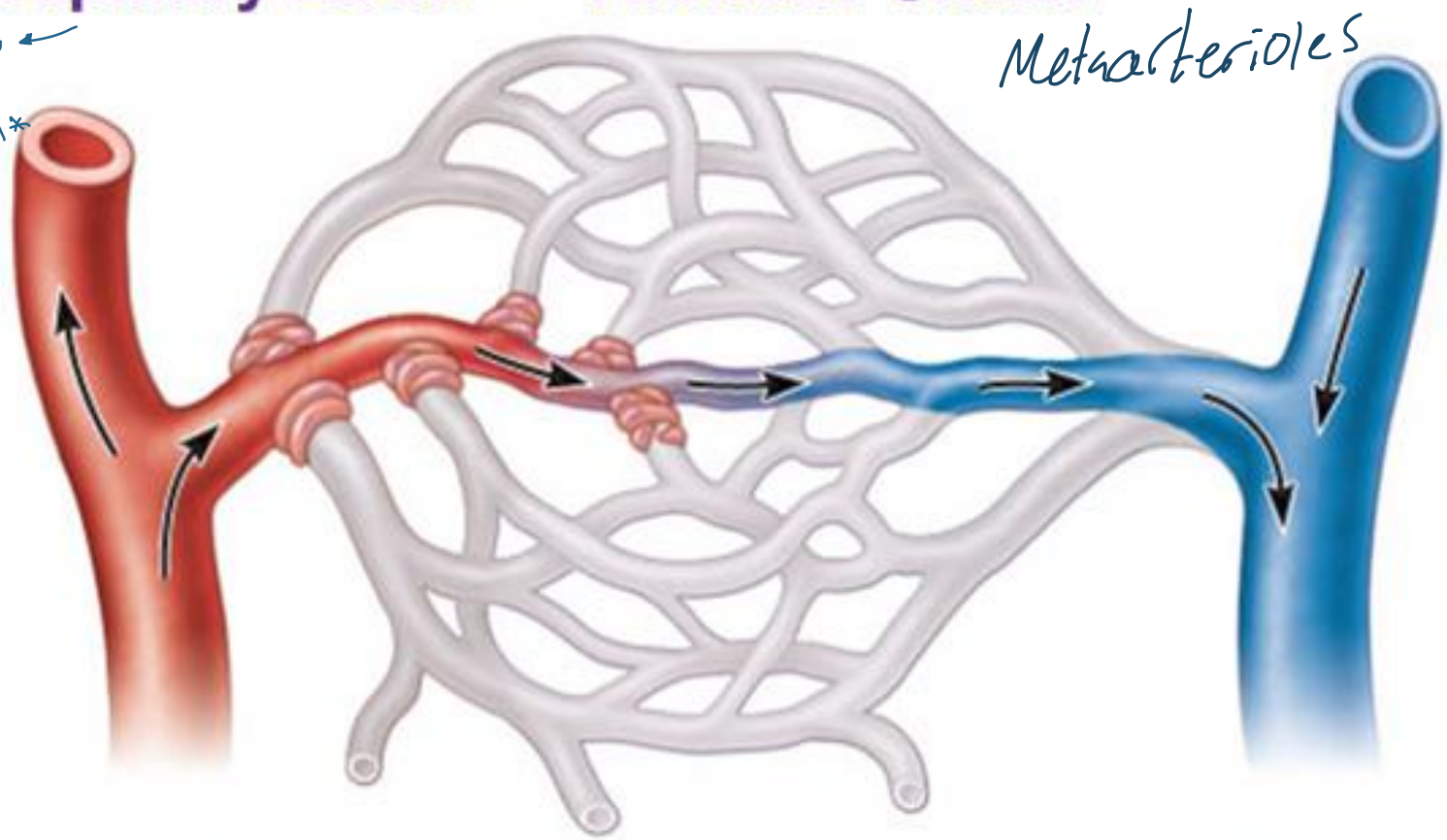
- Bypass capillaries
- Speed and regulate flow
- Precapillary sphincters
  - Cuff of smooth muscle that surrounds each true capillary
  - Regulates blood flow into the capillary

- Blood flow is regulated by vasomotor nerves and local chemical conditions



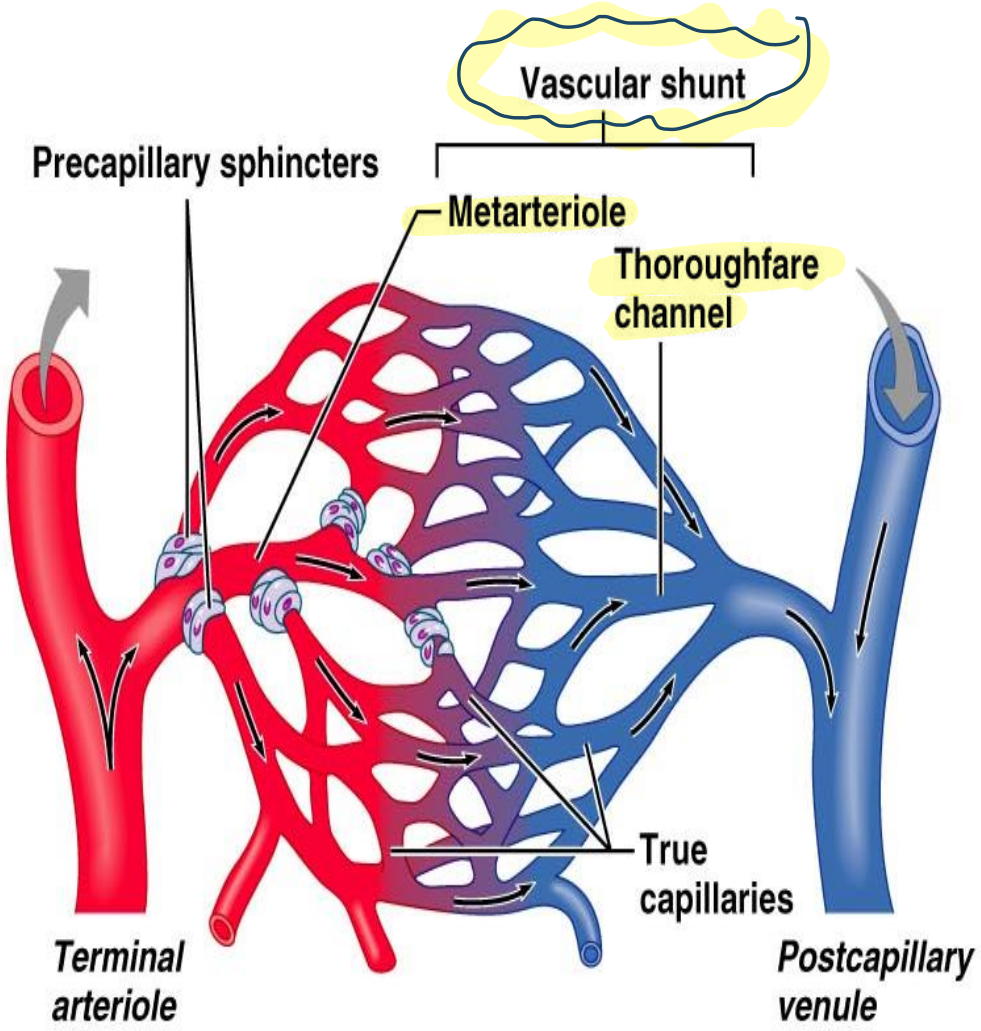
Capillary Beds – "Vascular Shunt"

Active ازا tissue بعتمد على الـ
Inactive او
tissue الـ* Inactive كان ازا ما بحتاج كتير
بستخدم طريق الـ Vascular shunt

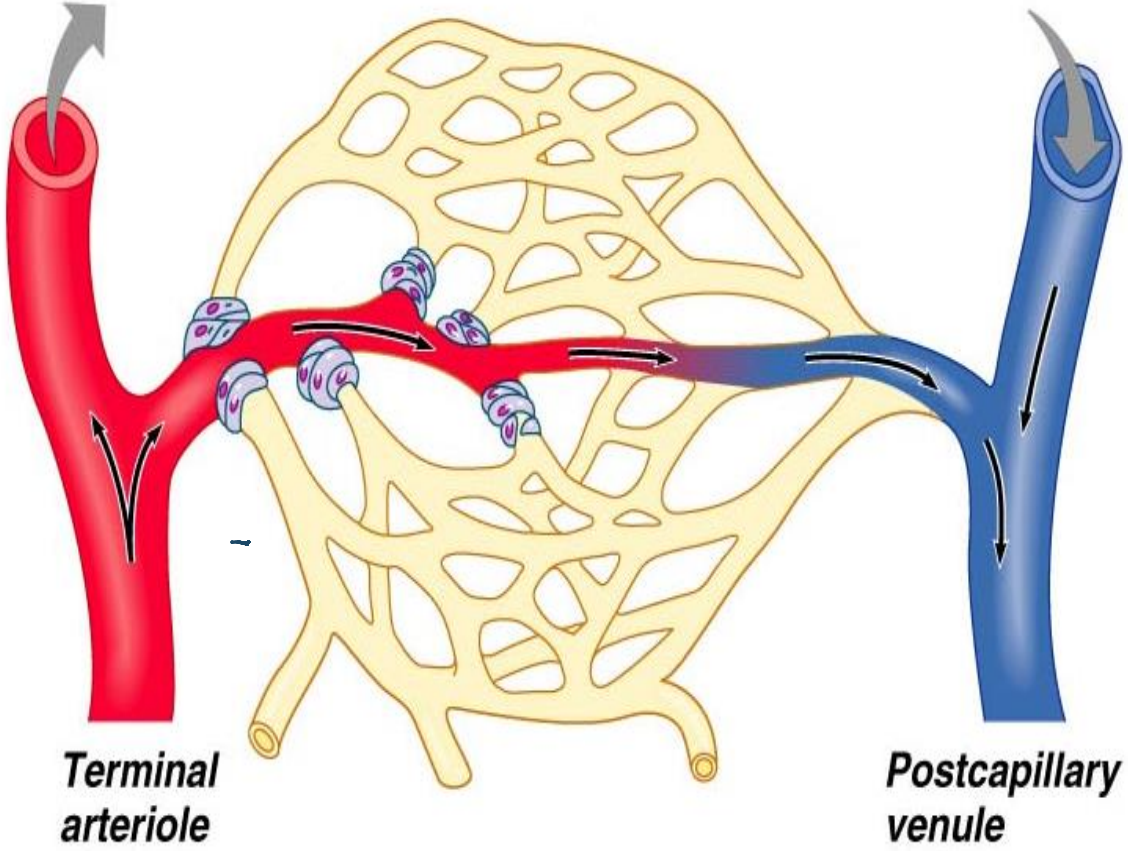


Terminal arteriole *Postcapillary venule*

(b) Sphincters closed (sympathetic stimulation)—blood flows *straight through* Metarteriole Thoroughfare Channel and *bypasses* the true capillaries, "shunting" blood away from this area of tissue.



(a) Sphincters open



(b) Sphincters closed

Make Up of Blood Vessels:
Veins and Venules (Contrasted to Arteries)

- Thinner walls
  - Less muscle
  - Less elastic
- More numerous
- Larger diameter → ↓R → ↑BF
- Closer to skin

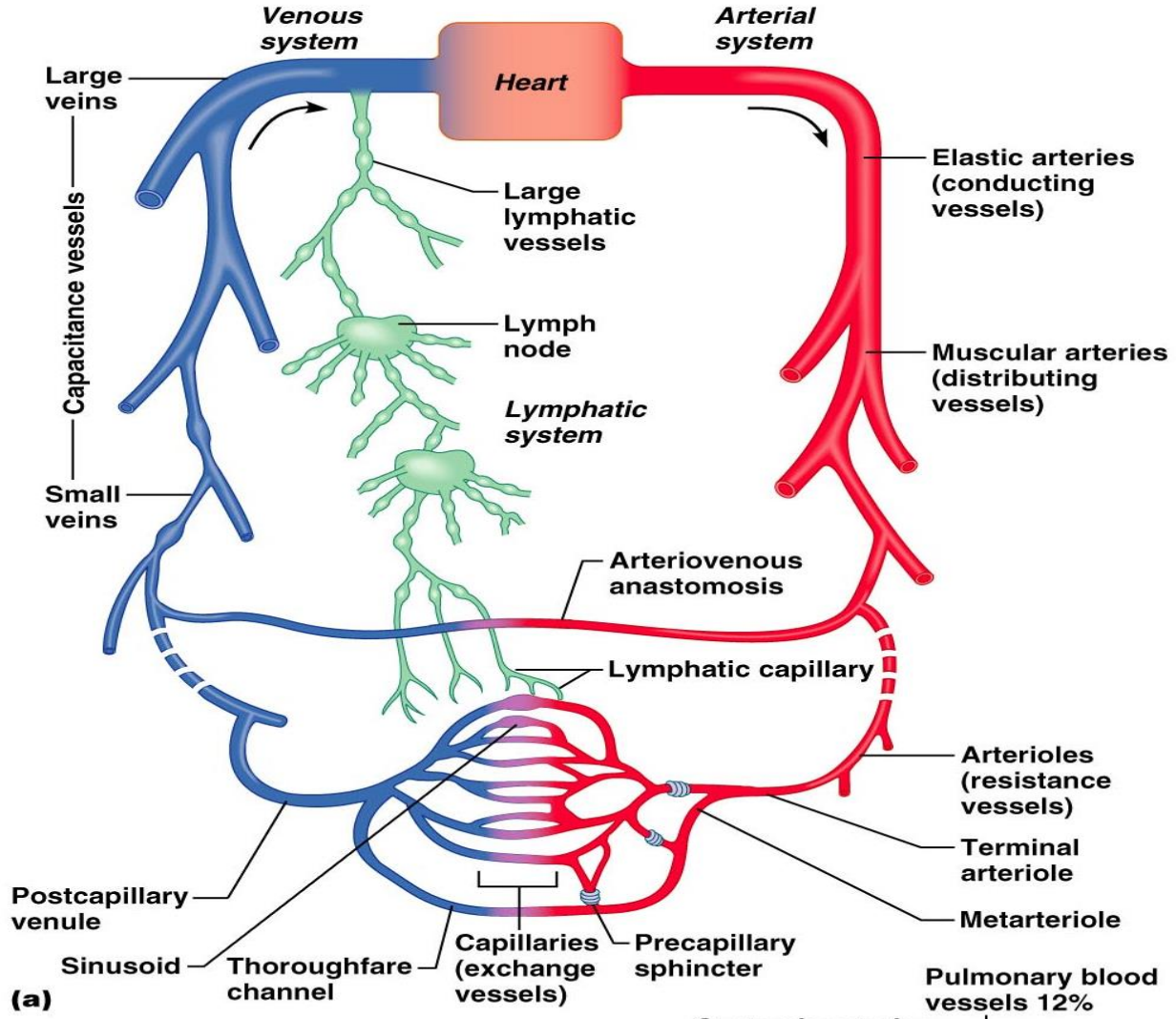
* معظم الدم موجود بالـ Veins

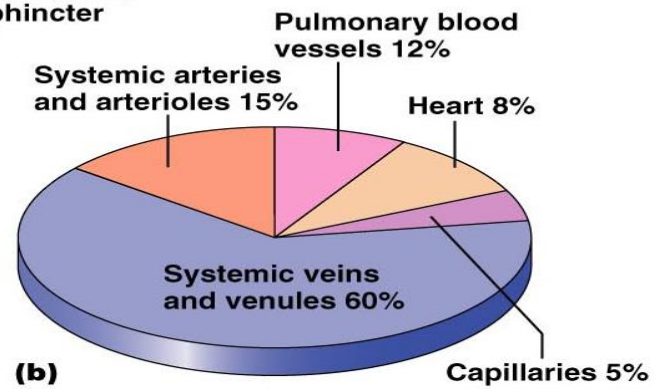
Venous System: Veins

- Veins have much **lower blood pressure** and **thinner walls** than arteries
- To return blood to the heart, veins have special adaptations
  - Large-diameter lumens, which offer little resistance to flow
  - Valves (resembling semilunar heart valves), which prevent backflow of blood

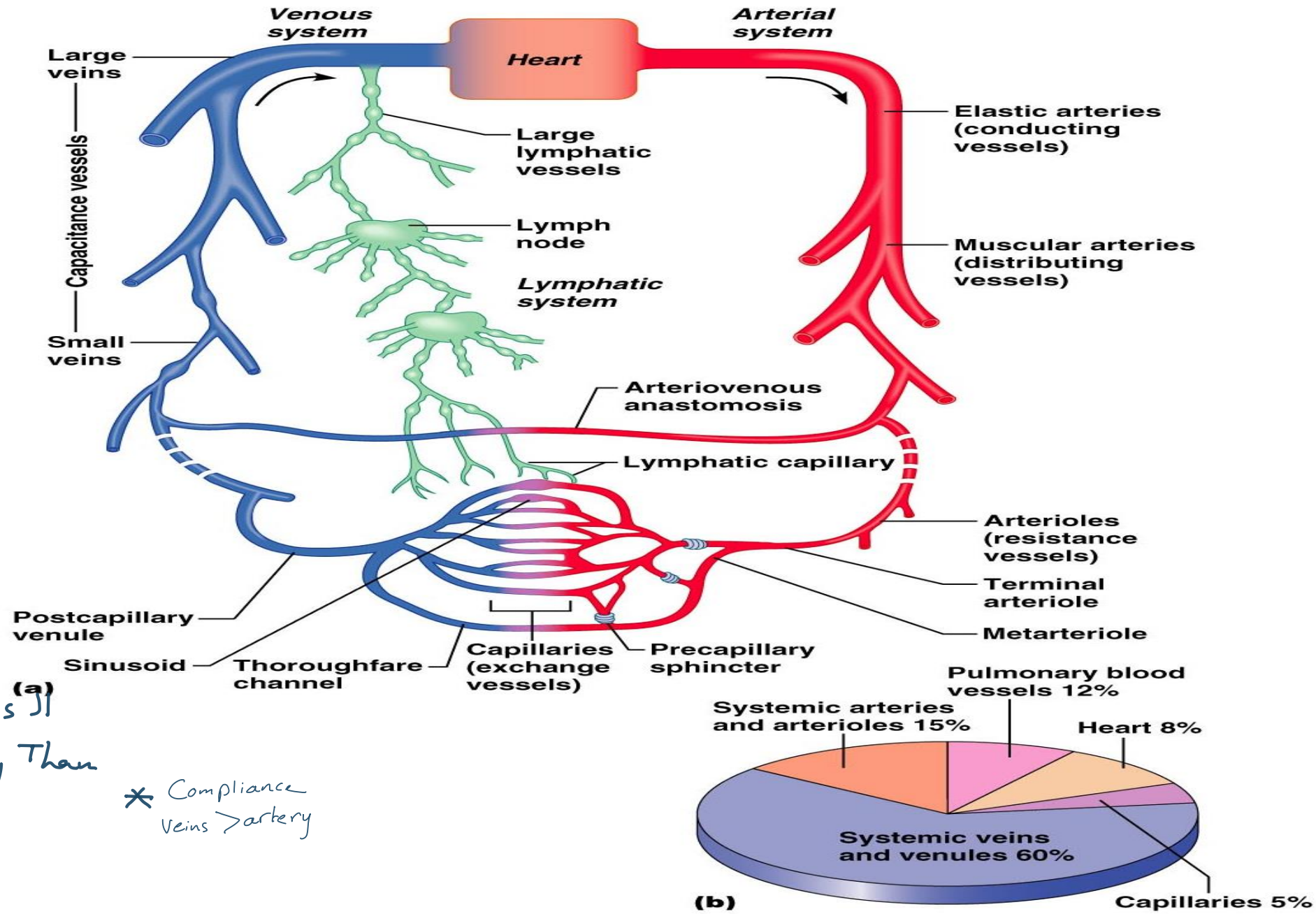
Vascular Anastomoses

- Merging blood vessels
- Arterial anastomoses provide alternate pathways (collateral channels) for blood to reach a given body region
  - If one branch is blocked, the collateral channel can supply the area with adequate blood supply





Vascular Components



High Compliance عند Veins من artery Than

* Compliance = $\frac{V}{P}$

* Compliance Veins > artery

Blood Pressure (BP)

$P = \frac{F}{A}$

- Force per unit area exerted on the wall of a blood vessel by its contained blood
  - Expressed in millimeters of mercury (mm Hg)
  - Measured in reference to systemic arterial BP in large arteries near the heart
- The differences in BP within the vascular system provide the driving force that keeps blood moving from higher to lower pressure areas

Blood Pressure

↓BV ⟹ ↓BP ↑BV ⟹ ↑BP

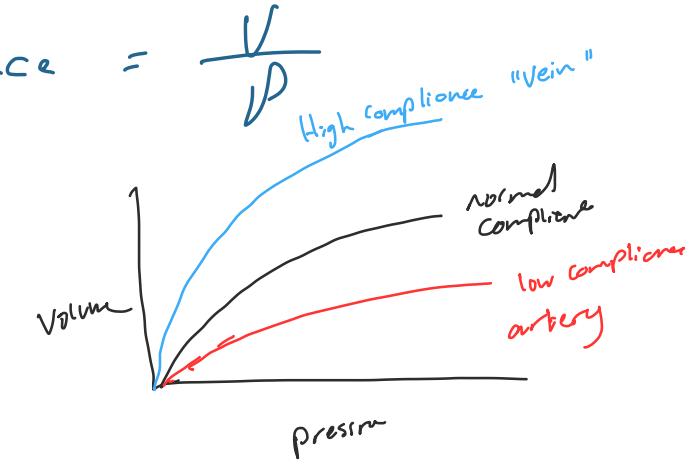
- **Force exerted by blood against a vessel wall**

Depends on

- Volume of blood forced into the vessel
- Compliance of vessel walls = Volume / pressure

Compliance = V / P

عندو Artery !!
Elastic recoil
low compliance عشان هيك عندو



- **Systolic pressure**

- Peak pressure exerted by ejected blood against vessel walls during cardiac systole (ventricular contraction)
- Averages 120 mm Hg

- **Diastolic pressure**

- Minimum pressure in arteries when blood is draining off into vessels downstream, lowest level of arterial pressure during ventricular cycle
- Averages 80 mm Hg

Systemic Blood Pressure

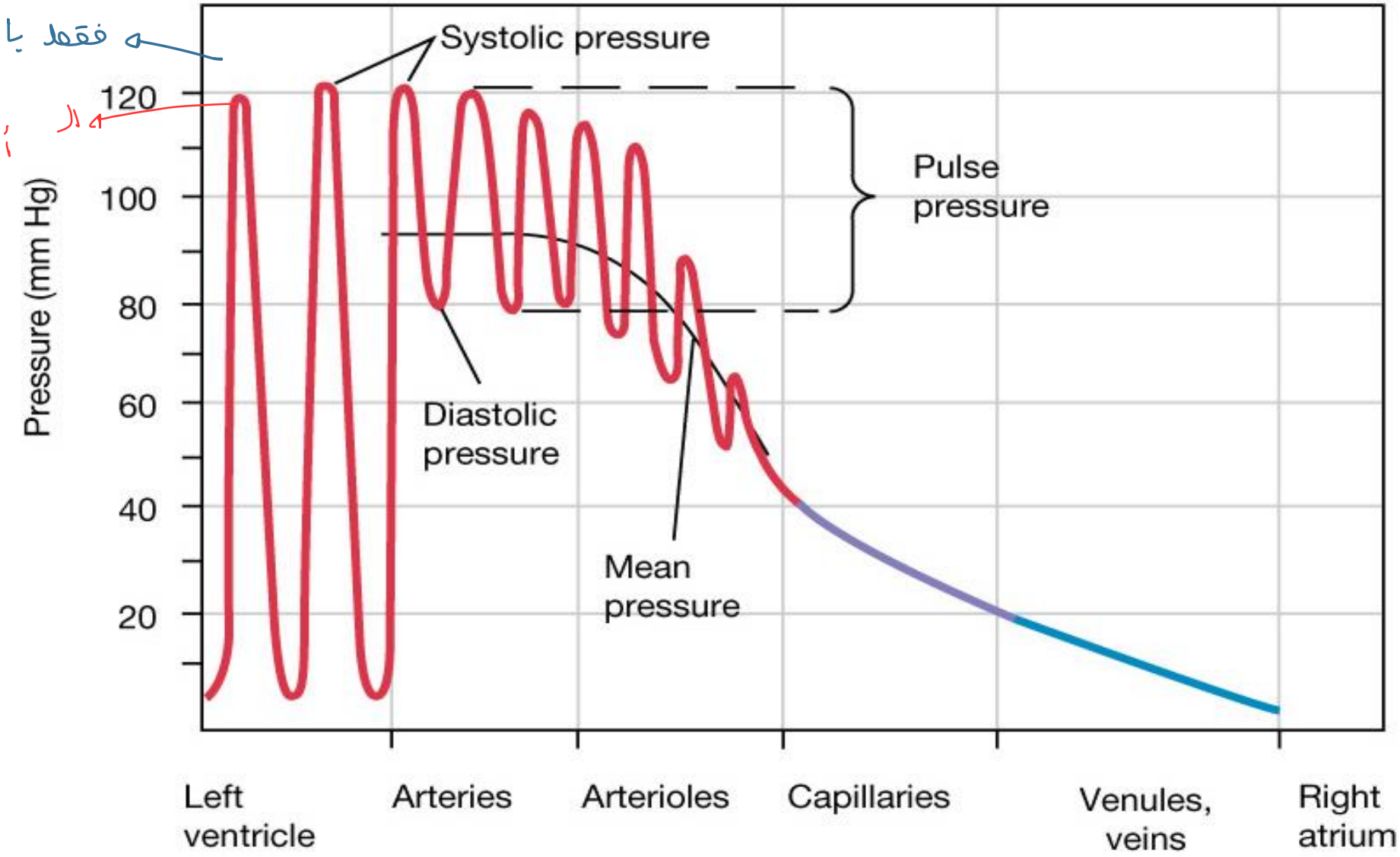
- Systemic pressure:
  - Is highest in the aorta
  - Declines throughout the length of the pathway
    - Is 0 mm Hg in the right atrium
- The steepest change in blood pressure occurs in the arterioles

Blood Pressures:
Pulse and Mean Arterial Pressures

* pulse pressure = Systoly - Diastoly
120 - 80

Artery فقط بال

pressure
Aorta أعلى شي بال



Blood Pressure (BP): Measurements

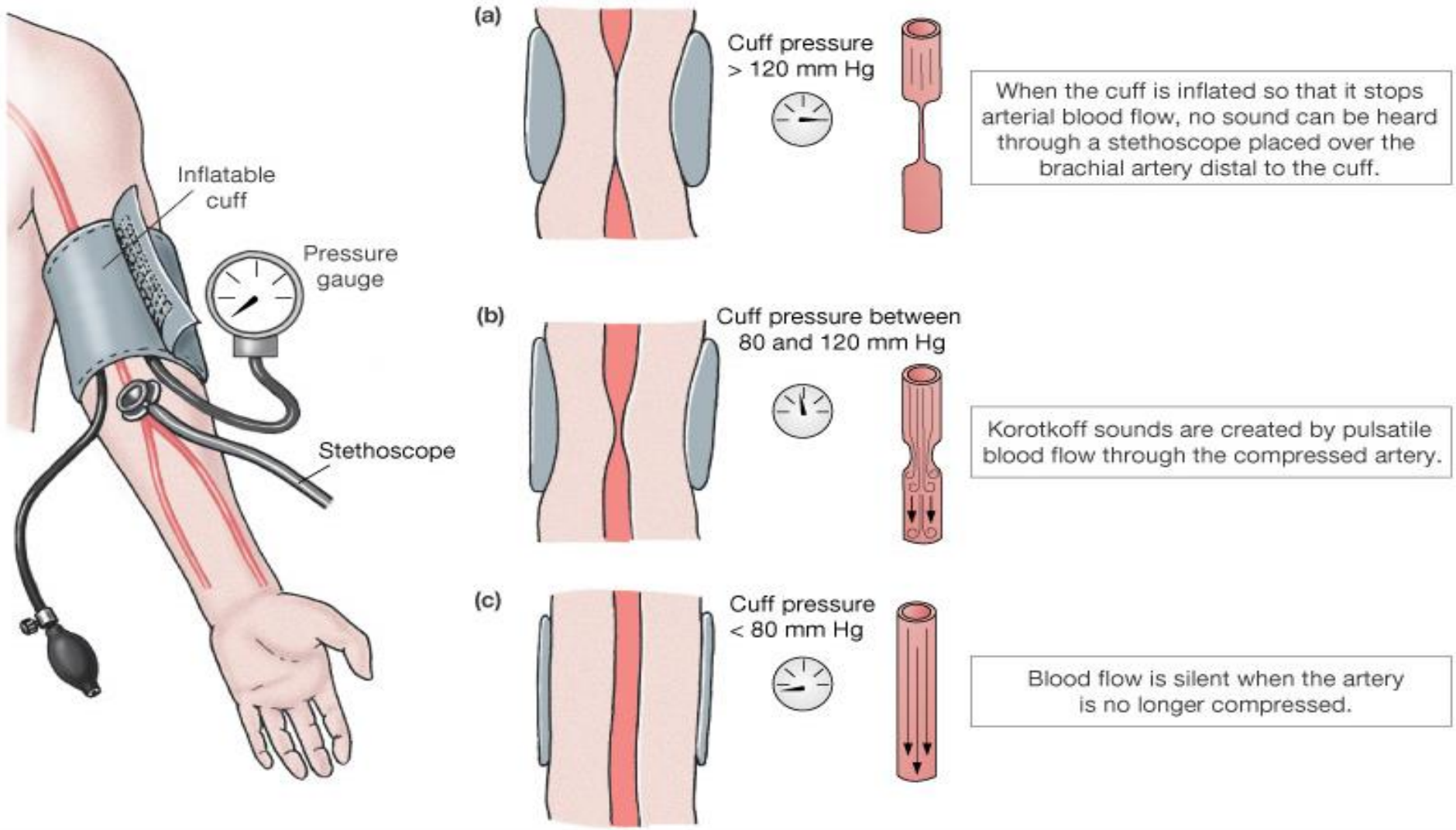
- Blood pressure:
  - Systolic over diastolic
  - About 120/80 mmHg
- Pulse pressure = Systolic P – Diastolic P
  (measures the strength of the pressure wave)
- Mean arterial pressure (MAP) =

  Diastolic P + 1/3 pulse P

  / OR

  $MAP = \text{systoly pressure} - \frac{2}{3}\ \text{pulse pressure}$
- Sphygmomanometer
  - Estimate of BP
  - Korotkoff sounds

Blood Pressure (BP): Measurements



Sounds of Korotkoff

Are sounds caused by the resumption of blood flow into the forearm.

onset of Korotkoff sounds at systolic pressure, and diminishing sounds as diastolic pressure is reached.

* كما يروح على الـ sounds يكون الـ diastolic

- **Venous BP**
- Venous BP is steady and changes little during the cardiac cycle
- The pressure gradient in the venous system is only about **20 mm Hg**
- **Veins** have thinner walls, thus **higher compliance**.
- Vascular compliance
  - Tendency for blood vessel volume to increase as blood pressure increases
  - More easily the vessel wall stretches, the greater its compliance
  - Venous system has a large compliance and acts as a blood reservoir

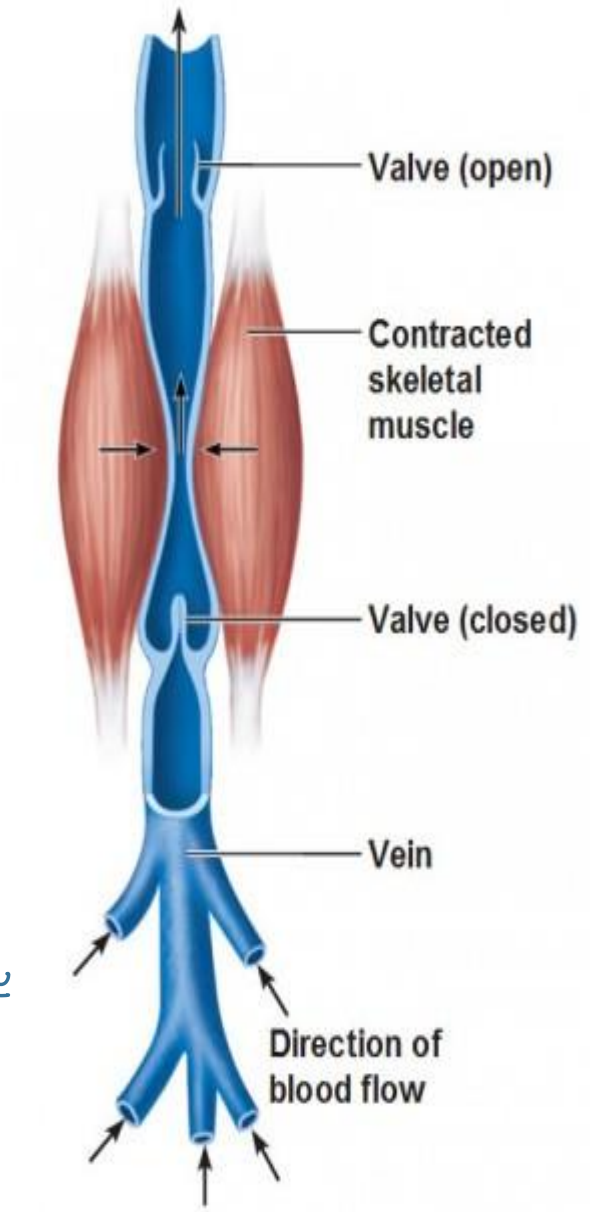
2/3 blood volume is in veins.

Veins → Thinner walls → Higher Compliance

* Stretch → greater it's compliance
* Venous system → large compliance
  → Act as blood reservoir

Venous Return

- Venous pressure is driving force for return of blood to the heart
- EDV, SV, and CO are controlled by factors which affect venous return
- Venous BP alone is too low to promote adequate blood return and is aided by the:
  - **Respiratory "pump"** – pressure changes created during breathing squeeze local veins (increase intra-abdominal pressure)
  - **Muscular "pump"** – contraction of skeletal muscles push blood toward the heart
  - **Cardiac pump**
  - **Gravity:** facilitate blood return from superior region
  - **Valves** prevent backflow during venous return

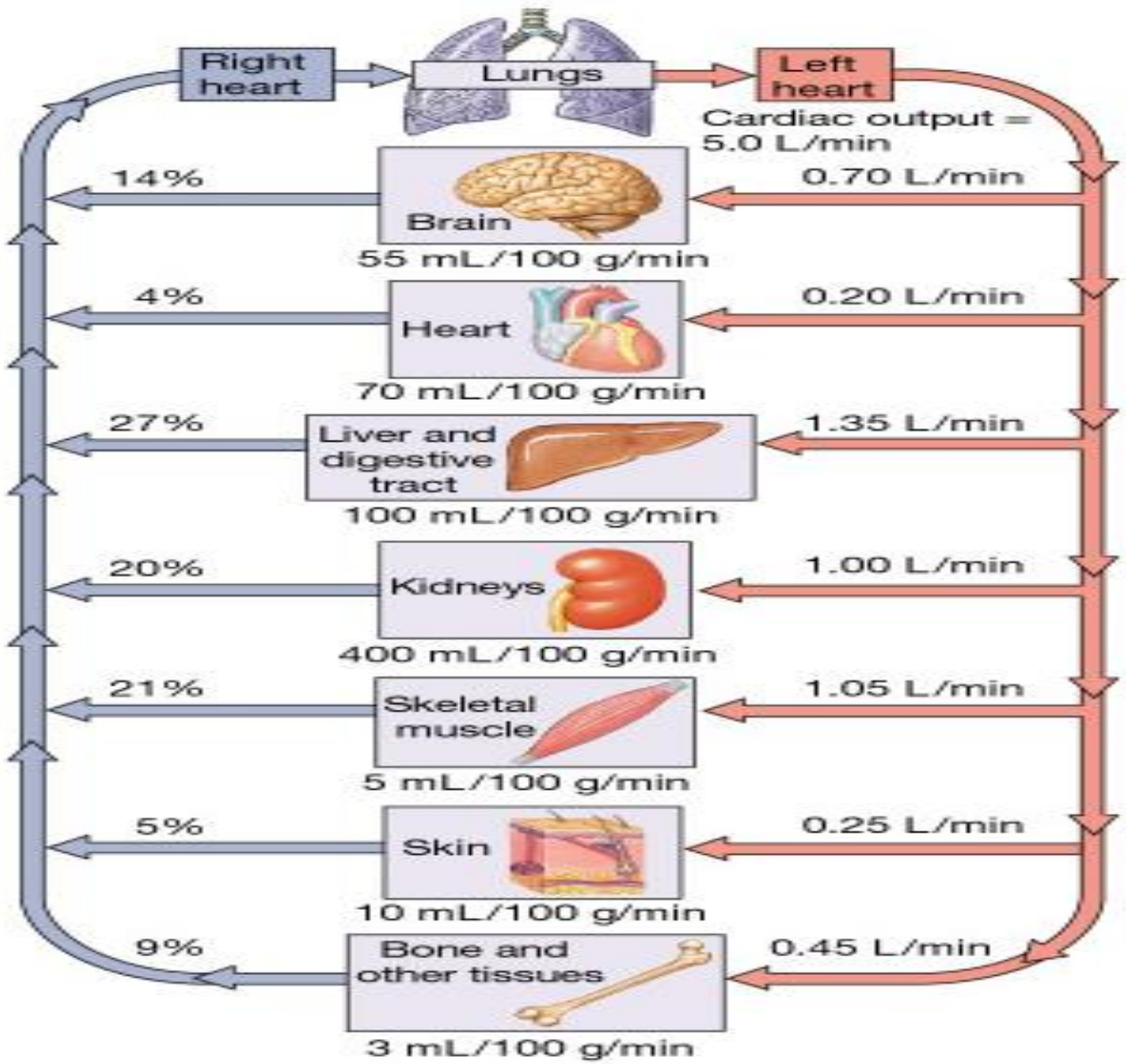


Distribution of Blood in the Body Organs

- Responds to metabolic need

- Local & CNS regulators:
  - ↑ or ↓ arteriolar resistance
  - Precapillary sphincters

Distribution of Blood in the Body Organs



Angiogenesis: Growth of New Blood Vessels

- A part of normal body maturation and growth
- In Adults:
  - Wound healing
  - Endometrium: lining after menstruation

- A balance between angiogenic (VEGF and FGF) and antiangiogenic (angiostatin and endostatin) cytokines
- Abnormal growth to service cancerous tissue

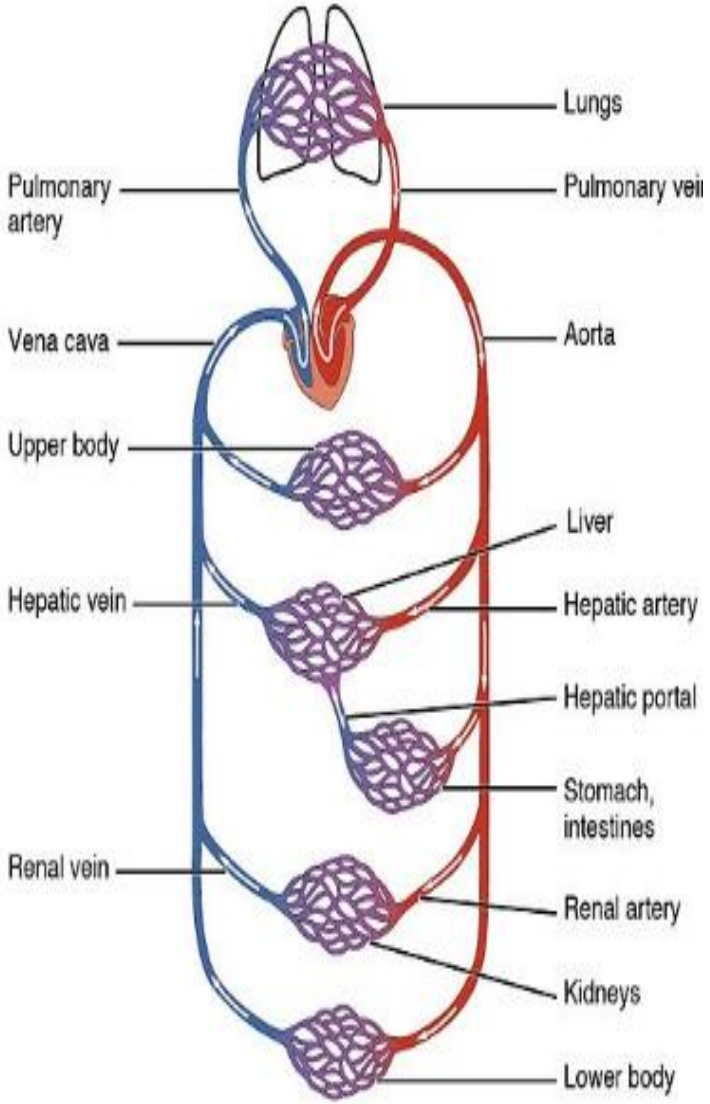
Capillary Exchange

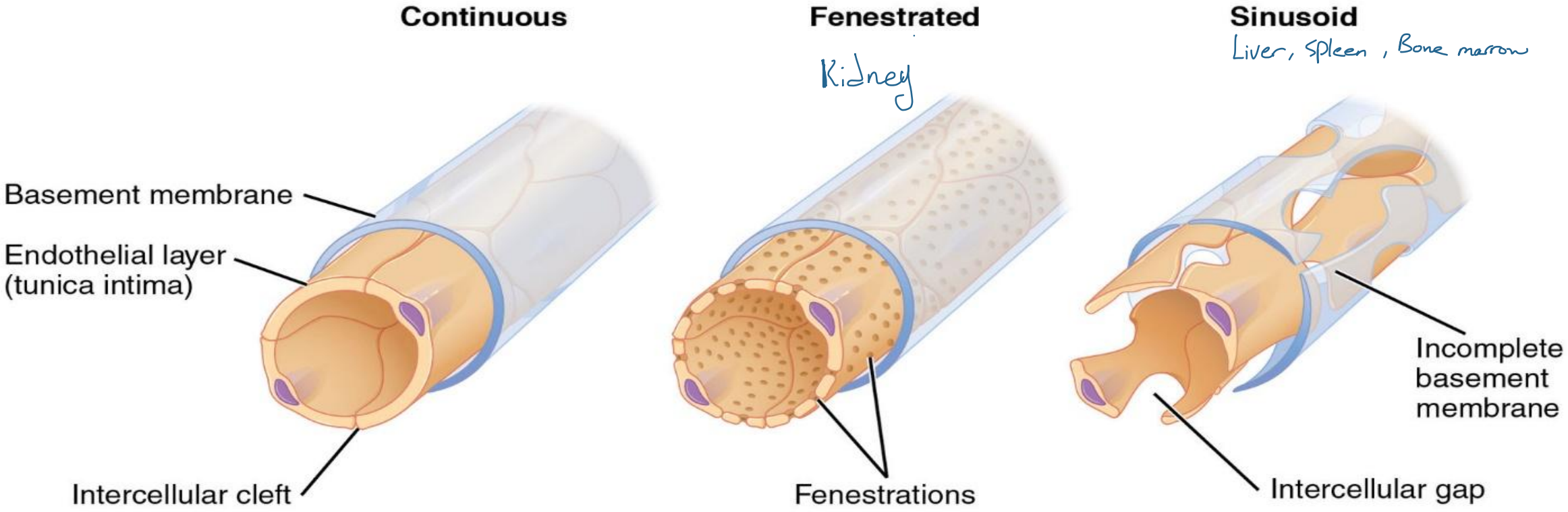
Dr Safa Abdul Ghani

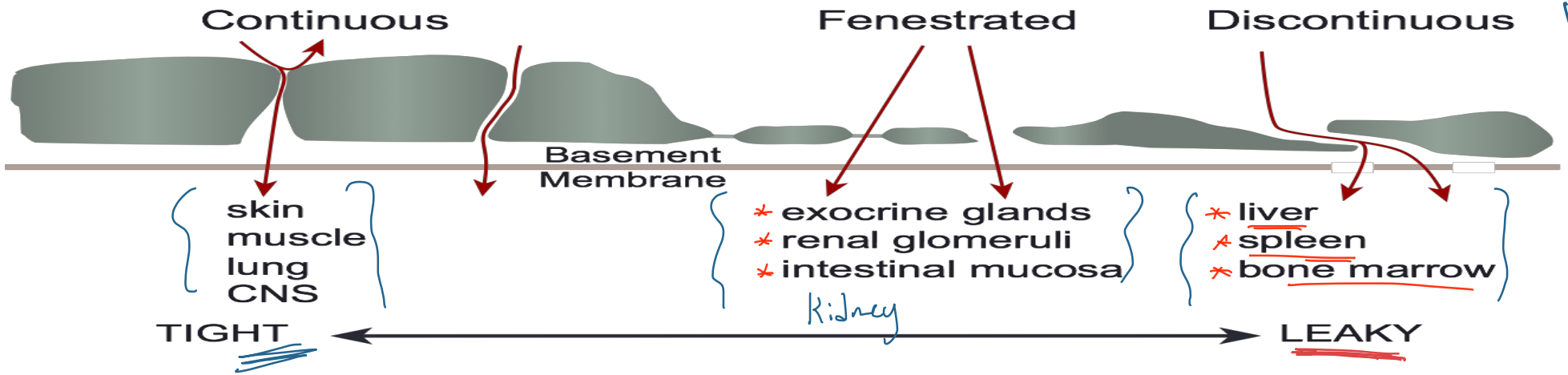
Capillaries

- Capillaries are the smallest blood vessels
  - Walls consisting of a thin tunica interna, one cell thick
    - Around 5 to 10 µm in diameter→Allow only a single RBC to pass at a time

- There are three structural types of capillaries: continuous, fenestrated, and sinusoids







* البروتينات على حسب حجمها ازا كانت small ممكن تدخل من Fenestrated الـ

Continuous Capillaries

Brain → Continuous
Kidney → Fenestrated
liver → Sinusoid

water, O_2, glucose, Amino acid

RBC, protein, Platelet ... X
Contenious ما بتقلو عبرا

- Continuous capillaries are abundant in the skin and muscles
  - Endothelial cells provide an uninterrupted lining
  - Adjacent cells are connected with tight junctions
  - Intercellular clefts allow the passage of fluids

- Continuous capillaries of the brain:
  - Have tight junctions completely around the endothelium
  - Constitute the blood-brain barrier

Continuous Capillaries

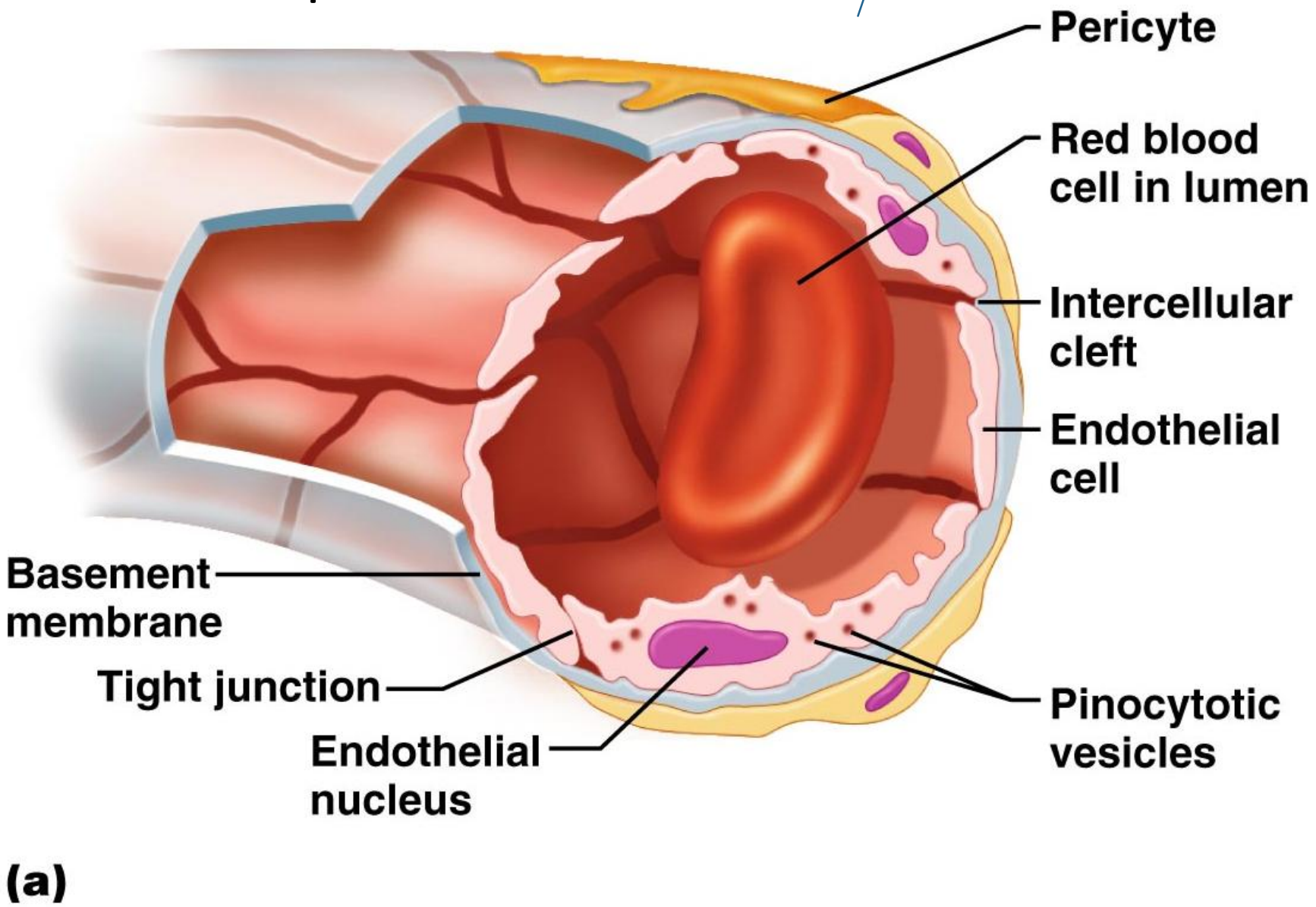
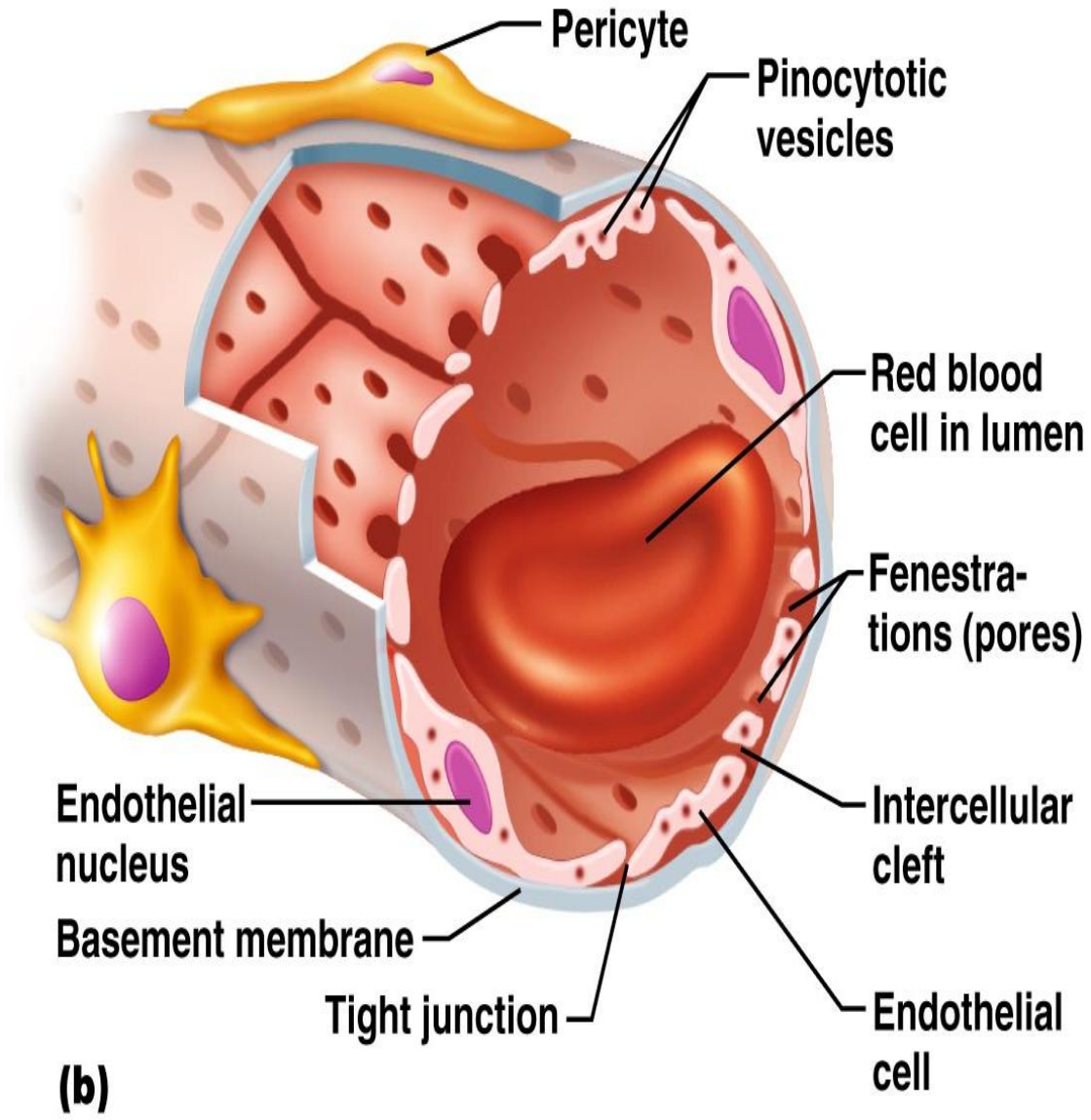


Figure 19.3a

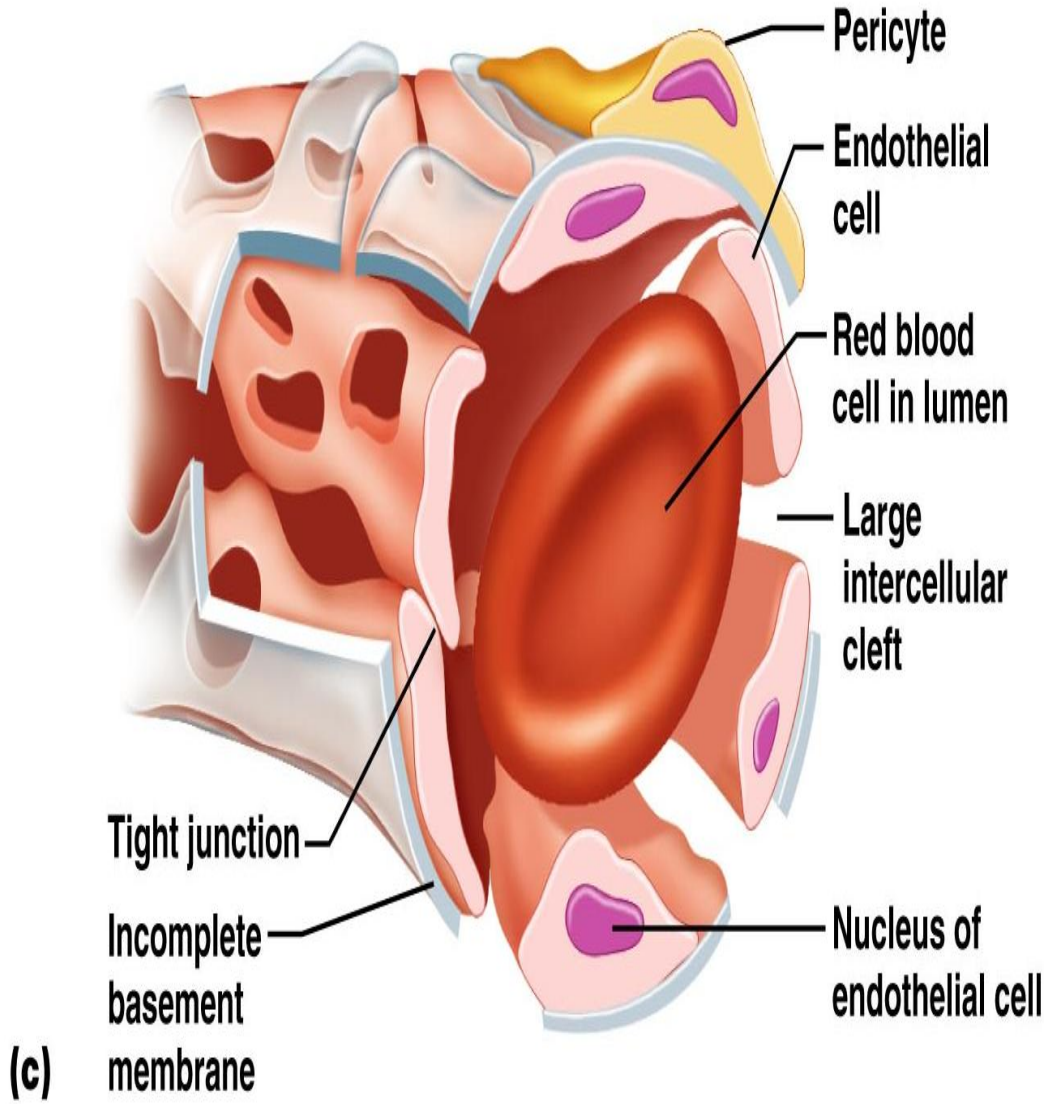
Fenestrated Capillaries

- Found wherever active capillary **absorption** or **filtrate** formation occurs (e.g., small intestines, endocrine glands, and kidneys)
- Characterized by:
  - An endothelium full of pores (fenestrations)
  - Greater permeability than other capillaries



Sinusoids

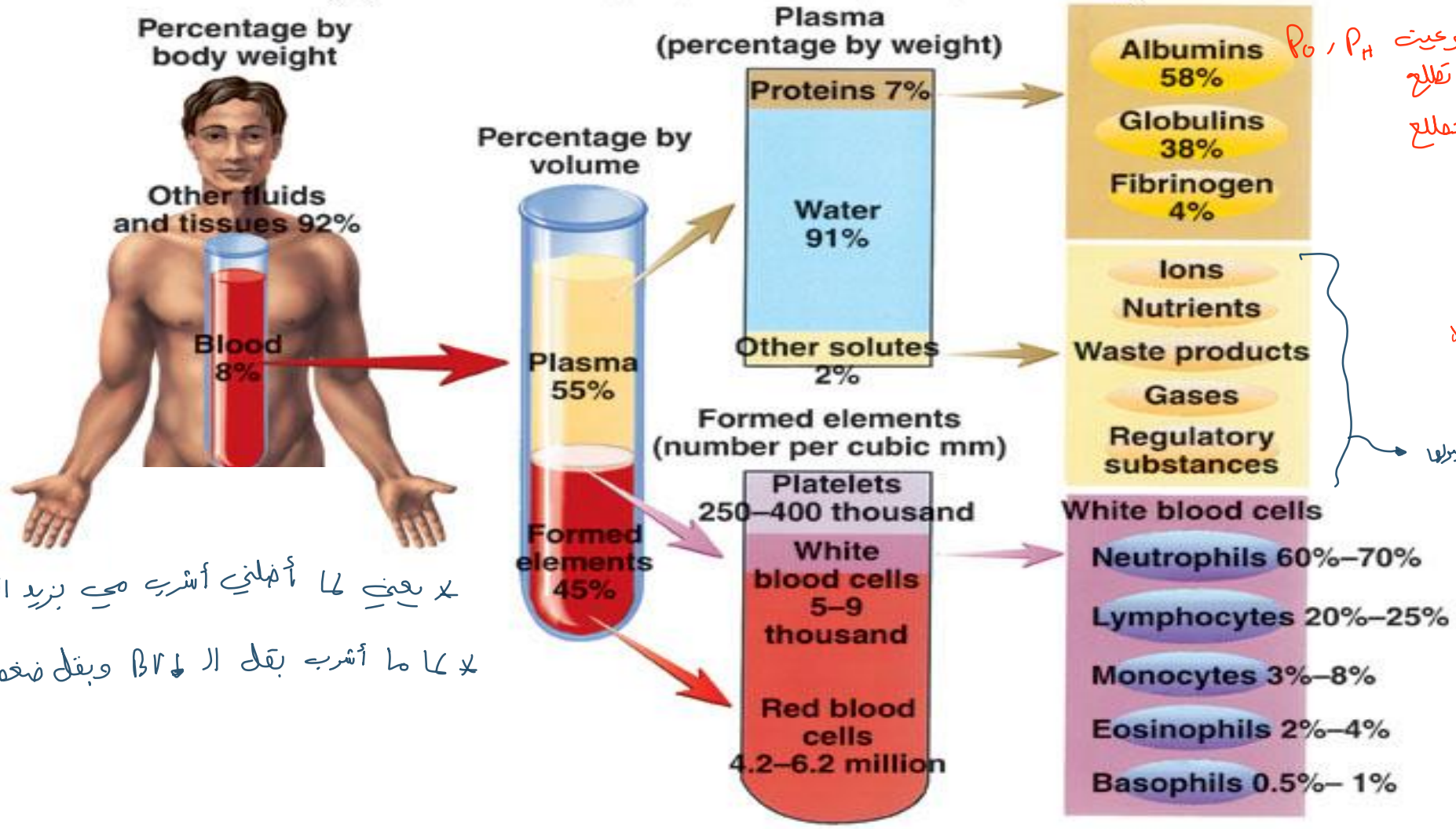
- Highly modified, **leaky**, fenestrated capillaries with large lumens & spleen
- Found in the liver, bone marrow, lymphoid tissue, and in some endocrine organs ← لهينكو بروتينات sinusoid بحاجك لا
- Allow large molecules (proteins and blood cells) to pass between the blood and surrounding tissues



Capillary Exchange

- Proteins & RBCs stay in capillary
- Water, oxygen, glucose – move out
- CO_2, wastes, water – move in

Composition of Blood



P_H = Hydrostatic pressure ← أولها هو الأعلى بعديها بقل ← الدم بتطلع برا

P_O = Orotic / Osmotic pressure ← بسحب الموا لجوا الـ Blood

* يعني أول اشي يكون P_H أعلى بعدها بيجي الـ P_O ← من أول الـ Capillary بضلو ثابت

* يعني الحالة الأعلى بين التوعيت هو اللي بيجبر انو الموا تدخل أو تطلع يعني بالبداية لما P_H اعلى الموا بتطلع

* ولما الـ P_O اعلى الموا بتدخل

* بكون Exchange

* في فترة لما الـ P_H = P_O فشو لما موا بتطلع ولما بتدخل

جدول الموا اللي بيصيرلها Exchange

* يعني لما أضلني أشرب مي بزيد الـ Blood volume BV ↑

* لما أشرب بقل الـ BV ↓ وبقل ضغطي

Exchange of Fluid between Capillaries and Tissues

- Distribution of ECF between plasma and interstitial compartments
  - Is in state of **dynamic equilibrium.**
  - Balance between tissue fluid and blood plasma.

Exchange between the plasma and interstitial fluid takes place either by:

I. **paracellular pathway** movement between endothelial cells
II. **Transcellular transport** movement through the cells

Smaller dissolved solutes and gases move by diffusion between or through the cells, depending on their lipid solubility. Larger solutes and proteins move mostly by vesicular transport

- **Diffusion**

A. Lipid soluble cpd like O2, CO2 diffuse easily through endothelial cells

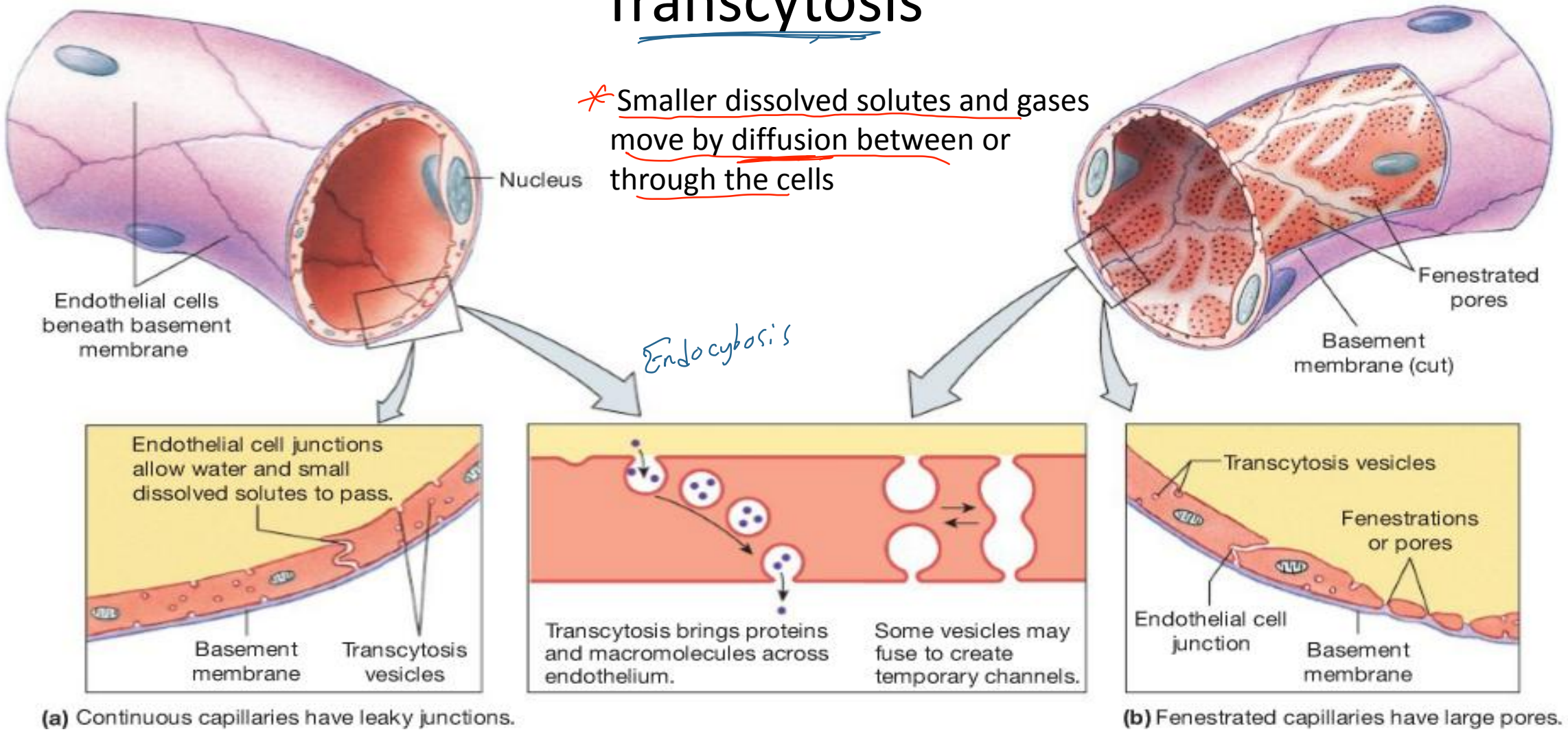
B. Ions and polar molecules are poorly soluble soluble in lipids and must pass through water filled channels

Diffusion distance is very small (1mm)

- **Mediated Transport** (channels, carriers)
- **Vesicle Transport**
- **Bulk Flow** (relate to pressure)

Most Capillary Exchange Takes Place by Diffusion and Transcytosis

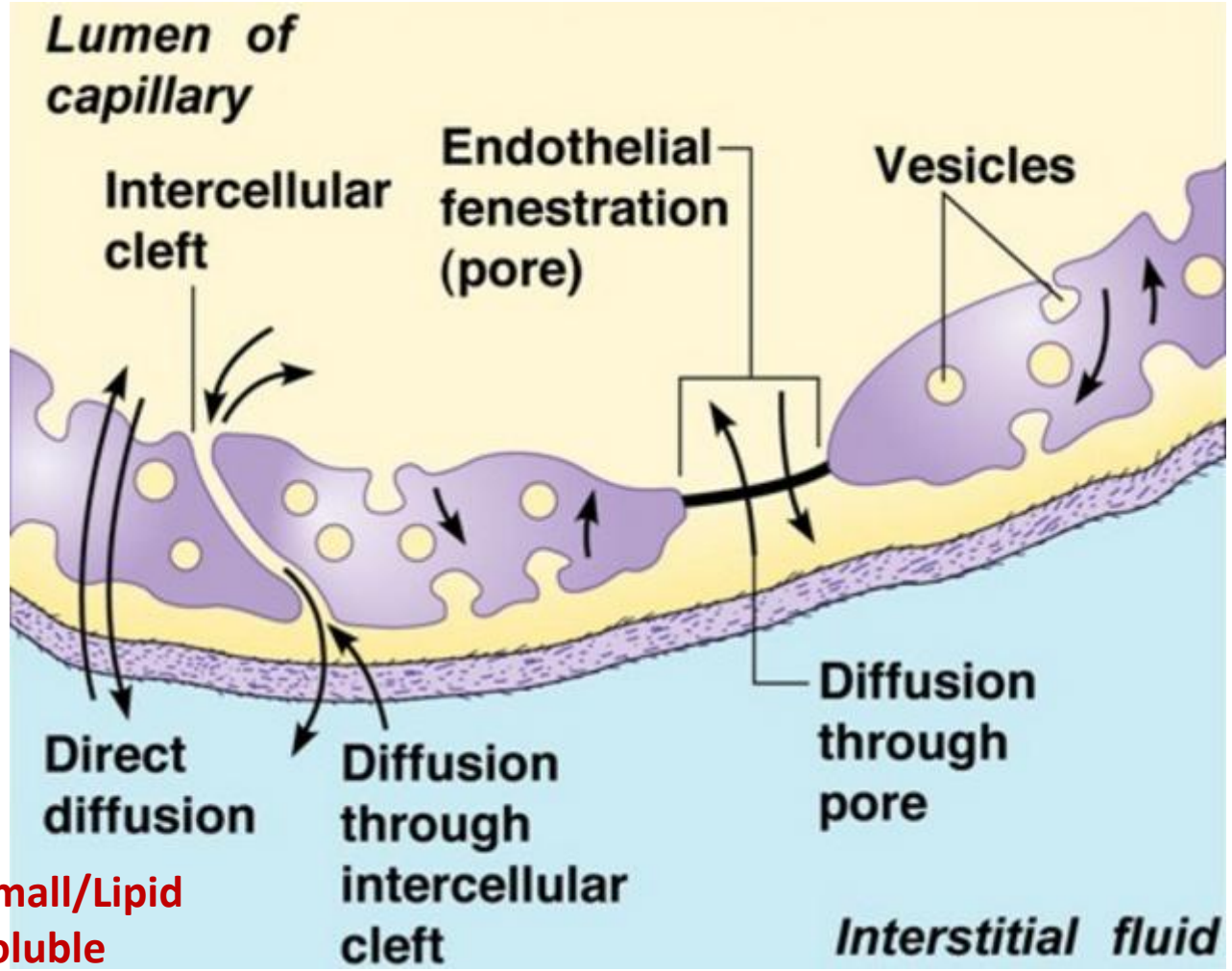
- Smaller dissolved solutes and gases move by diffusion between or through the cells



(a) Continuous capillaries have leaky junctions.

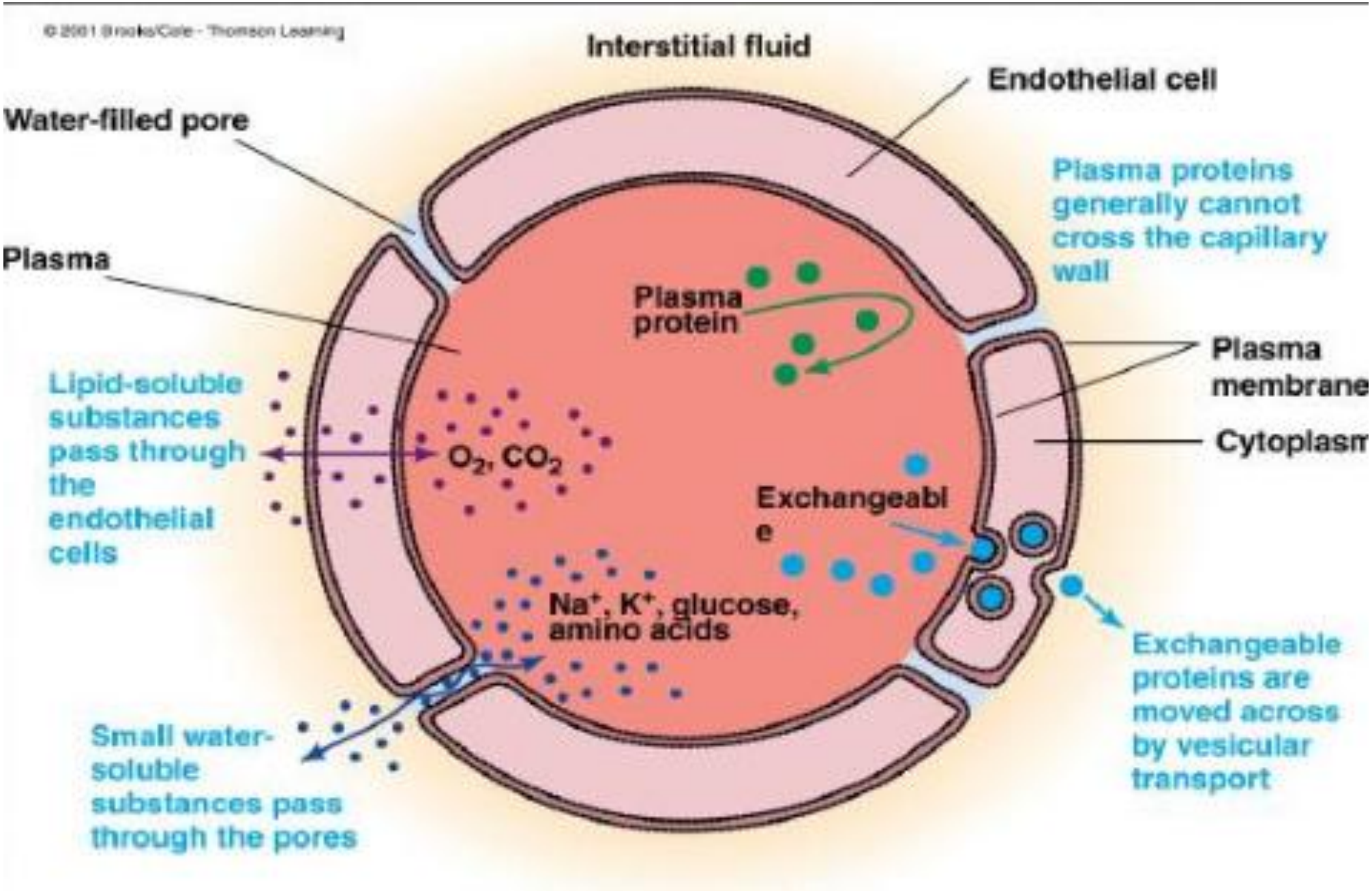
(b) Fenestrated capillaries have large pores.

- Direct diffusion across plasma membranes
- Endocytosis or exocytosis
- Some capillaries have gaps (intercellular clefts)
  - Plasma membrane not joined by tight junctions
- Fenestrations (pores) of some capillaries



Small/Lipid soluble

Water soluble substances



Capillary Exchange and Interstitial Fluid Volume Regulation

Factors affecting movement of fluid from capillaries

- **Blood pressure**
- **Capillary permeability**
- **Osmosis** H_2O

From low concentration to High concentration
From hypoosmotic to hyperosmotic

القلب (ventricles) هو اللي بجلب الـ Hydrostatic pressure

P_H = Hydrostatic pressure ← أولها هو الأعلى بعديها بقل
← الموادّ بتطلع برا

P_O = Oncotic / osmotic pressure ← من أول الـ capillary بضلو ثابت
← بسحب الموادّ لجوا الـ Blood
* يعني أول اشي بكون P_H أعلى بعدها بصير الـ P_O

البروتينات هم اللي بعملو الـ Osmotic pressure

P_O , P_H * يعني الحملة الأعلى بين التوعين هو اللي بصير انو الموادّ تدخل أو تطلع
يعني بالبداية بما P_H اعلى الموادّ بتطلع
* وبما الـ P_O اعلى الموادّ بتدخل
* بكون Exchange
* في فترة بما الـ P_H = P_O فشي بما موادّ بتطلع وبما بتدخل
* بآخر الـ Capillary الـ P_H < P_O ← Net Absorbtion

* مصنع البروتينات هو الـ Liver

Capillary Filtration and Absorption Take Place by Bulk Flow

- **Bulk flow:** mass movement of fluid between the blood and the interstitial fluid as a results of hydrostatic or osmotic pressure gradients.
- If direction into capillaries: **Absorption**
- If direction out: **Filtration**

- **Two forces regulate bulk flow in the capillaries:**

1. Hydrostatic pressure
    - Exerted against the inner capillary wall.
    - Promotes formation of tissue fluid.
    - **Net filtration pressure**.

2.Osmotic Pressure
    - Exerted by plasma proteins.
    - Promotes fluid reabsorption into circulatory system.
    - **Net absorption** in venules side

حسب الحالة اذا $P_H > P_O$ * يصير Filtration

$P_O > P_H$ * يصير Absorbtion

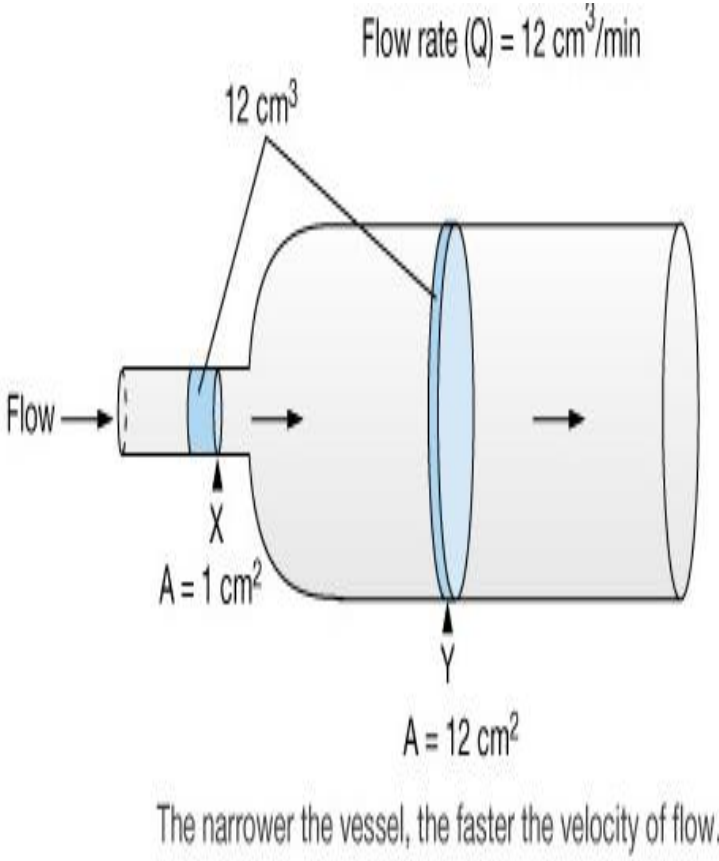
In Interstitial space ← Po = Zero

Capillary Blood Pressure

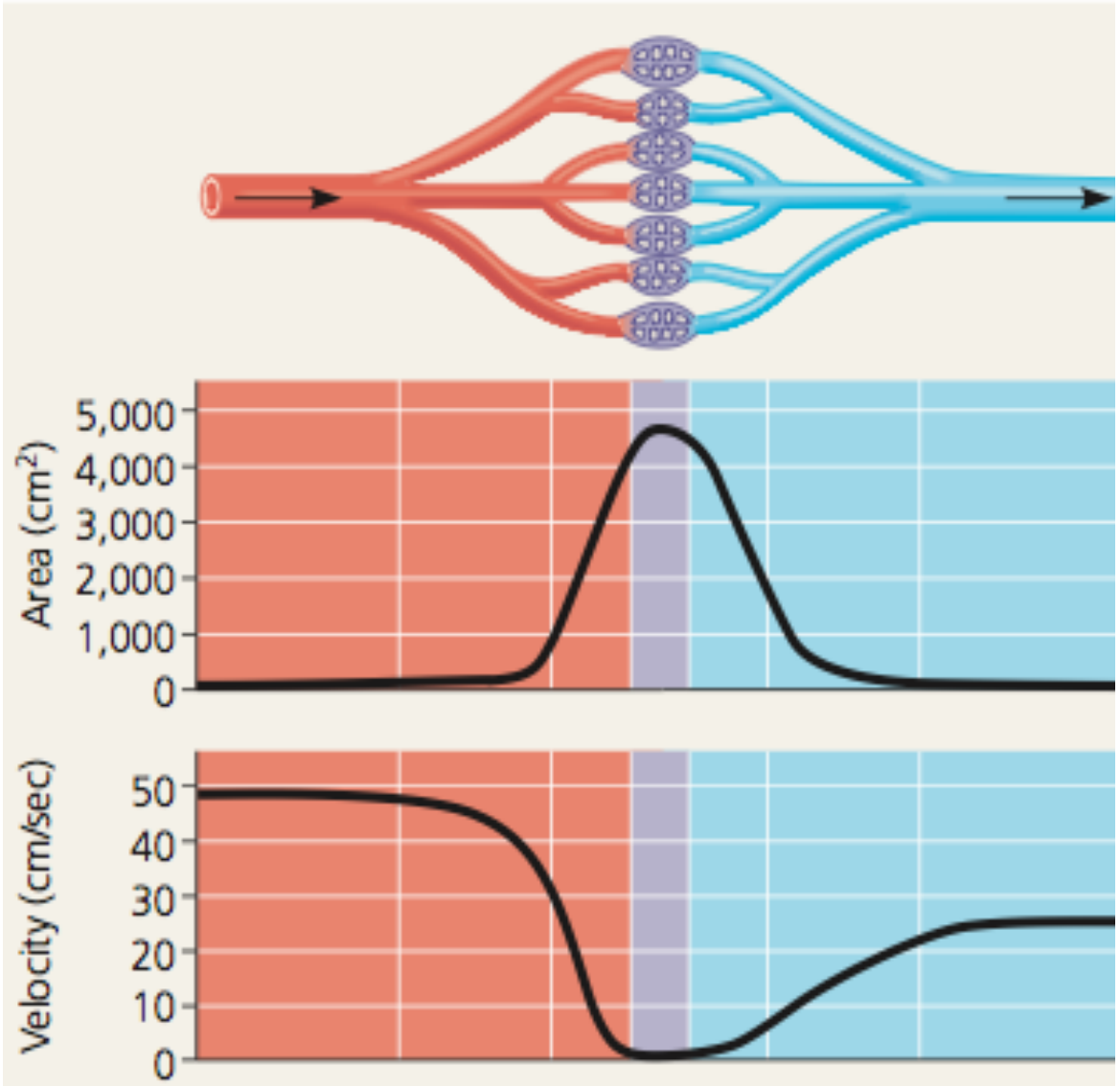
ازا صار في Inflamation البروتين بتجمع بال Interstitial space ويصير في عنا مرض اسمو Edema

لانو بالوضع الطبيعي محتوى يكون في بروتين بال Interstitial space

- Capillary BP ranges from 20 to 40 mm Hg
- Low capillary pressure is desirable because high BP would rupture fragile, thin-walled capillaries
- Low BP is sufficient to force filtrate out into interstitial space and distribute nutrients, gases, and hormones between blood and tissues



Velocity (v) = Flow rate (Q) / Cross-sectional area (A)	
At point X	**At point Y**
$v = \frac{12\ cm^3/min}{1\ cm^2}$	$v = \frac{12\ cm^3/min}{12\ cm^2}$
v = 12 cm/min	v = 1 cm/min



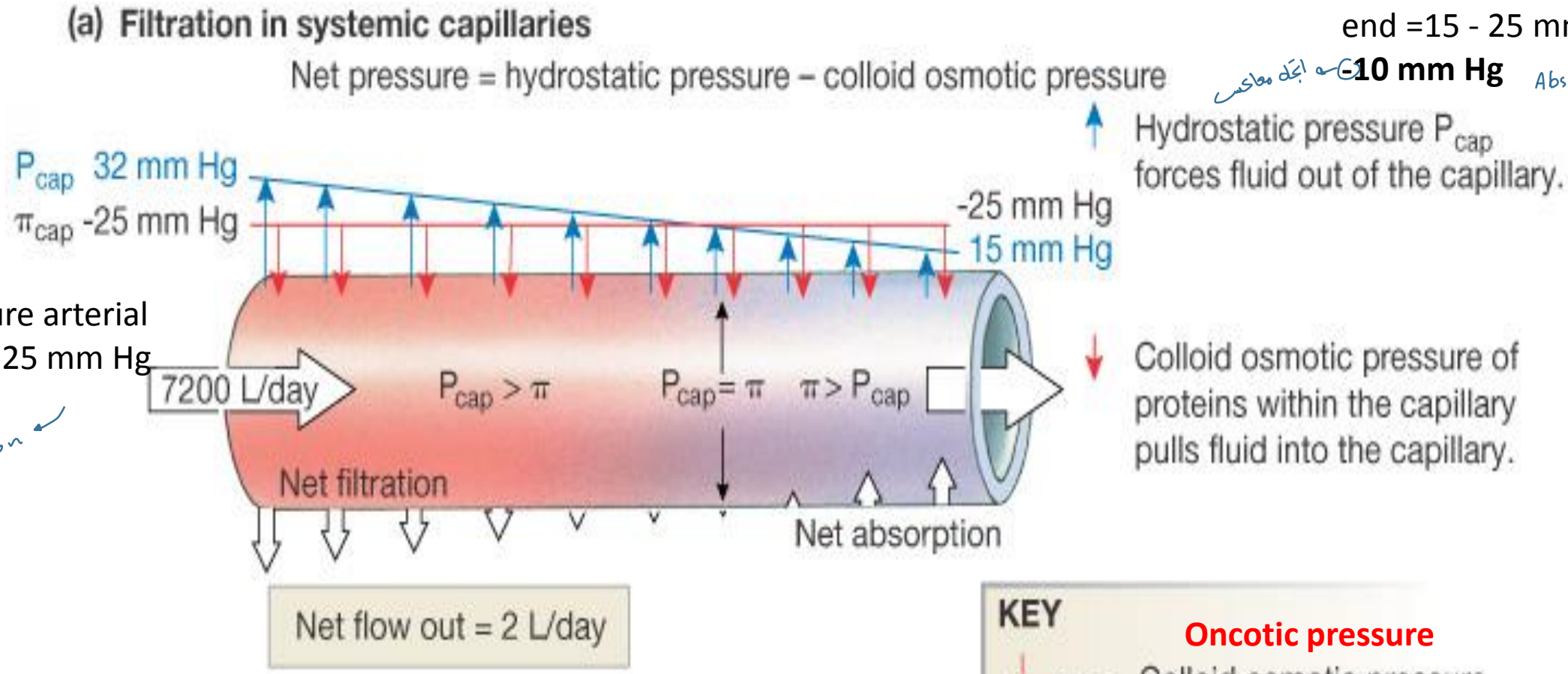
Velocity of flow is higher in a smaller vessel than in a larger vessel

From this, you might conclude that blood moves very rapidly through the capillaries because they are the smallest blood vessels. However, the primary determinant for velocity is not the diameter of an individual capillary but the **total cross-sectional area** of all the capillaries

Because the total crosssectional area of the capillaries is so large, the velocity of flow through them is low.

Capillary Exchange:
Colloidal Osmotic Pressure is Constant

Net P ressue venous end =15 - 25 mm Hg = **-10 mm Hg** Absorbtion



Net pressure arterial end = 32 - 25 mm Hg =**7 mm Hg** Filtration

At the arterial end there is net filtration, and at the venous end there is net absorption

Diffusion Rate (DR)

$DR \propto \Delta P \times S \times$ Surface area

$DR \propto \frac{1}{\text{Distance}}$

Diffusion Rate (DR)

$(P_1 - P_2)$

DRgas = **$\underline{\Delta P \text{ X } S \text{ (solubility) X SA (surface area)}}$**

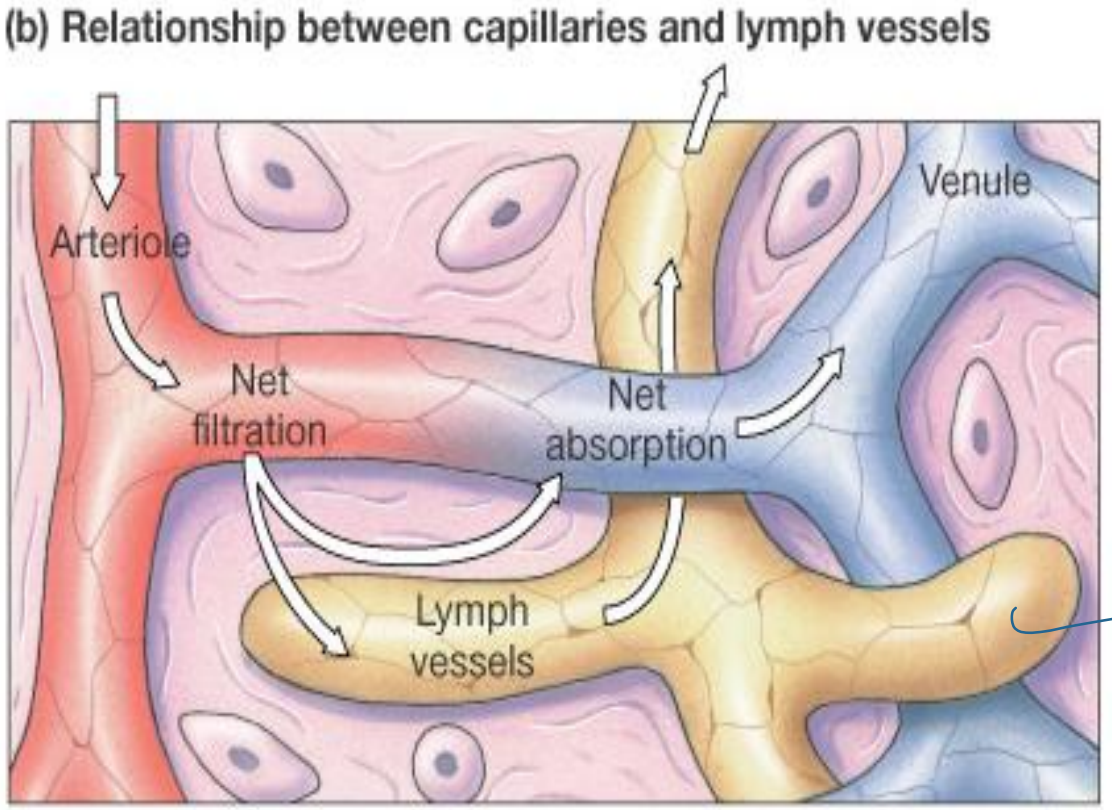
Distance

$\Delta P = \Delta HP$ (HP cap- HP isf) - ΔOP (HP cap- HP isf)

Net Out Flow Into ECF

Fluid gained by tissues is removed by lymphatic system.

- Net filtration – net absorption = net out flow
- About 2 L/day collected by lymph vessels



باخد الحي دهـ الزيادة

Lymphatic System: Structure and Roles (overview)

- The lymphatic system interacts with 3 physiologic systems:
  CVS, GIT, and immune system

- Function of lymphatic system:
  1) Returning fluid & proteins from interstitial space to the circulatory system
  2) Transport of fat from GIT to circulation
  3) Immune defense: lymphocytes & macrophages

Lymphatic System: Structure and Roles (overview)

هو باخد كل المي الجتعله بال interstitial space

* اللي بخرب هاد الجهاز هو tumor or virus

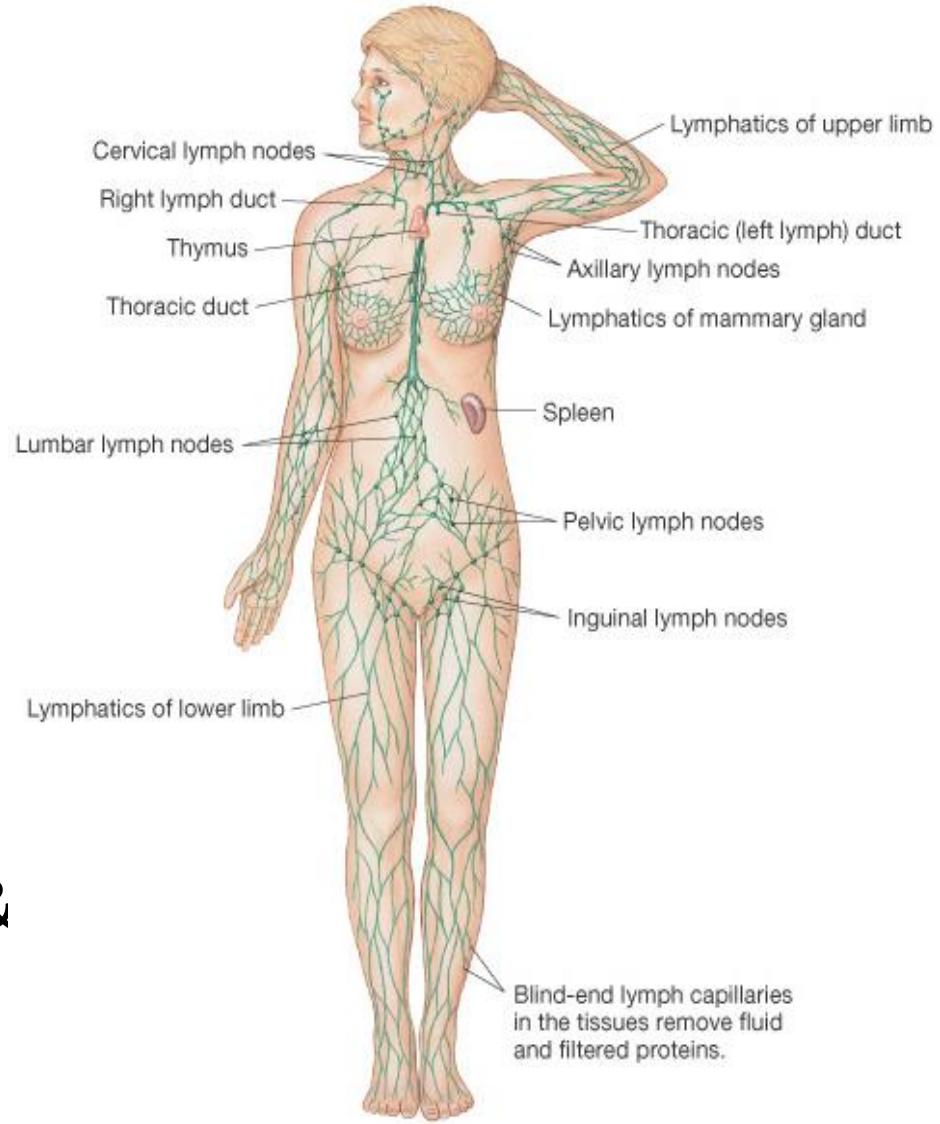
- Lymphatic structures
  - Lymph capillaries (have blind-ends)
  - Lymph vessels & valves
  - Lymph nodes & organs

- Lymph capillaries:

  - Close to blood capillaries.

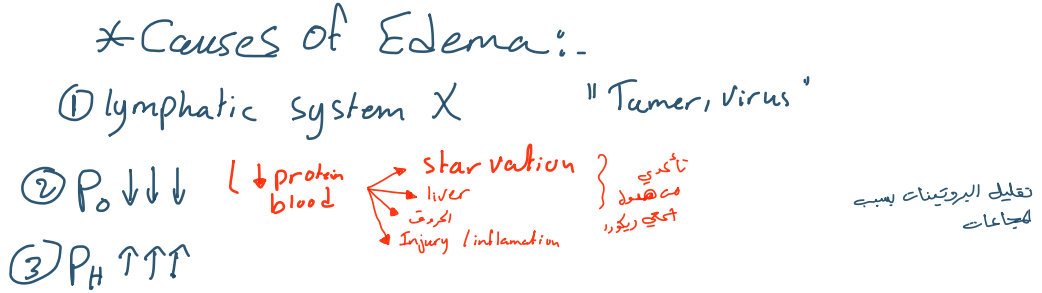
  - Single layer of flattened endothelium

  - Large gaps between cells (allow fluid, proteins & bacteria to pass into lymphatic vessels)



Lymphatic System: Structure and Roles (overview)

- Alteration in capillary exchange cause: **Edema**



Factors that disrupt the normal balance between capillary filtration and absorption include:

* العوامل اللي بتزيد الـ Hydrostatic pressure

1. **Increase in capillary hydrostatic pressure**.

(elevated venous pressure) One common cause of increased venous pressure is **heart failure** Hypertension

2. **Decrease in plasma protein concentration**.

severe malnutrition or liver failure. The liver is the main site for plasma protein synthesis.

3. **Increase in interstitial proteins**

Protein from damage of cells should be removed by (lymphatic system)

Collection of interstitial fluid: edema

- **Causes of edema:**

  1) Inadequate drainage of lymph

  2) Capillary filtration that greatly exceeds capillary absorption.

- Inadequate drainage occurs with obstruction (cancer, parasites, or fibrotic tissue due to radiation)

- Abnormal capillary filtration-absorption balance:

  1) Increase in P_{cap} (heart failure)

  2) A decrease in plasma protein levels (malnutrition, liver failure)

  3) An increase in interstitial proteins (inflammation)

Elephantiasis (lymphatic Filariasis)

Wuchereria bancrofti

Regulation of blood pressure

Blood Pressure (BP): Measurements

* ΔP : فرق الضغط بين منطقتين

* Pressure : الضغط بمنطقة معينة

* BP : systemic

- Blood pressure:
  - Systolic over diastolic
  - About 120/80 mmHg
- Pulse pressure = Systolic P – Diastolic P
  (measures the strength of the pressure wave)
- Mean arterial pressure (MAP) =

  Diastolic P + 1/3 pulse P

  Or **systolic P minus 2/3 pulse pressure**

- Sphygmomanometer

* Factors Controlling MAP :
The Driving Pressure for Blood Flow

* vasodilation → ↓ BP

1. Cardiac output
2. Arteriolar resistance

↑CO=HR x SV CVS

BV↑ P↑

Kidney: بتتحكم بكمية الماء يعني بالـ BV

Vasso Constriction Blood vessels

اللي بتحكمو بالـ pressure بالجسم

MAP α CO x R Arteriolar

↳ CO & R مع طردي

3. Blood volume
4. Distribution

BV ↑ H_2O ↑ ⟹ ↑BP

CO ↑ → ↑BP

↑R → ↑BP

"Vaso contriction"

MAP & Co. R

Control of Local Blood Flow

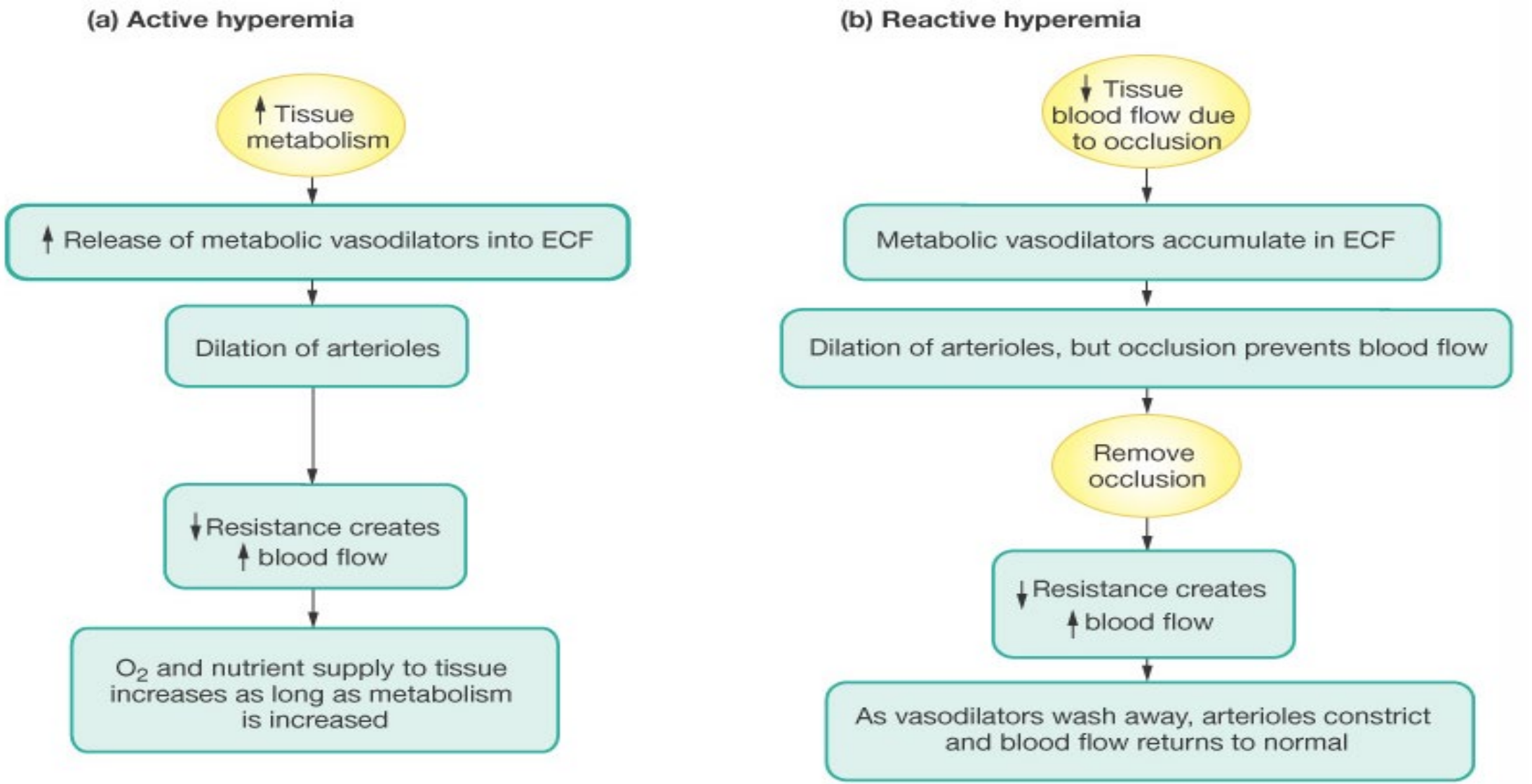
- **Myogenic autoregulation**: vascular smooth muscle has the ability regulate its own state of contraction. (Basal Tone)

- **Paracrine:**
  - Active hyperemia → الـ Tissue هم بجيبها دم كتير
  - Reactive hyperemia → اشي خارجي هلا تسكير

- **Sympathetic nerves** – CNS

Myogenic

Control of Local Blood Flow

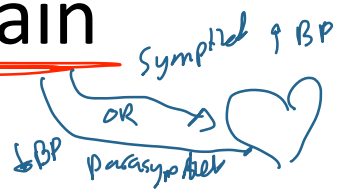


Maintaining Blood Pressure

* Hypertension عندهم اللي
بعطوهم مدر للبول
عشان يقل H_2O ↓ BV ↓ BP ←

Kidney

- Maintaining blood pressure requires:
  - Cooperation of the heart, blood vessels, and kidneys
  - Supervision of the brain

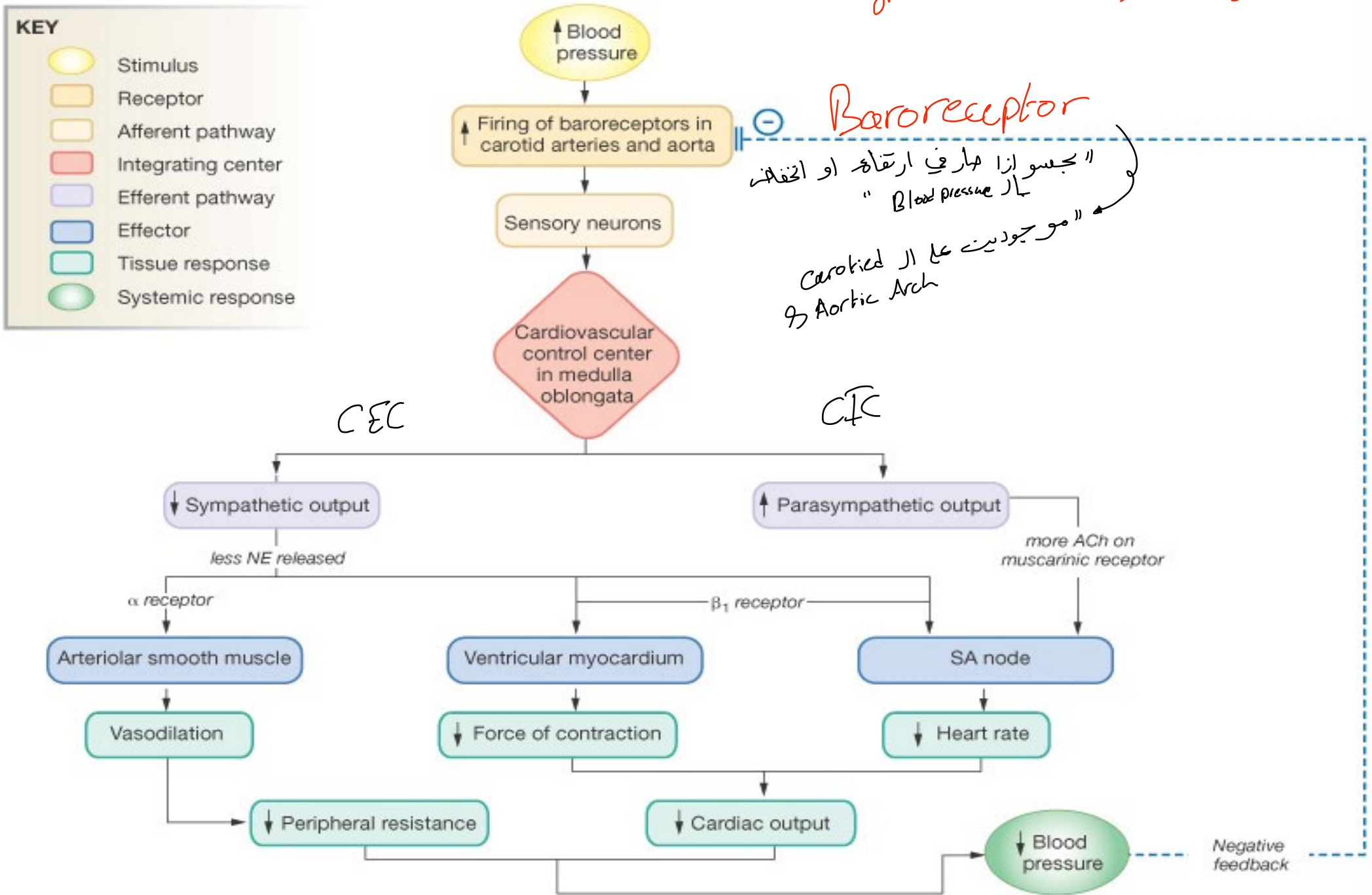


- The main factors influencing blood pressure are:
  - Cardiac output (CO)
  - Peripheral resistance (PR)
  - Blood volume

CO PR BV

Regulation of Blood Pressure

Hypertension أخطر من Hypotension *



Controls of Blood Pressure

- **Short-term controls**:
  - Are mediated by the **nervous system** and **blood borne** chemicals
  - Counteract moment-to-moment fluctuations in blood pressure by altering peripheral resistance
  1. **Baroreceptor reflex** (pressure sensitive)
  2. **Chemoreceptor reflex** ($\downarrow O_2$, $\uparrow CO_2$, and $\uparrow H^+$ sensitive)
  3. **Hormones**: epinephrine, norepinephrine/ ADH / ANP

- **Long-term controls** regulate blood volume
  1. **Renin angiotensin Aldosterone** Kidney

Cardiovascular Center in Medulla Oblongata

Control Center for heart and blood vessels

In medulla Oblingata

Cardiovascular center –**cardiac centers** plus the **vasomotor center** that integrate blood pressure control by altering cardiac output and blood vessel diameter

A. Cardio center

Autonomic of the heart

- Cardioaccelatory center: sympathetic CEC
- Cardioinhibitory center: Parasympathatic CIC

B. Vasomotor center → "Sympthetic" just

Autonomic control of the heart

-Stimulation of vasomotor center: Vasoconstriction (Sympathatic)

- Inhibition of vasomotor center: Vasodilation

External Innervation

Higher centres in Cerebral Cortex:

↓ ↓

<u>Hypothalamus</u>:

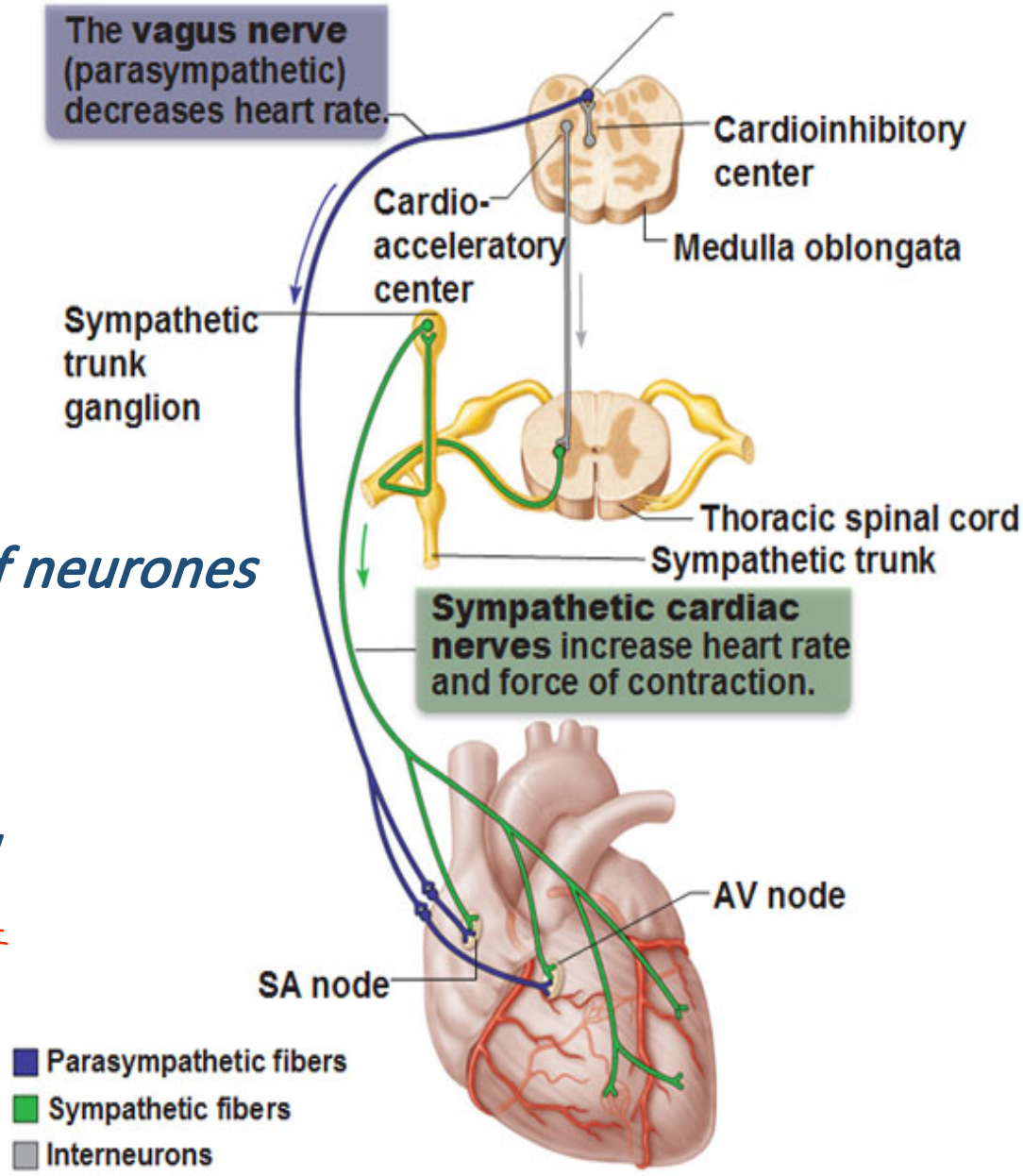
Posterior group of neurones *Middle group of neurones*

↓ ↓

Medulla oblongata:

Cadio-acceleratory centre **Cardioinhibitory centre**

Sympthetic Parasympathetic



Cardio-vascular regulation

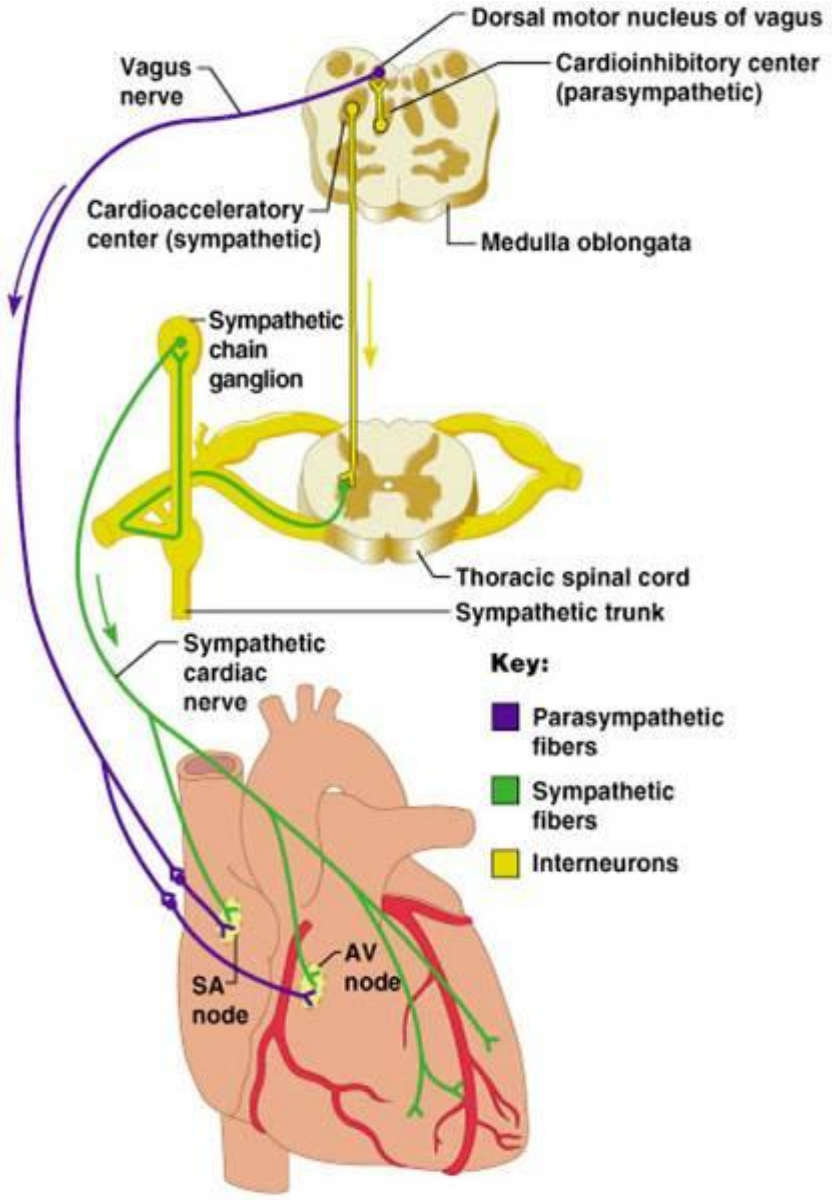
- Middle Group of Neurons (MGN) (hypothalamus)

Cardio-inhibitory centres (CIC)
(Medulla Oblongata)

Connected to Parasympathetic nerve through Efferent Vagus (release of Ach neurotransmitter)

Muscarinic receptors on SA node

Stimulation = ↓ HR & ↓ BP



Posterior Group of Neurons (PGN)

(hypothalamus)

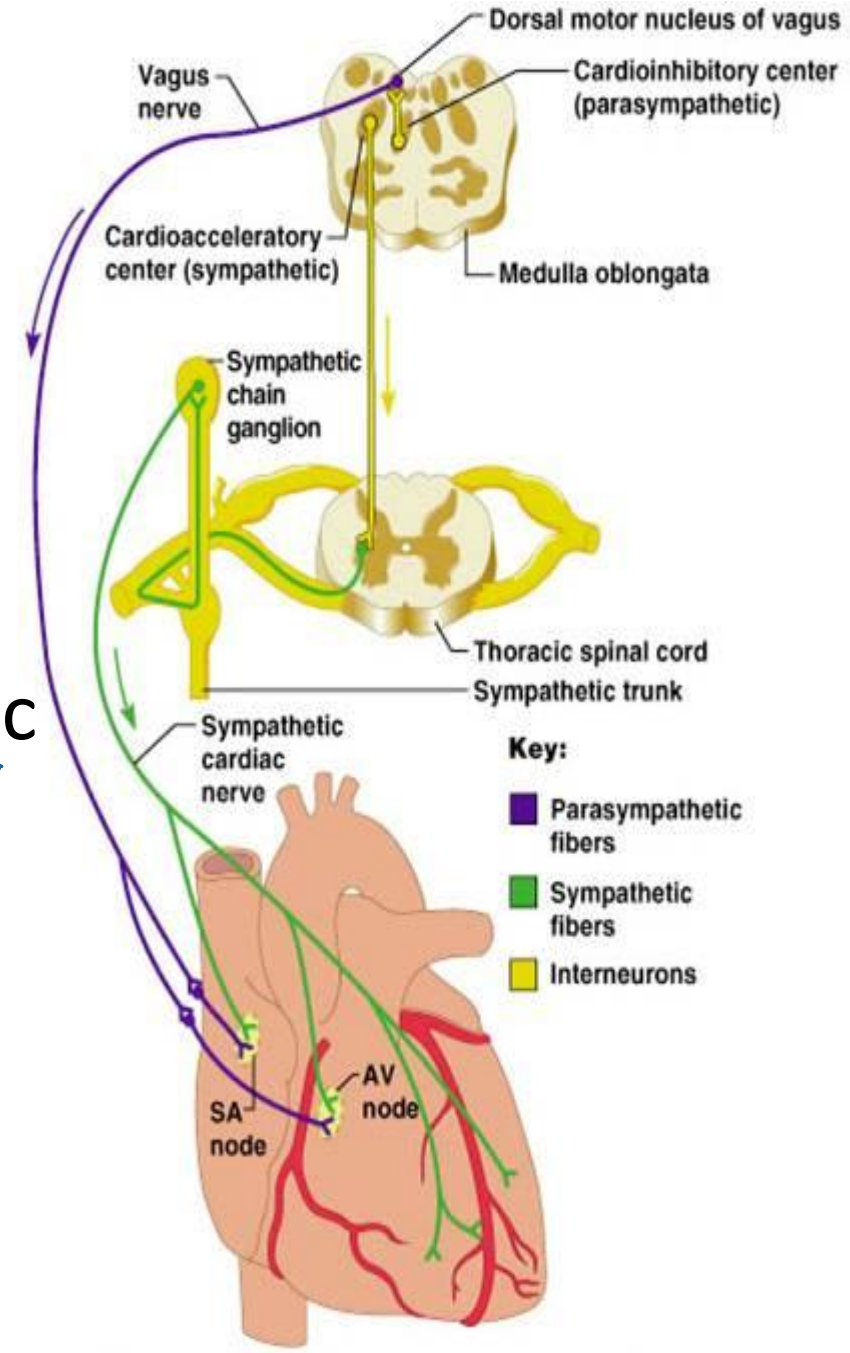
Cardio-acceleratory centres (CEC)

(Medulla Oblongata)

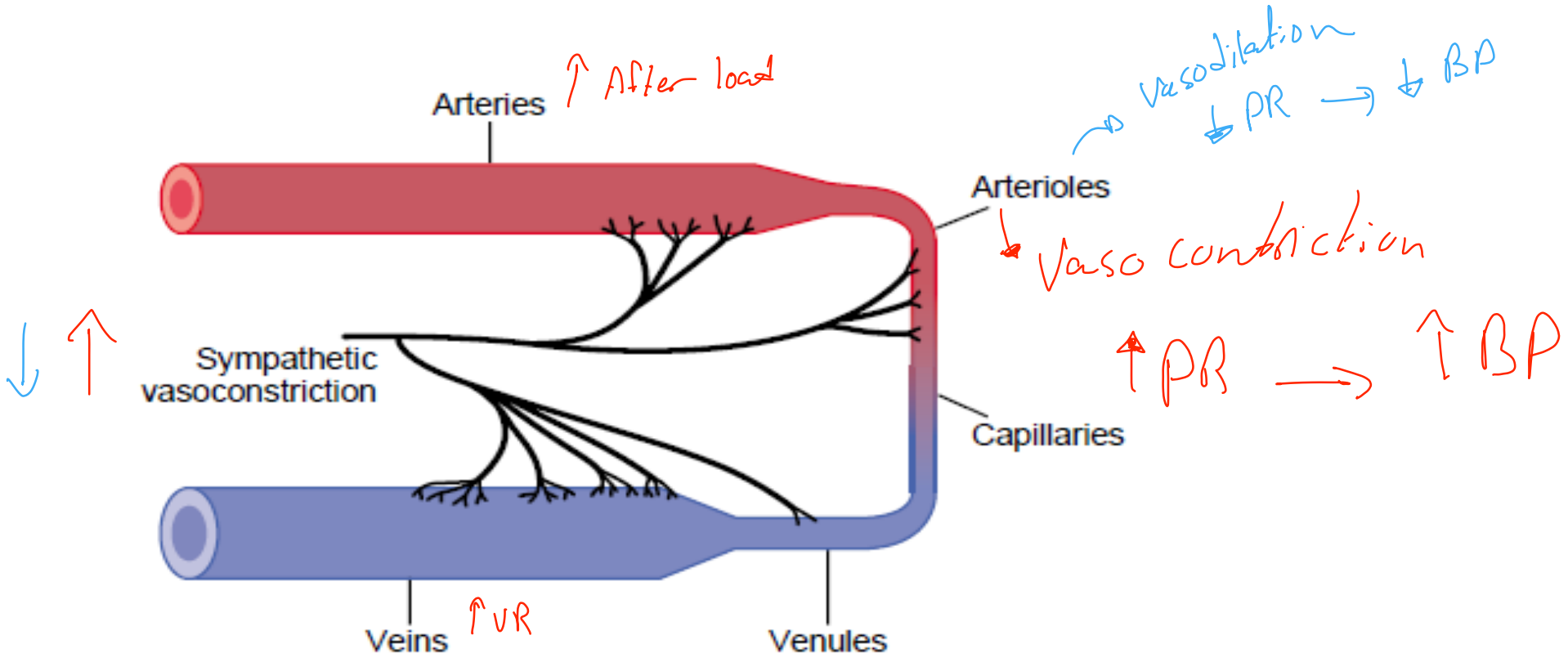
Connected to Sympathetic nerve through cardiac plexus (release of adrenaline neurotransmitter)

Beta receptors on SA node

Stimulation = ⬆HR & ⬆BP

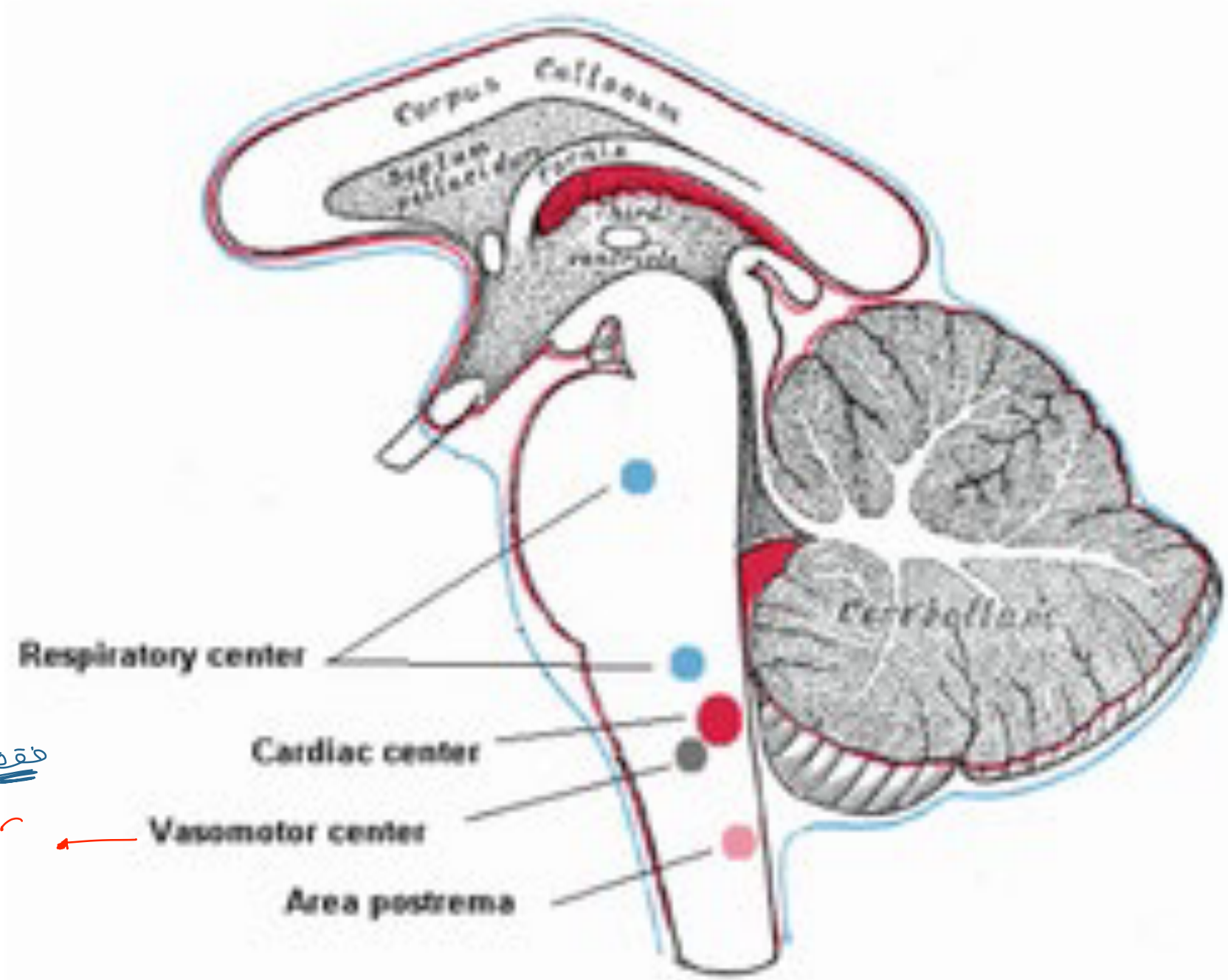


Sympathetic innervation of the circulation



The sympathetic vasoconstrictor innervation:

kidneys, intestines, spleen, and skin >> skeletal muscle and brain.



Sympathetic motor neurons "Efferent"

Vasomotor Center (VMC) in the Brain

Vasomotor center – a cluster of sympathetic neurons in the medulla that oversees changes in blood vessel diameter

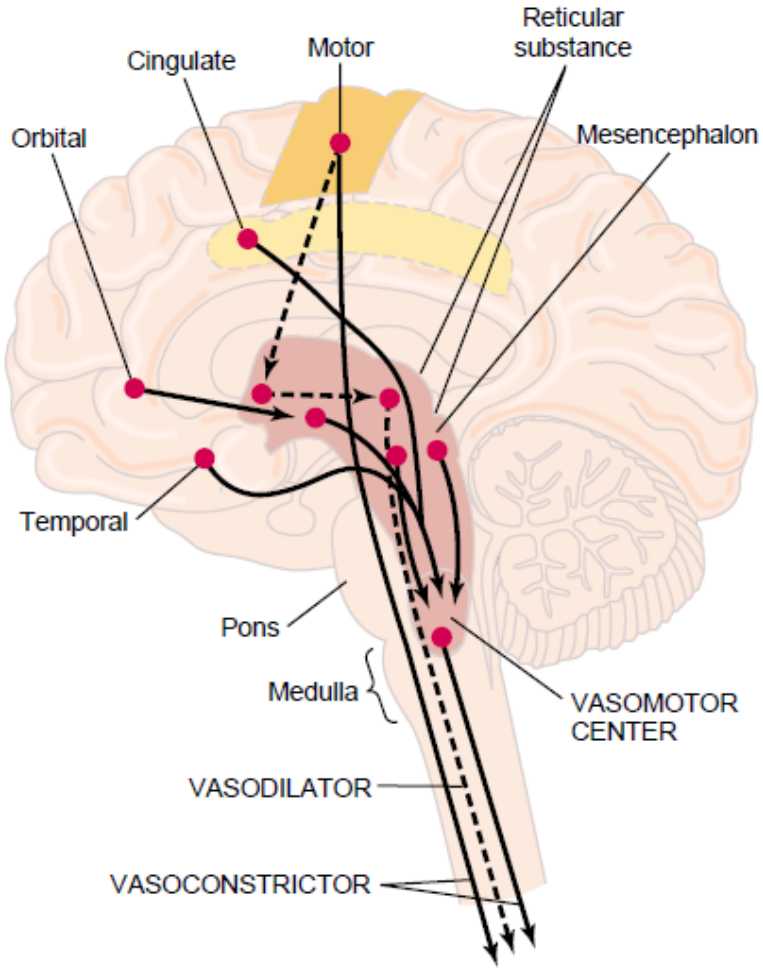
Maintains blood vessel tone by innervating smooth muscles of blood vessels, especially arterioles

There are 3 important areas in this centre:

1) **A vasoconstrictor area**: secretes NE

2) **A vasodilator area**: its fibres project upward t the vasoconstrictor area and inhibit it causing vasodilatation

3) A sensory area: receives sensory nerve signals from the vagus and glossopharyngeal nerves the it control the vasoconstrictor and vasodilator centers



Reflexes:

Vasoconstrictor reflexes

- **Stimuli** by:
  - Unpleasant stimuli (Pain, Loud noise, cold)
  - Psychotic or emotional factors (fears, excitement)
  - Increase CO_2 (hypercapnia) or sever O_2 (hypoxia)
  - Decrease blood temperature
  - Spread activity of respiratory centres (during insp)

- **Response**:
- Vasomotor center sends impulses to keep arterioles partially constricted (vasoconstriction)

Reflexes:

Vasodilator reflexes

- **Stimuli** by:
  - Pleasant stimuli (Warmth)
  - Psychotic or emotional factors (good news, satisfaction)
  - Decrease CO2
  - Increase blood temperature
  - Reflexes from salivary secretions

- **Response**:
- Vasomotor center sends impulses to keep arterioles dilated (vasodilation)

↓PR ↓BP

Short-Term Mechanisms: Neural Controls

- Neural controls of peripheral resistance:
  - Alter blood distribution in response to demands (ex: metarteriol sphincters)
  - Maintain MAP by altering blood vessel diameter

- Neural controls operate via reflex involving:
  - Baroreceptors
  - Vasomotor centers and vasomotor fibers
  - Vascular smooth muscle

Short-Term Mechanisms: Vasomotor Activity

- Sympathetic activity causes:
  - Vasoconstriction and a rise in BP if increased
  - BP to decline to basal levels if decreased

- Vasomotor activity is modified by:
  - Baroreceptors (pressure-sensitive)
  - chemoreceptors (O_2, CO_2, and H^+ sensitive)
  - higher brain centers
  - bloodborne chemicals and hormones

Control of the Vasomotor Center by Higher Nervous Centers.

Hypothalamus:

- Is higher integrated center of autonomic system, including feeding, regulation of body temperature, fluid balance and endocrine secretion.
- It **has a powerful excitatory or inhibitory** effects on the vasomotor center.

The *posterolateral portions* of the hypothalamus cause mainly excitation, so increases HR & BP

- The *anterior portion* can cause either mild excitation or inhibition, depending on the precise part of the anterior hypothalamus stimulated.

Control of the Vasomotor Center by Higher Nervous Centers.

Cerebral cortex

By affecting hypothalamus then VMC

- Many parts of the *cerebral cortex* can also excite or inhibit the vasomotor center.

(1) Limbic area regulates the activity of lower centers.

(2) Responses of BP to pain, anxiety and during exercise.

Short-Term Mechanisms: Baroreceptor-Initiated Reflexes

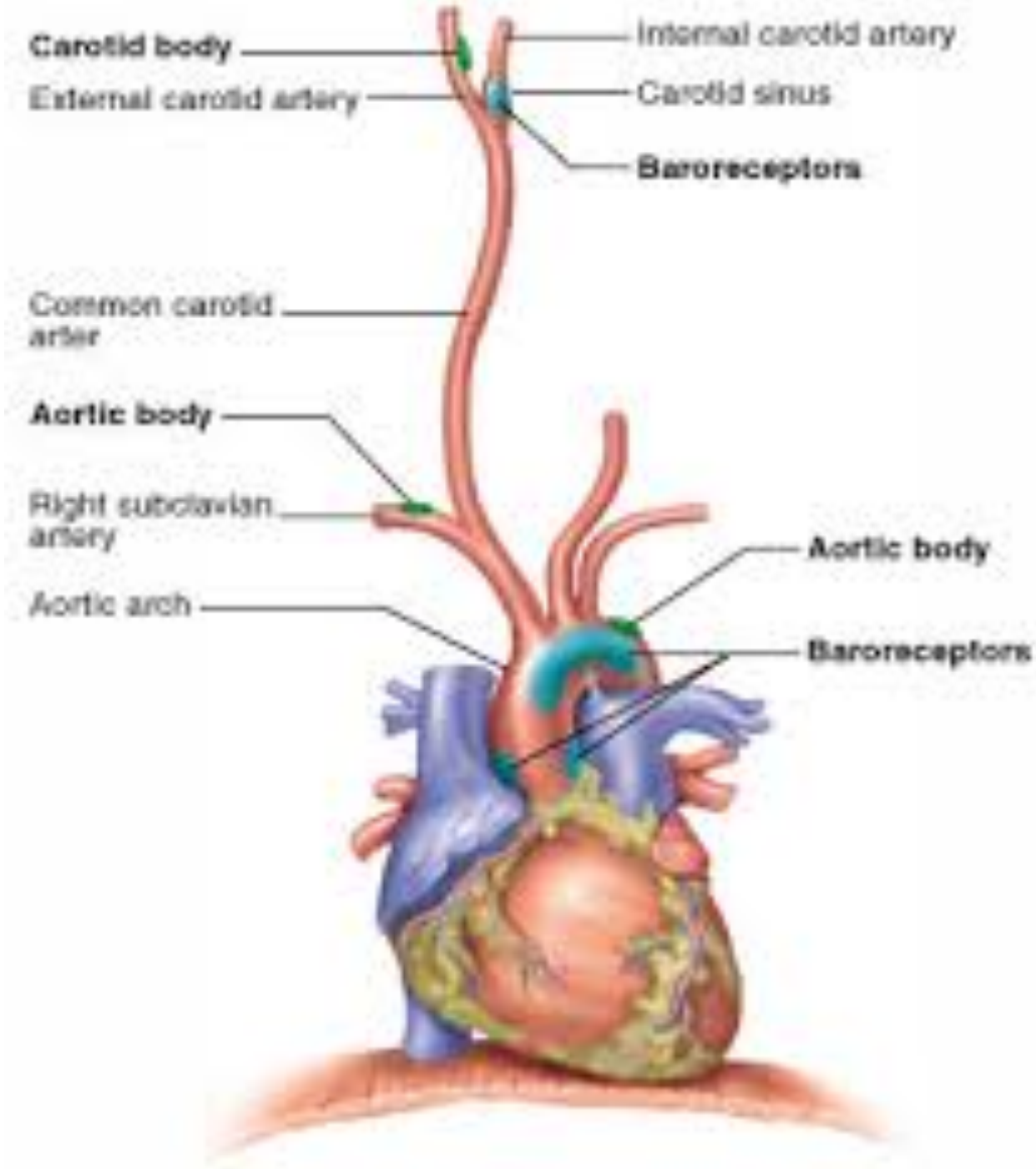
- Increased blood pressure stimulates the **cardioinhibitory center** to:
  - Increase vessel diameter
  - Decrease heart rate, cardiac output, peripheral resistance, and blood pressure

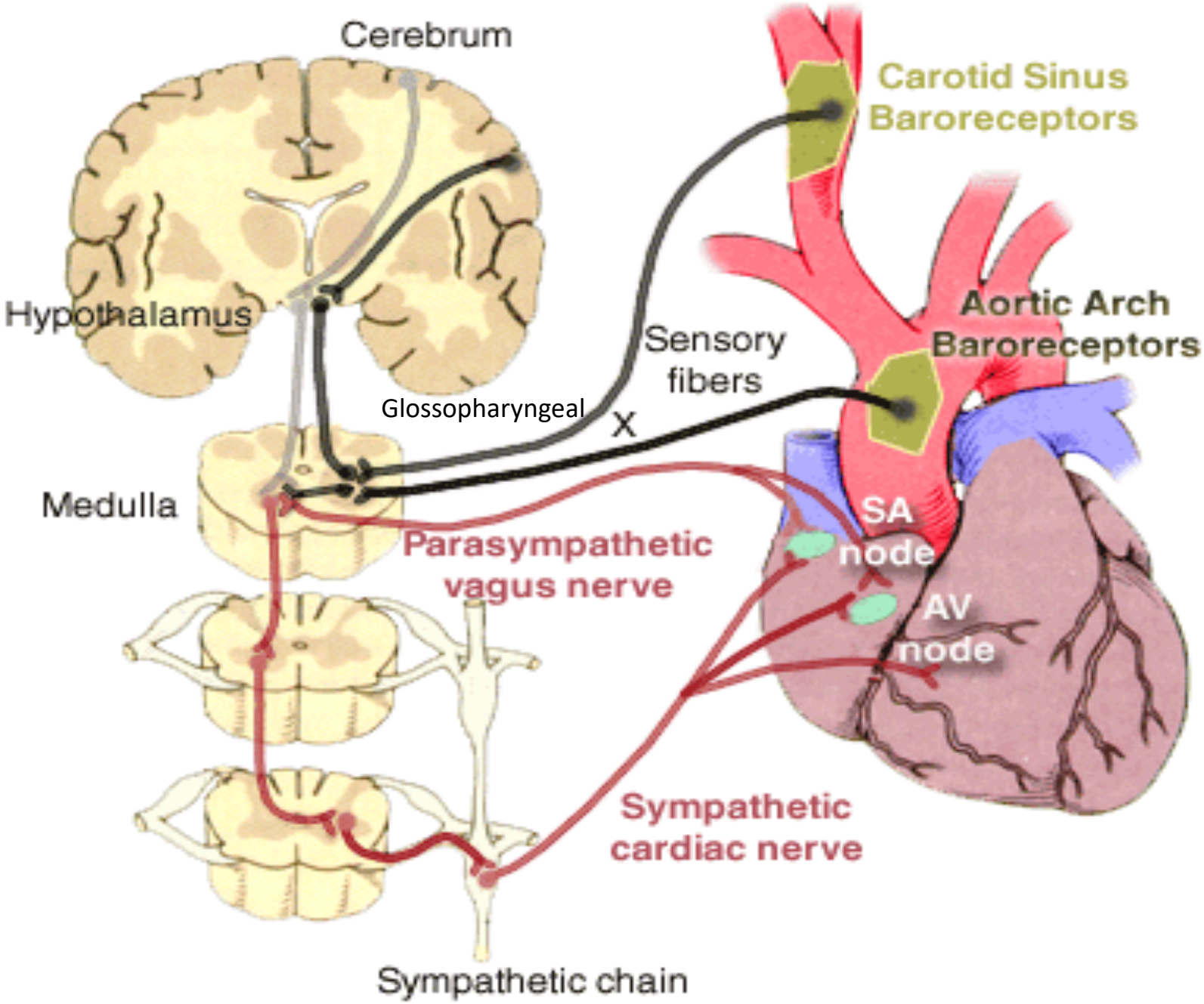
CIC

- Declining blood pressure stimulates the **cardioacceleratory center** to:
  - Increase cardiac output and peripheral resistance

CEC

- Low blood pressure also stimulates the **vasomotor center** to constrict blood vessels


Carotid body
External carotid artery
Internal carotid artery
Carotid sinus
Baroreceptors
Common carotid artery
Aortic body
Right subclavian artery
Aortic arch
Aortic body
Baroreceptors


Cerebrum
Carotid Sinus
Baroreceptors
Hypothalamus
Sensory
fibers
Aortic Arch
Baroreceptors
Glossopharyngeal
X
Medulla
SA
node
Parasympathetic
vagus nerve
AV
node
Sympathetic
cardiac nerve
Sympathetic chain

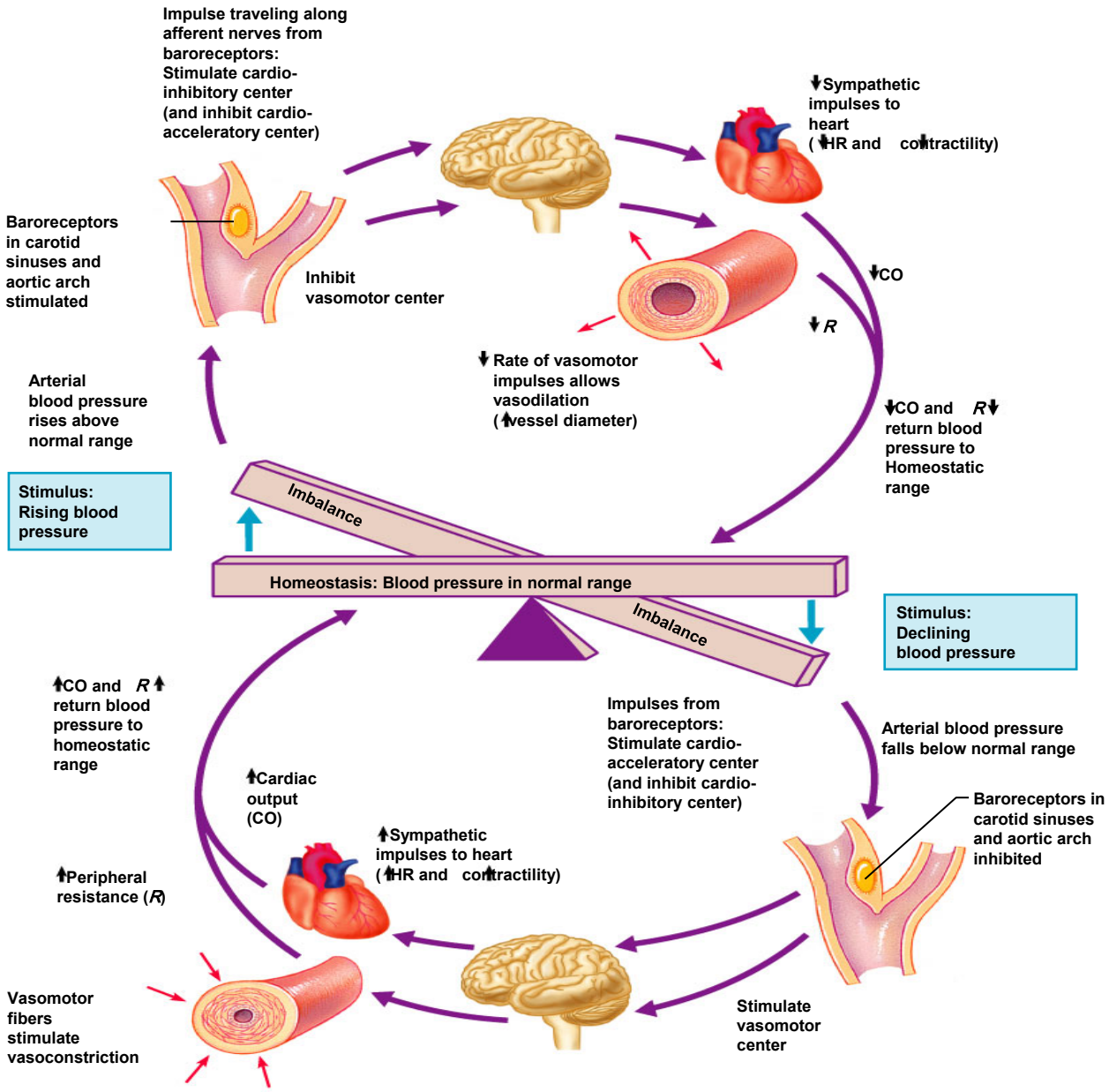

Impulse traveling along afferent nerves from baroreceptors: Stimulate cardio-inhibitory center (and inhibit cardio-acceleratory center)
Sympathetic impulses to heart (HR and contractility)
Baroreceptors in carotid sinuses and aortic arch stimulated
Inhibit vasomotor center
CO
R
Rate of vasomotor impulses allows vasodilation (vessel diameter)
Arterial blood pressure rises above normal range
CO and R return blood pressure to Homeostatic range
Stimulus: Rising blood pressure
Imbalance
Homeostasis: Blood pressure in normal range
Imbalance
Stimulus: Declining blood pressure
CO and R return blood pressure to homeostatic range
Impulses from baroreceptors: Stimulate cardio-acceleratory center (and inhibit cardio-inhibitory center)
Arterial blood pressure falls below normal range
Cardiac output (CO)
Sympathetic impulses to heart (HR and contractility)
Baroreceptors in carotid sinuses and aortic arch inhibited
Peripheral resistance (R)
Vasomotor fibers stimulate vasoconstriction
Stimulate vasomotor center

Figure 19.8

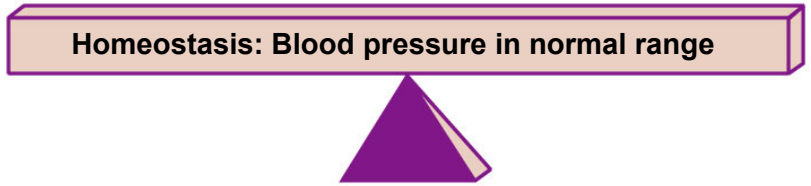


Figure 19.8

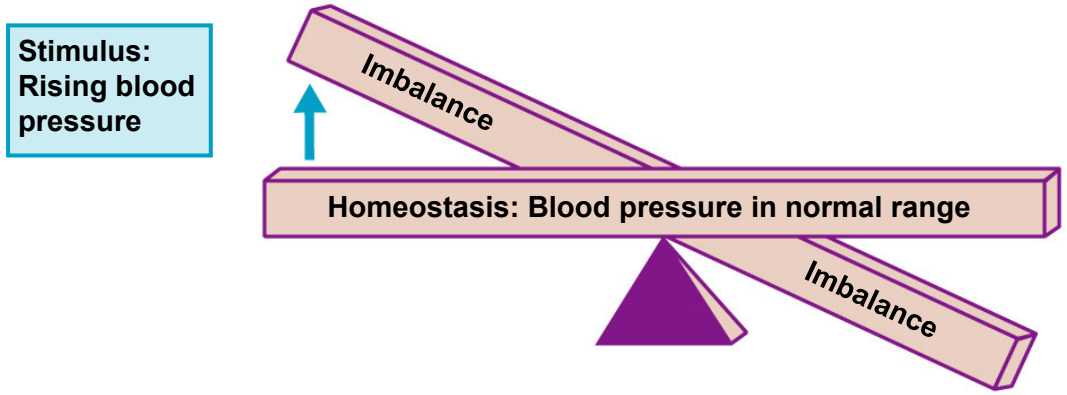
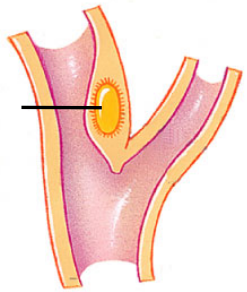

Stimulus:
Rising blood pressure
Imbalance
Homeostasis: Blood pressure in normal range
Imbalance

Figure 19.8

يحس بزيادة Blood pressure ←

Baroreceptors in carotid sinuses and aortic arch stimulated



Arterial blood pressure rises above normal range

Stimulus: Rising blood pressure

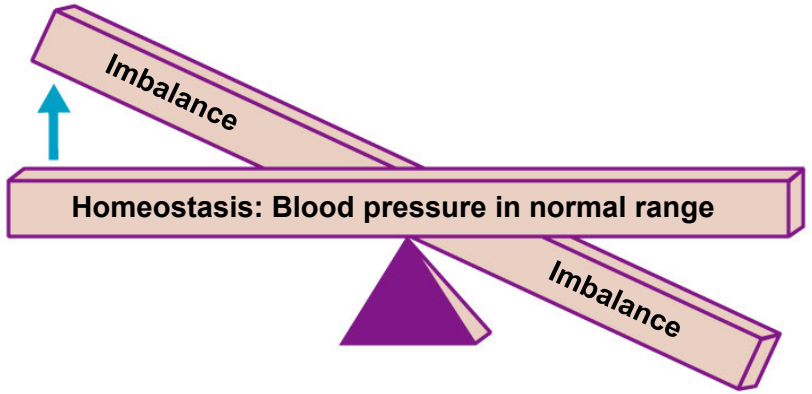


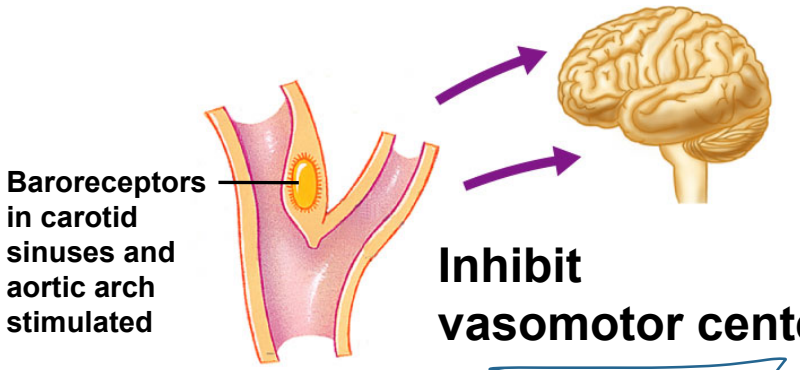
Figure 19.8

Impulse traveling along afferent nerves from baroreceptors: Stimulate cardio- Inhibitory center (and inhibit cardio-acceleratory center)

parasympthetic ↑

↓ sympthetic

↓ sympthetic



Baroreceptors in carotid sinuses and aortic arch stimulated

Inhibit vasomotor center

Arterial blood pressure rises above normal range

Stimulus: Rising blood pressure

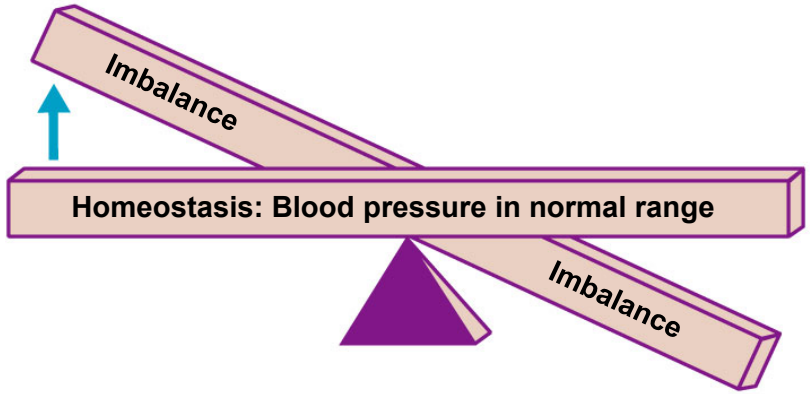


Figure 19.8

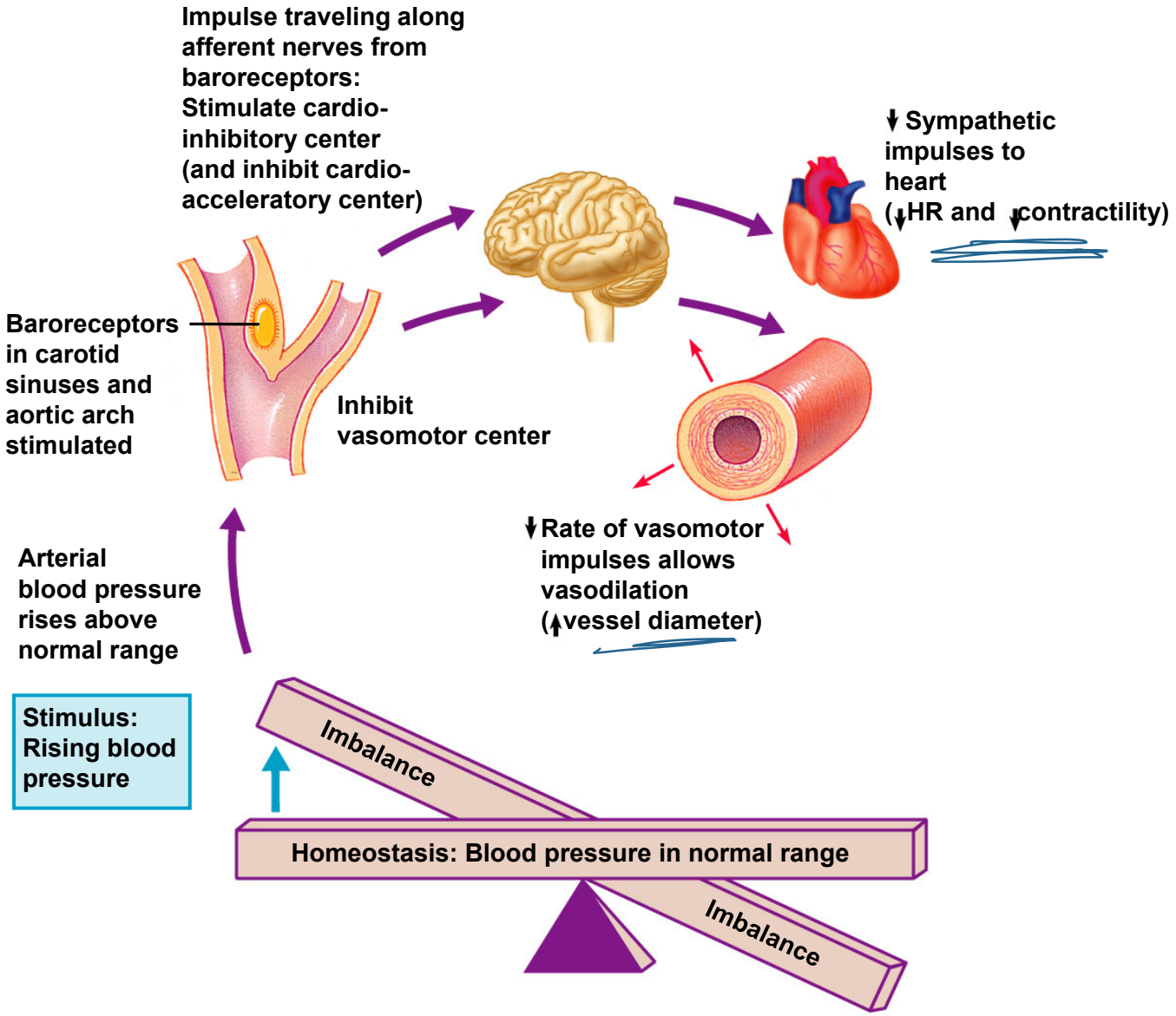

Impulse traveling along afferent nerves from baroreceptors: Stimulate cardio-inhibitory center (and inhibit cardio-acceleratory center)
Sympathetic impulses to heart (HR and contractility)
Baroreceptors in carotid sinuses and aortic arch stimulated
Inhibit vasomotor center
Rate of vasomotor impulses allows vasodilation (vessel diameter)
Arterial blood pressure rises above normal range
Stimulus: Rising blood pressure
Imbalance
Homeostasis: Blood pressure in normal range
Imbalance

Figure 19.8

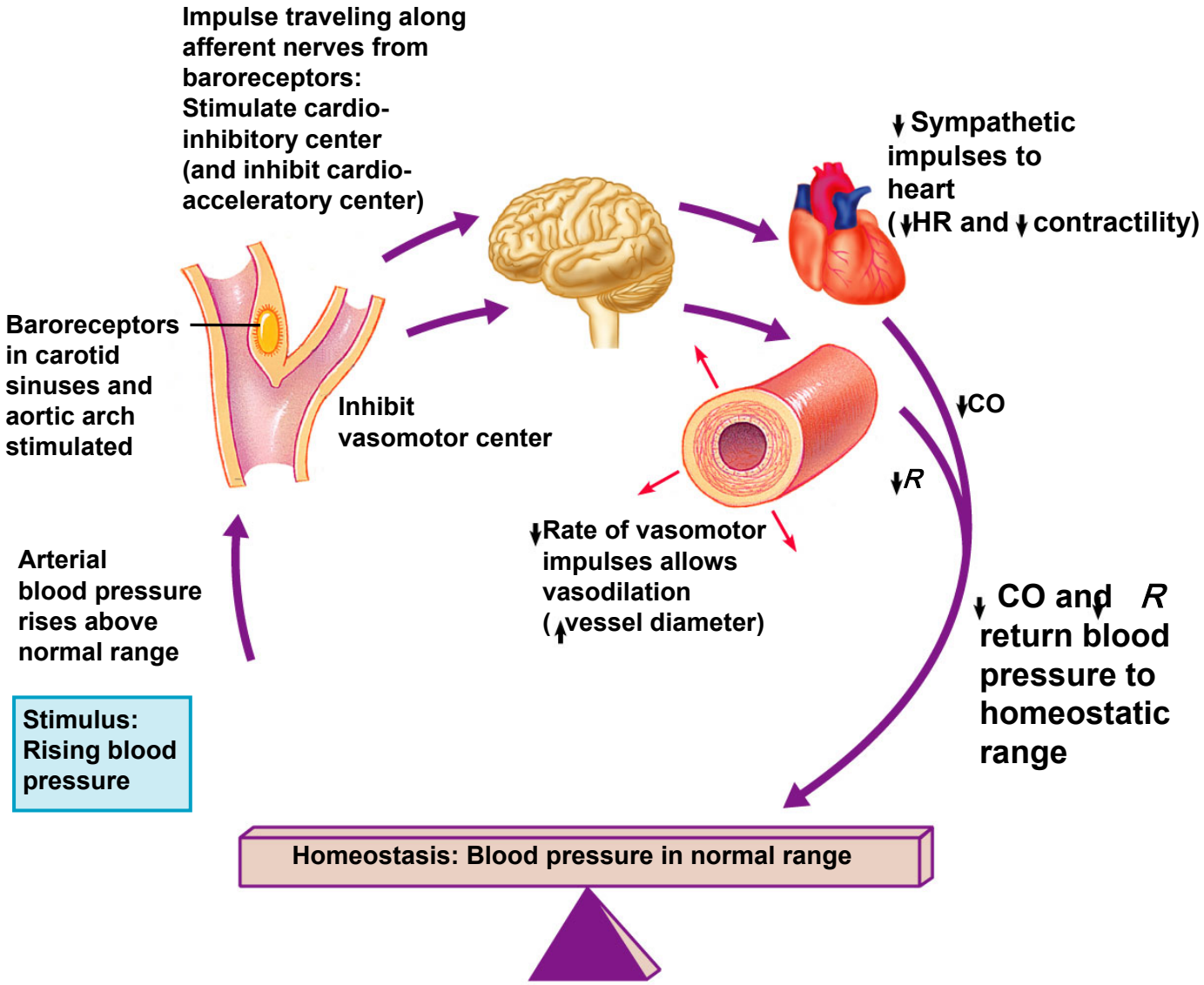
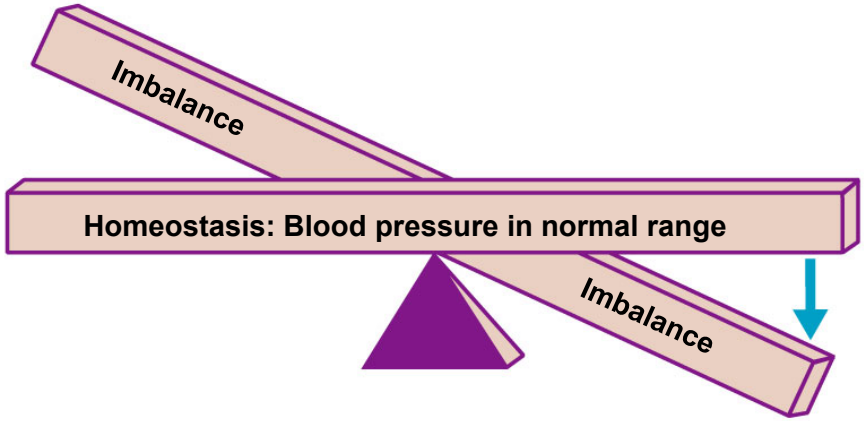

Impulse traveling along afferent nerves from baroreceptors: Stimulate cardio-inhibitory center (and inhibit cardio-acceleratory center)
↓ Sympathetic impulses to heart (↓HR and ↓ contractility)
Baroreceptors in carotid sinuses and aortic arch stimulated
Inhibit vasomotor center
↓CO
↓R
↓Rate of vasomotor impulses allows vasodilation (↑vessel diameter)
Arterial blood pressure rises above normal range
↓ CO and ↓ R return blood pressure to homeostatic range
Stimulus: Rising blood pressure
Homeostasis: Blood pressure in normal range

Figure 19.8



Stimulus:
Declining
blood pressure

Figure 19.8

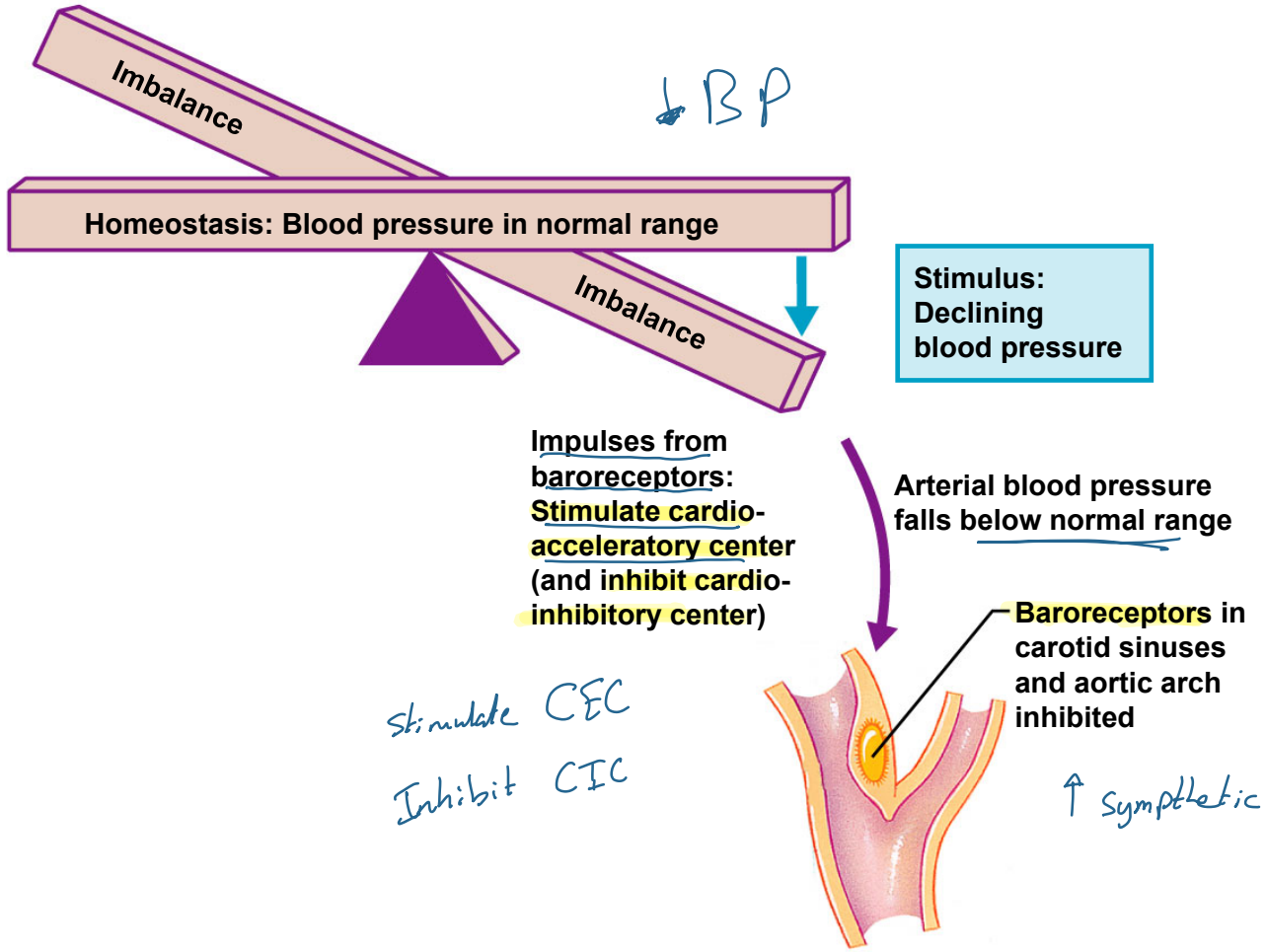

Imbalance
↓ BP
Homeostasis: Blood pressure in normal range
Imbalance
Stimulus: Declining blood pressure
Impulses from baroreceptors: Stimulate cardio-acceleratory center (and inhibit cardio-inhibitory center)
Arterial blood pressure falls below normal range
Baroreceptors in carotid sinuses and aortic arch inhibited
Stimulate CEC
Inhibit CIC
↑ Symptletic

Figure 19.8

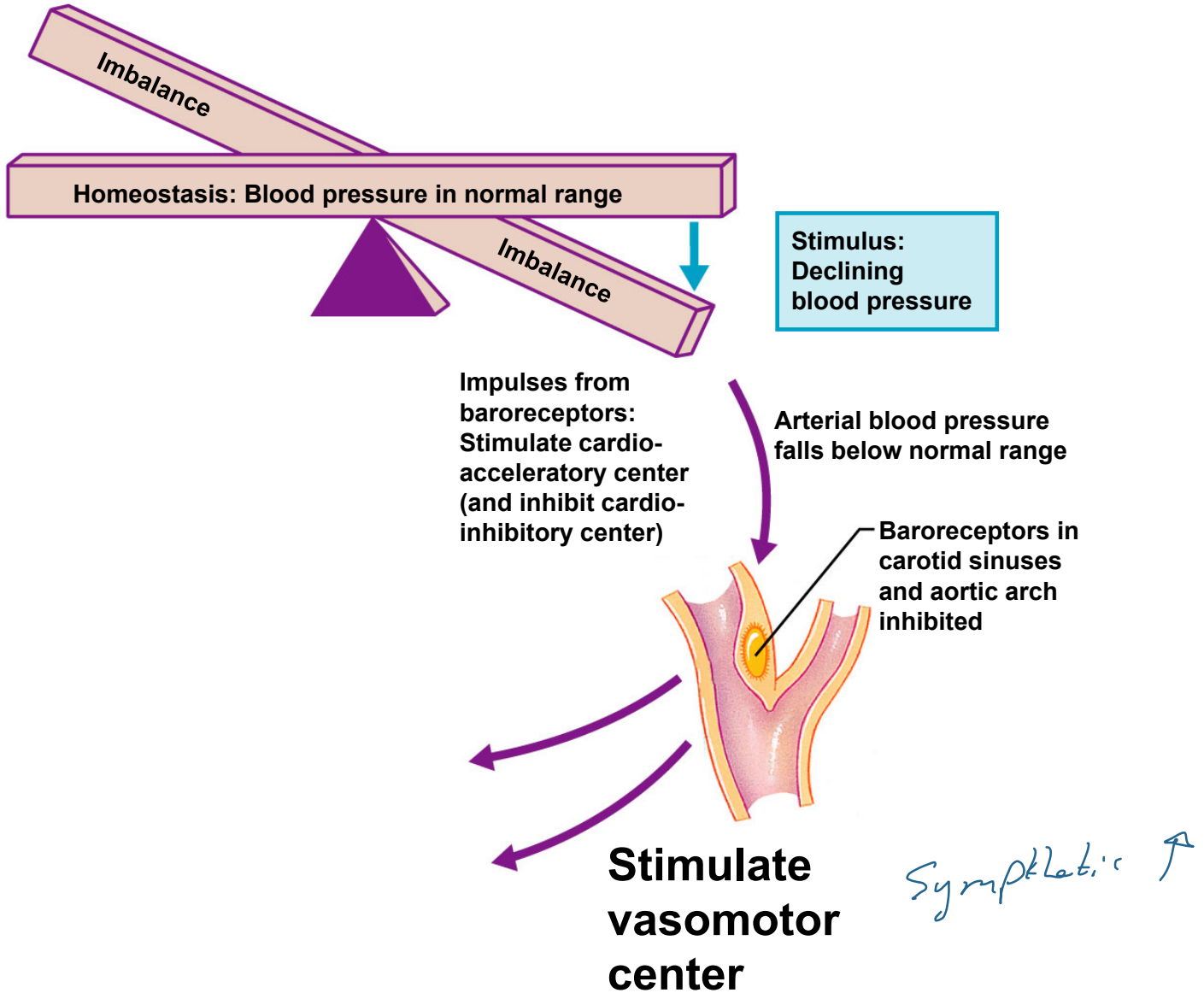

Imbalance
Homeostasis: Blood pressure in normal range
Imbalance
Stimulus: Declining blood pressure
Impulses from baroreceptors: Stimulate cardio-acceleratory center (and inhibit cardio-inhibitory center)
Arterial blood pressure falls below normal range
Baroreceptors in carotid sinuses and aortic arch inhibited
Stimulate vasomotor center
Sympathetic ↑

Figure 19.8

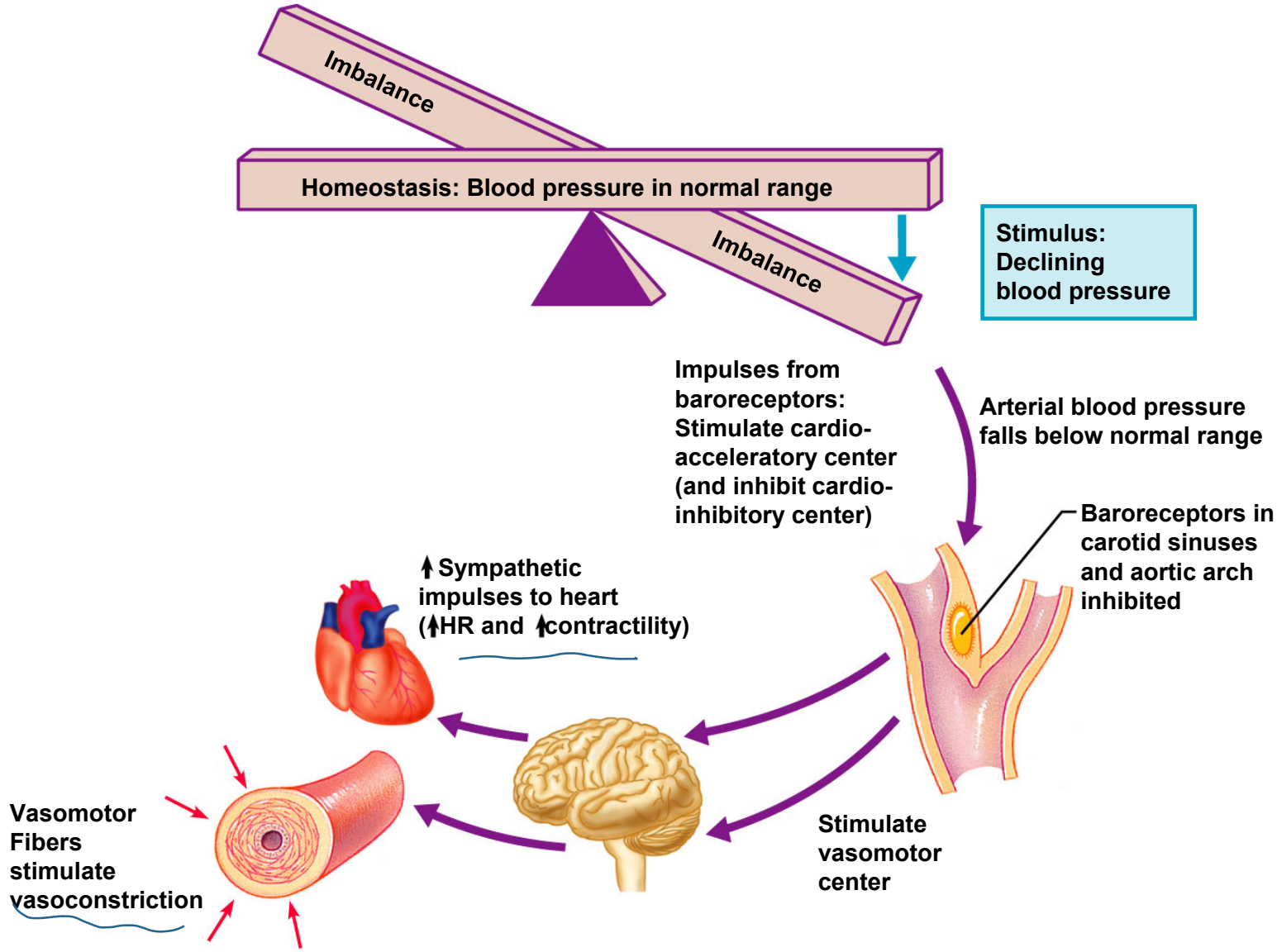

Imbalance
Homeostasis: Blood pressure in normal range
Imbalance
Stimulus:
Declining
blood pressure
Impulses from
baroreceptors:
Stimulate cardio-
acceleratory center
(and inhibit cardio-
inhibitory center)
Arterial blood pressure
falls below normal range
Baroreceptors in
carotid sinuses
and aortic arch
inhibited
Sympathetic
impulses to heart
(HR and contractility)
Vasomotor
Fibers
stimulate
vasoconstriction
Stimulate
vasomotor
center

Figure 19.8

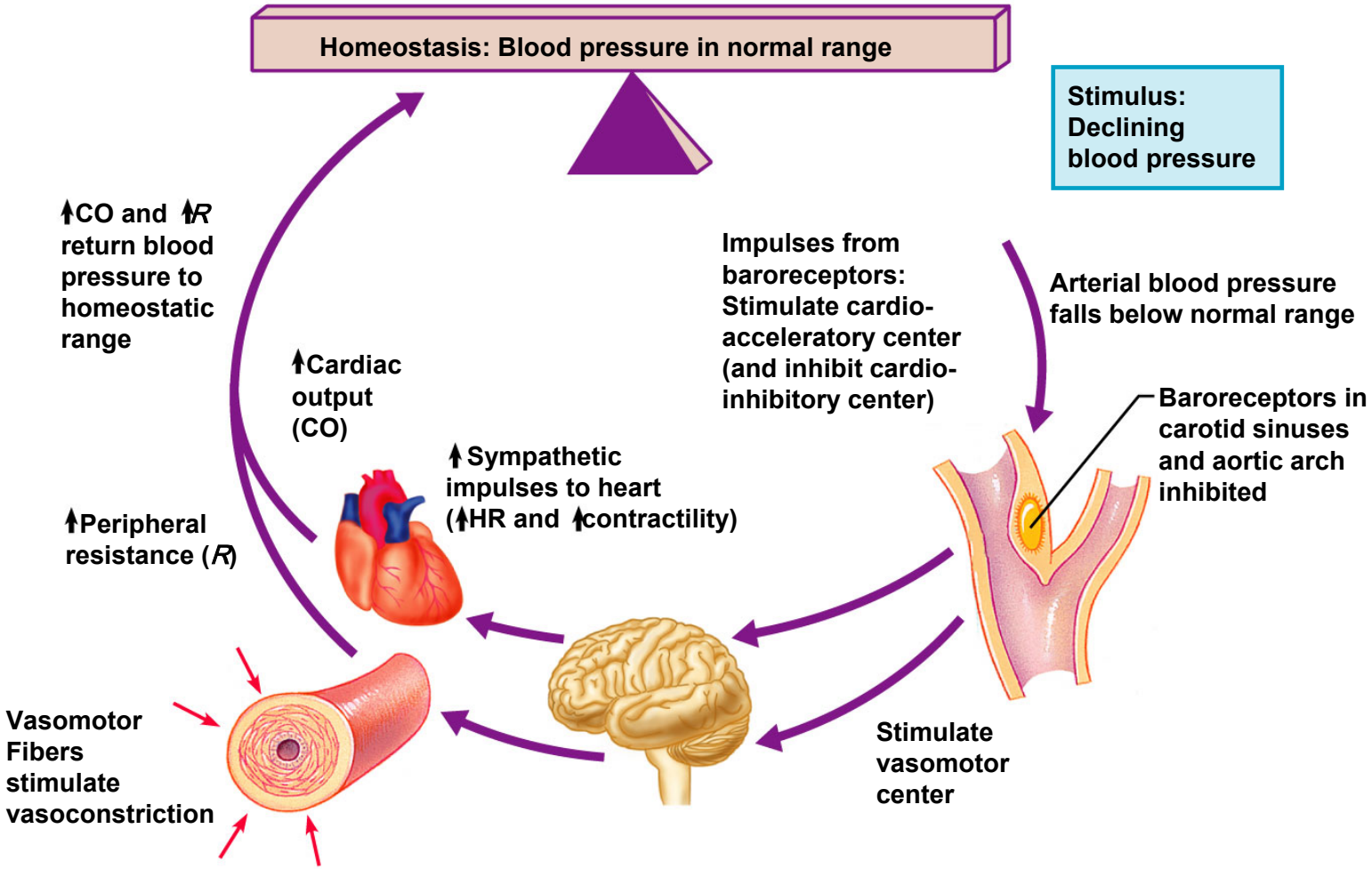

Homeostasis: Blood pressure in normal range
Stimulus: Declining blood pressure
↑CO and ↑R return blood pressure to homeostatic range
↑Cardiac output (CO)
↑Peripheral resistance (R)
↑Sympathetic impulses to heart (↑HR and ↑contractility)
Impulses from baroreceptors: Stimulate cardio-acceleratory center (and inhibit cardio-inhibitory center)
Arterial blood pressure falls below normal range
Baroreceptors in carotid sinuses and aortic arch inhibited
Stimulate vasomotor center
Vasomotor Fibers stimulate vasoconstriction

Figure 19.8

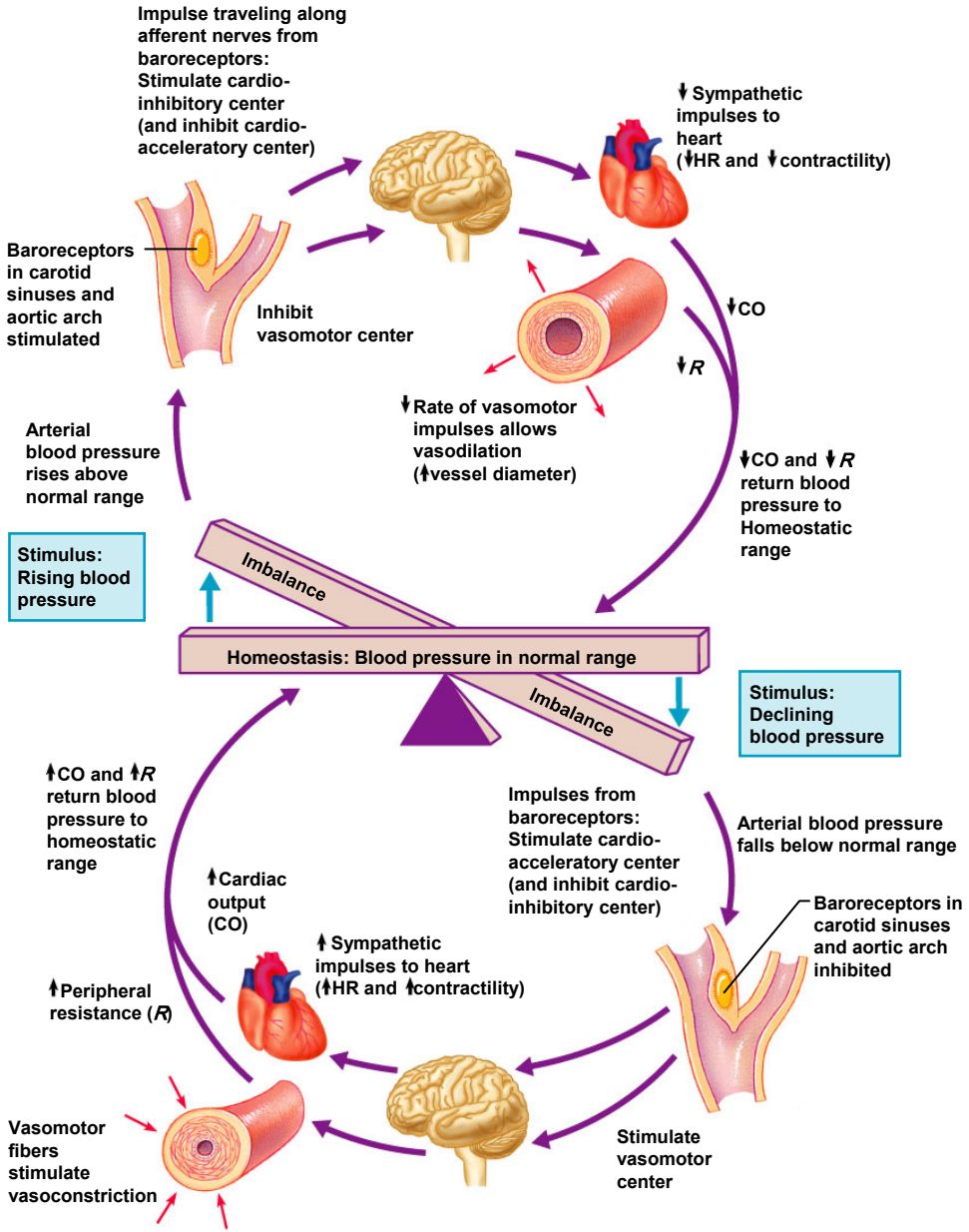

Impulse traveling along afferent nerves from baroreceptors: Stimulate cardio-inhibitory center (and inhibit cardio-acceleratory center)
Sympathetic impulses to heart (HR and contractility)
Baroreceptors in carotid sinuses and aortic arch stimulated
Inhibit vasomotor center
CO
R
Rate of vasomotor impulses allows vasodilation (vessel diameter)
Arterial blood pressure rises above normal range
CO and R return blood pressure to Homeostatic range
Stimulus: Rising blood pressure
Imbalance
Homeostasis: Blood pressure in normal range
Imbalance
Stimulus: Declining blood pressure
CO and R return blood pressure to homeostatic range
Impulses from baroreceptors: Stimulate cardio-acceleratory center (and inhibit cardio-inhibitory center)
Arterial blood pressure falls below normal range
Cardiac output (CO)
Baroreceptors in carotid sinuses and aortic arch inhibited
Sympathetic impulses to heart (HR and contractility)
Peripheral resistance (R)
Vasomotor fibers stimulate vasoconstriction
Stimulate vasomotor center

Figure 19.8

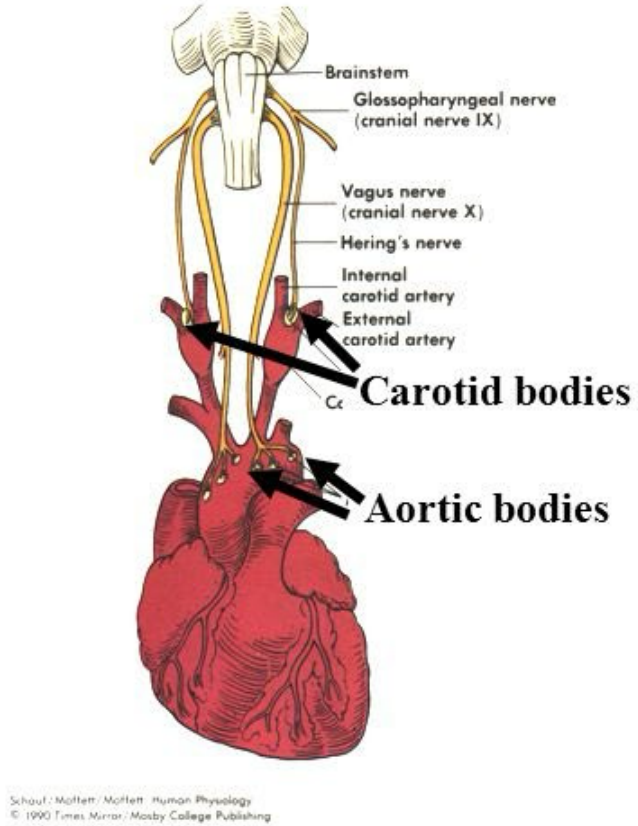
Chemoreceptor

Short-Term Mechanisms: Chemical Controls

↓ O_2 ↑ CO_2 ↑ H^+ (↓ pH) → Vasomotor center تحفز ↑ sympathetic

- Blood pressure is regulated by chemoreceptor reflexes sensitive to oxygen and carbon dioxide
  - Prominent chemoreceptors are the carotid and aortic bodies
  - Reflexes that regulate BP are integrated in the medulla (MO)
  - Higher brain centers (cortex and hypothalamus) can modify BP via relays to medullary centers

Peripheral Chemoreceptors



Sense tension of oxygen and carbon dioxide; and $[H^+]$ in the blood

Control of Arterial Pressure by the Carotid and Aortic Chemoreceptor

- The chemoreceptors are cells sensitive to O2 lack, CO2 and H^+ excess.
- They are located in the two carotid bodies, and several aortic bodies adjacent to the aorta.
- chemoreceptors are always in close contact with arterial blood.
- The chemoreceptors excite nerve fibres that, along with the baroreceptor fibres, pass through the vagus nerve into the vasomotor centre
- Whenever the arterial pressure falls below a critical level (below 80 mm Hg), the chemoreceptors become stimulated (due to lack O2, or excess CO2)
- The signals transmitted from the chemoreceptors excite the vasomotor center, and this elevates the arterial pressure back toward normal.
- This reflex becomes specially important in critical **hypotension** to help prevent still further fall in pressure.

Acidosis
↓PH

- Low blood O2, high CO2, low pH → stimulate VMC

decrease parasympathetic

Increase sympathetic

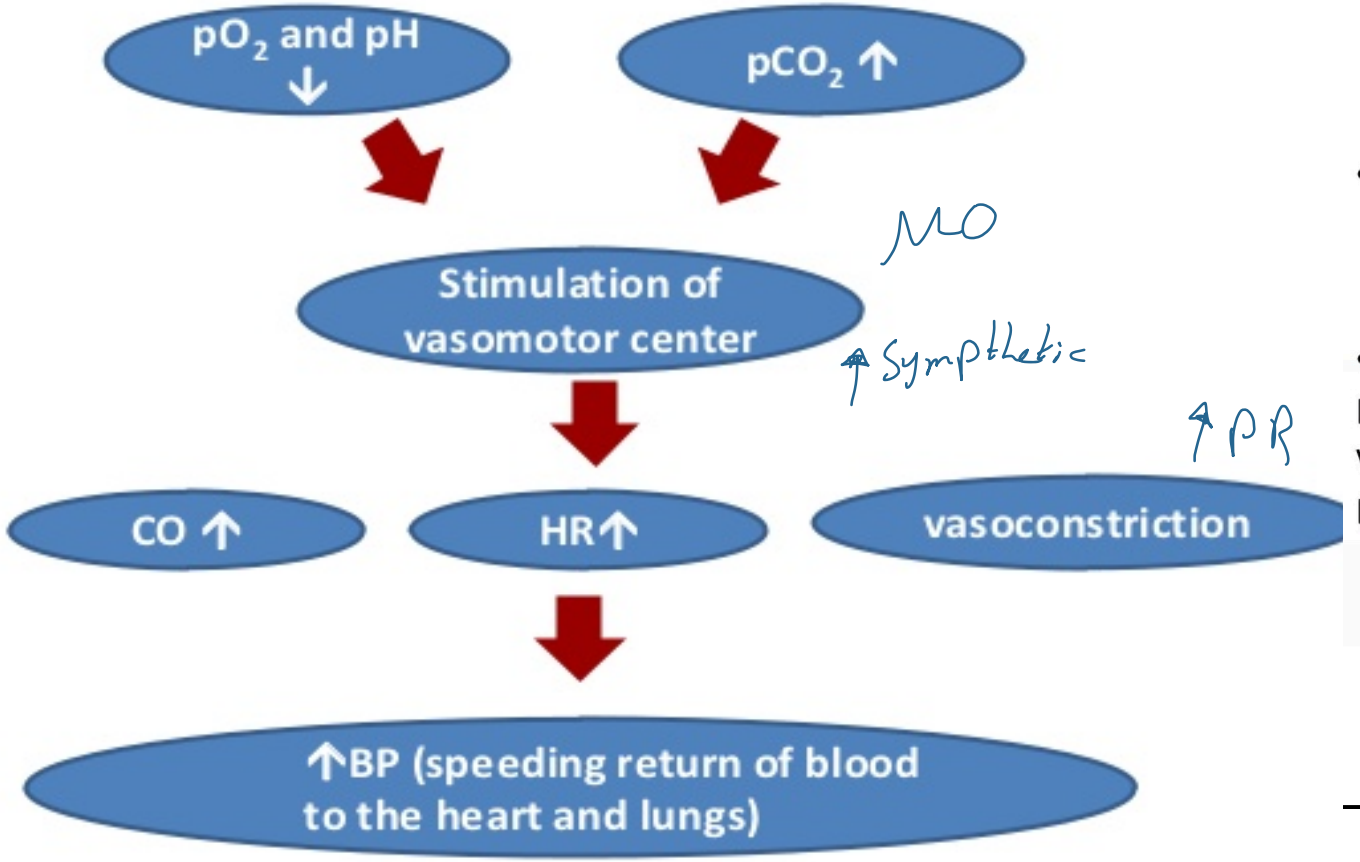
Vasoconstriction

Increase HR, SV

➢ **Increase in BP (speeding the return of blood to the heart and lung)**

Chemoreceptor

- Chemosensitive cells that respond to changes in pCO_2 and pO_2 and pH levels (Hydrogen ion).



- Low blood O2, high CO2, low pH → stimulate VMC

- Decrease parasympathetic

Increase sympathetic

Vasoconstriction

Increase HR, SV

➢ Increase in BP (speeding the return of blood to the heart and lung)

2023-11-13 17:46:39

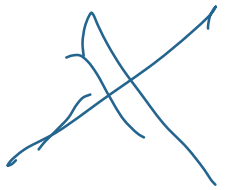
Humoral Control of the Circulation

- It means control of the circulation by substances secreted or absorbed into the body fluids—such as hormones and ions.

- Some of these substances are formed by special glands and transported in the blood.

- Others are formed in local tissue areas and cause only local circulatory effects.

Chemicals that Increase Blood Pressure



- Adrenal medulla hormones – norepinephrine and epinephrine increase blood pressure
- Antidiuretic hormone (ADH) – causes intense vasoconstriction in cases of extremely low BP-prevent loss of water in urine (water reabsorption)—produced by hypothalamus
- Angiotensin II – kidney release of renin generates angiotensin II, which causes vasoconstriction
- Endothelium-derived factors – endothelin and prostaglandin-derived growth factor (PDGF) are both vasoconstrictors

Chemicals that Decrease Blood Pressure

- Atrial natriuretic peptide (ANP) – causes blood volume and pressure to decline– released by cells in right atria in response to high BP and blood volume---- cause vasodilation and increase loss of Na in urine
- Nitric oxide (NO) – is a brief but potent vasodilator
- Inflammatory chemicals – histamine, prostacyclin, and kinins are potent vasodilators
- Alcohol – causes BP to drop by inhibiting ADH

- Sudden change in position
- **Low pressure receptors:** located in *pulmonary arteries* to prevent increase BP in pulmonary system.
- Muscle exercise: cause activation of vasoconstrictor area and cardioaccelatory center, increasing BP
- Stress: increase BP and HR
- Ischemic Response: during ischemia decrease blood pressure thus we have to increase activity of VMC to compensate

Long-Term Mechanisms: Renal Regulation

- Long-term mechanisms control BP by altering blood volume
- Baroreceptors adapt to chronic high or low BP
  - Increased BP stimulates the kidneys to eliminate water, thus reducing BP
  - Decreased BP stimulates the kidneys to increase blood volume and BP

Kidney Action and Blood Pressure

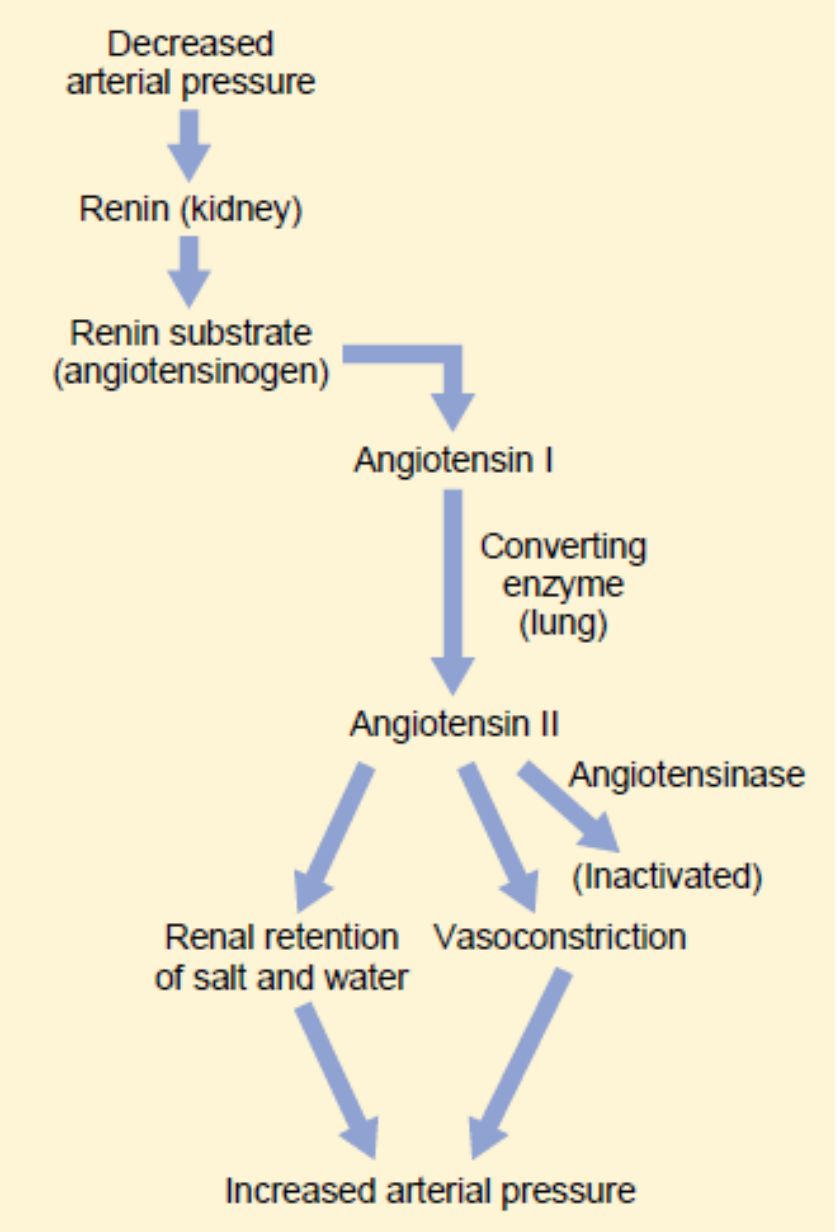
- Kidneys act directly and indirectly to maintain long-term blood pressure
  - Direct renal mechanism alters blood volume
  - Indirect renal mechanism involves the renin-angiotensin mechanism

Aldosterone

Kidney Action and Blood Pressure

- Declining BP causes the release of renin, which triggers the release of angiotensin II
- Angiotensin II is a potent vasoconstrictor that stimulates aldosterone secretion
- Aldosterone enhances renal reabsorption and stimulates ADH release

Renin Ang Aldosterone system



Renin-angiotensin mechanism for arterial pressure control

- Angiotensin causes the kidneys to retain both salt and water in two major ways:

  1. It acts directly on the **kidneys** to cause salt and water retention.

  2. It causes the **adrenal glands** to secrete aldosterone, which increases salt and water reabsorption by the kidney tubules.

- This angiotensin effect has a long-term effect, and is more powerful than the acute vasoconstrictor mechanism in raising the arterial pressure.

Control of Arteriolar Smooth Muscle

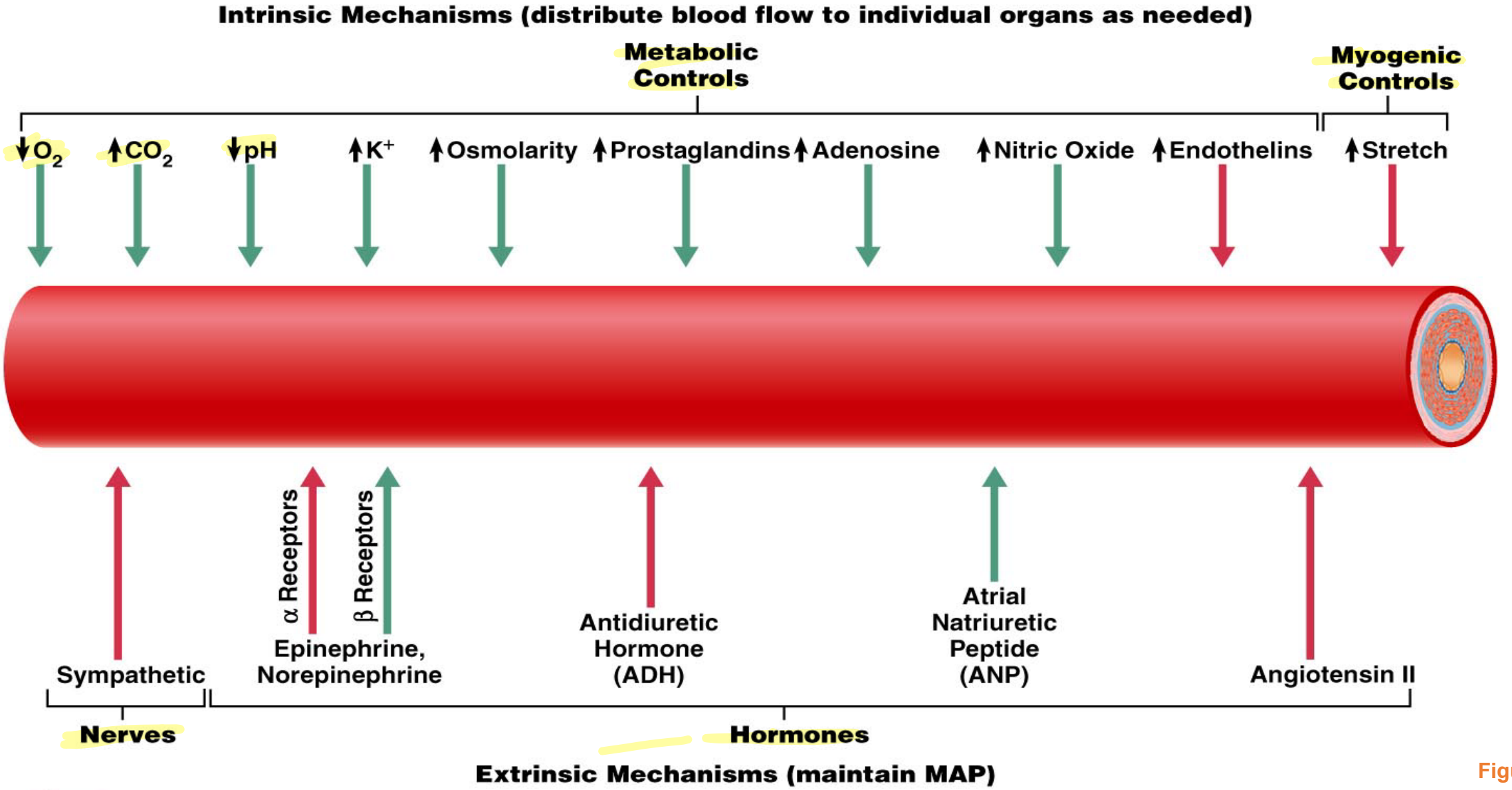
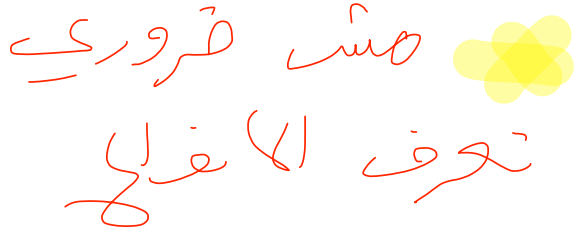


Figure 19.14

Hypertension

- Hypertension maybe transient or persistent
- Primary or essential hypertension – risk factors in primary hypertension include diet, obesity, age, race, heredity, stress, and smoking
- Secondary hypertension – due to identifiable disorders, including excessive renin secretion, arteriosclerosis, and endocrine disorders

Causes of hypertension



- Cardiac factors: factors increasing cardiac output/ drugs like digoxin
- Vascular factors: Arteriosclerosis/ aging and loss elasticity/ drug causing vasoconstriction
- Neural factors: vagotectomy/stimu of Symp/ inhib of parasympathatic
- Psycological factors: stress fear excitement
- Hormonal factors: hyperactivity of adrenal medulla/renin agonist/ Adosterone agonist
- Renal factors: kidney failure/ antidiuretic drugs
- Blood factors: hyperglycemia/hypernatremia/ increase plasma fluids/ increase osmotic pressure/ increase plasma proteins

- **Obstructions:**

  Internal:thrombosis, blood clotting, increase cholesterol and blood lipids

  External: obesity, tumour

- **Blood volume:** due to increase water uptake and mainly decrease in urination, increase in blood osmolarity
- **Diet food intake:** increase salt intake, food rich in lipids and cholesterol

Hypotension

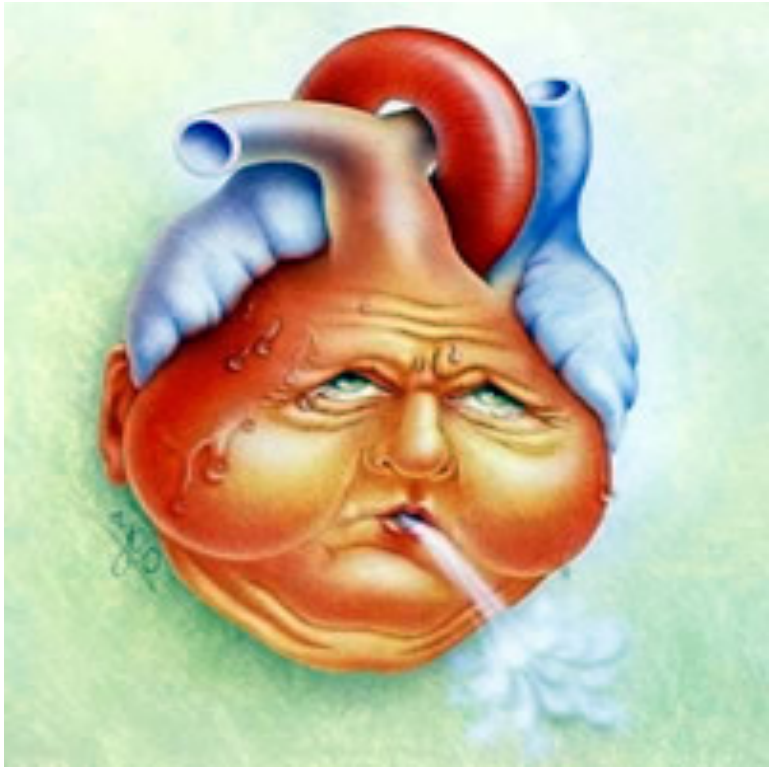
- Orthostatic hypotension – temporary low BP and dizziness when suddenly rising from a sitting or reclining position
- Chronic hypotension – hint of poor nutrition and warning sign for Addison's disease
- Acute hypotension – important sign of circulatory shock
  - Threat to patients undergoing surgery and those in intensive care units

Heart Failure

DR SAFA ABDUL GHANI

Definition of HF

- *A state in which the heart cannot provide sufficient cardiac output to satisfy the metabolic needs of the body*
- It is commonly termed **congestive heart failure (CHF)** since symptoms of increased venous pressure are often prominent

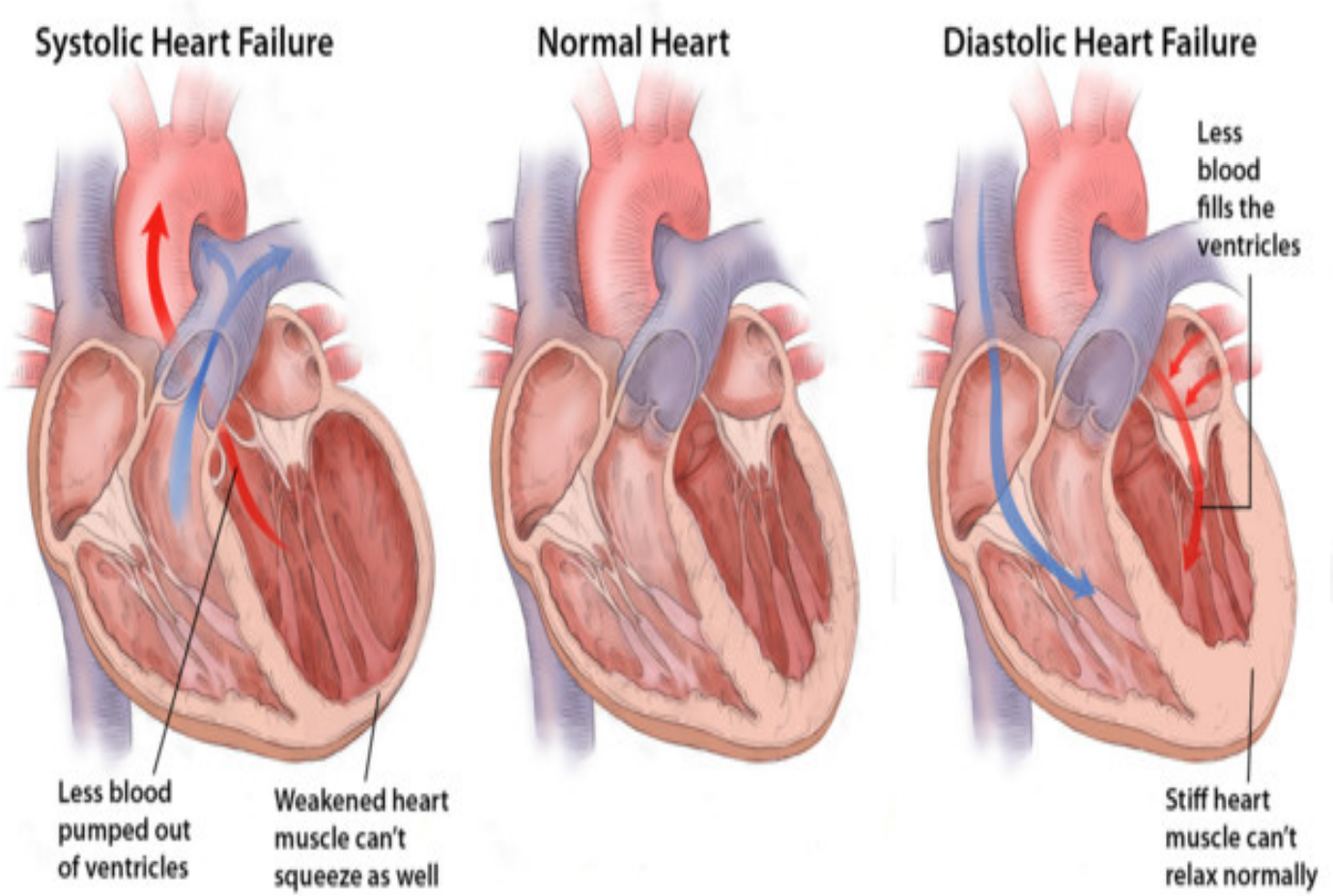


Forms of Heart Failure

- **Systolic & Diastolic**

  - **<u>Systolic failure</u>**
    - The heart loses its ability to contract or pump blood into the circulation **(weakened heart muscle)**

  - **<u>Diastolic failure</u>**
    - The heart loses its ability to relax because it becomes **stiff**
    - Heart can not fill properly between each beat



Types of CHF

- Left Ventricular Failure with Pulmonary Edema

- Right Ventricular Failure

Compensatory Mechanisms in CHF

- Neurohormonal system (increase HR)
- Renin-angiotensin-aldosterone system
- Ventricular hypertrophy (thicker muscle)

Neurohormonal System

- Stimulated by decreased perfusion → secretion of hormones:
  - Epinephrine:
    - Increases contractility
    - Increases rate and pressure
    - Vasoconstriction → Systemic vascular resistance
  - Vasopressin (antidiuretic hormone ADH):
    - Pituitary gland
    - Mild vasoconstriction, renal water retention

Renin-Angiotensin Mechanism

- Decreased renal blood flow secondary to low cardiac output triggers renin secretion by the kidneys
  - Aldosterone is released → increase in Na+ retention → water retention
  - BLOOD VOLUME increase →Preload increases
  - The heart will not be able to pump all this blood
  - In the peripheral veins, pressures rises and the capillary pressures increases
  - Fluid leaks from the capillaries into the surrounding tissues (congestion)
  - Worsening failure

Ventricular Hypertrophy

- Long term compensatory mechanism
- Increases in size due to increase in work load

Compensatory Mechanisms in Heart Failure

- Mechanisms designed for acute loss in cardiac output
- Chronic activation of these mechanisms worsens heart failure