Physiology of the Cardiovascular System

Part /2

Second Stage/ University of Anbar-College of Dentistry
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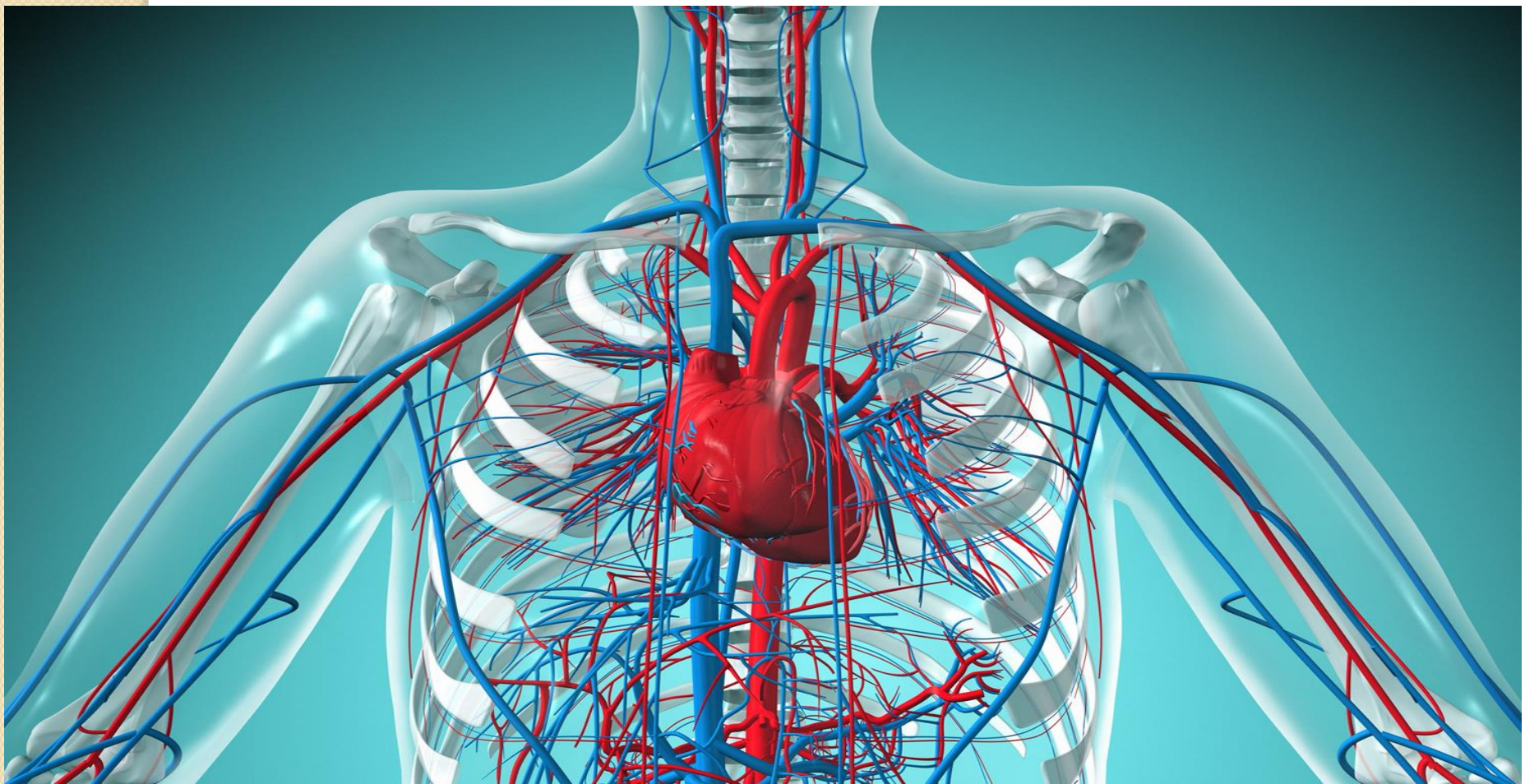


Cardiovascular system(CVS)

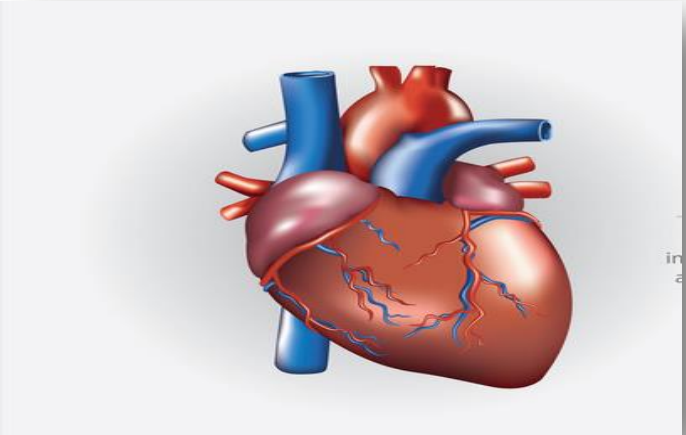
Introduction

- Is made up of heart and blood vessels and blood .
- Heart pumps the blood into the blood vessels.
- Blood vessels circulate the blood throughout the body and transport nutrients and oxygen to the tissues and remove carbon dioxide and waste products from the tissues

Cardiovascular system

The Heart

- Heart is a muscular organ that pumps blood throughout the circulatory system.
- It situated in between the two lungs in the mediastinum.
- It is made up of four chambers (2 atria and 2 ventricles).
- The musculature is more and thick in the ventricles than in the atria.
- The force of contraction of the heart depends upon the muscles

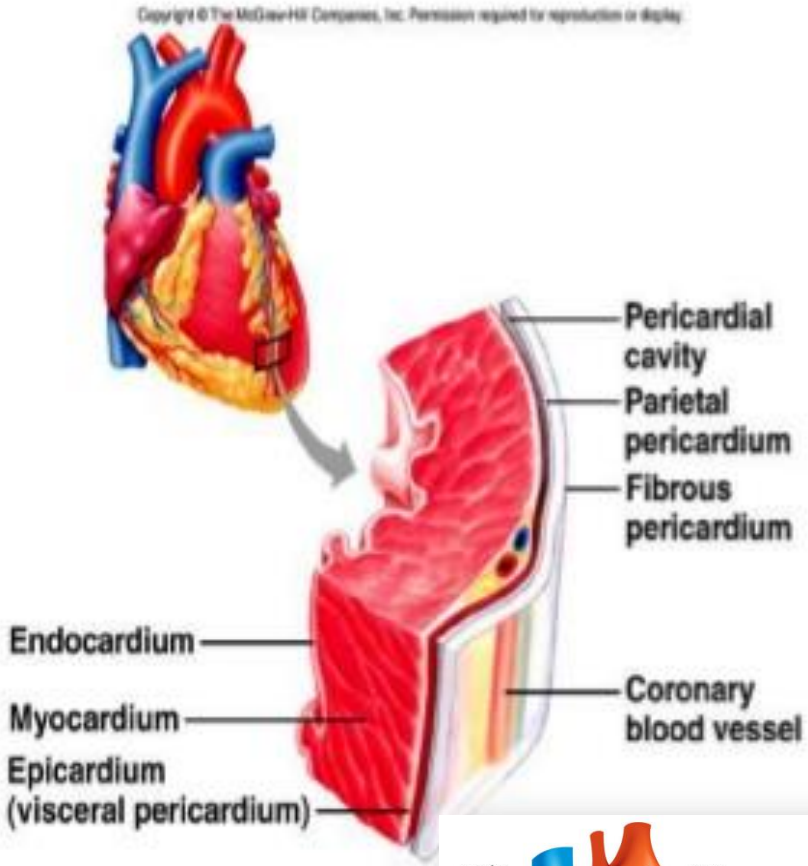


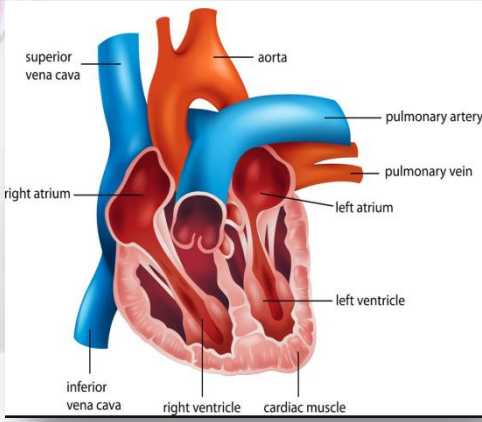
The Heart: Coverings

- Pericardium – a double serous membrane
  - Visceral pericardium
    - Next to heart
  - Parietal pericardium
    - Outside layer
- Serous fluid fills the space between the layers of pericardium

The Heart: Heart Wall

- Three layers
  - Epicardium
    - Outside layer
    - This layer is the parietal pericardium
    - Connective tissue layer
  - **Myocardium**
    - **Middle layer**
    - **Mostly cardiac muscle**
  - Endocardium
    - Inner layer
    - Endothelium





The Heart: Chambers

- Right and left side act as separate pumps
- Four chambers
  - Atria
    - Receiving chambers
      - Right atrium
      - Left atrium
  - Ventricles
    - Discharging chambers
      - Right ventricle
      - Left ventricle

The Heart: Valves

- Allow blood to flow in only one direction
- Four valves
  - Atrioventricular valves – between atria and ventricles
    - Bicuspid valve (left)
    - Tricuspid valve (right)
  - Semilunar valves between ventricle and artery
    - Pulmonary semilunar valve
    - Aortic semilunar valve

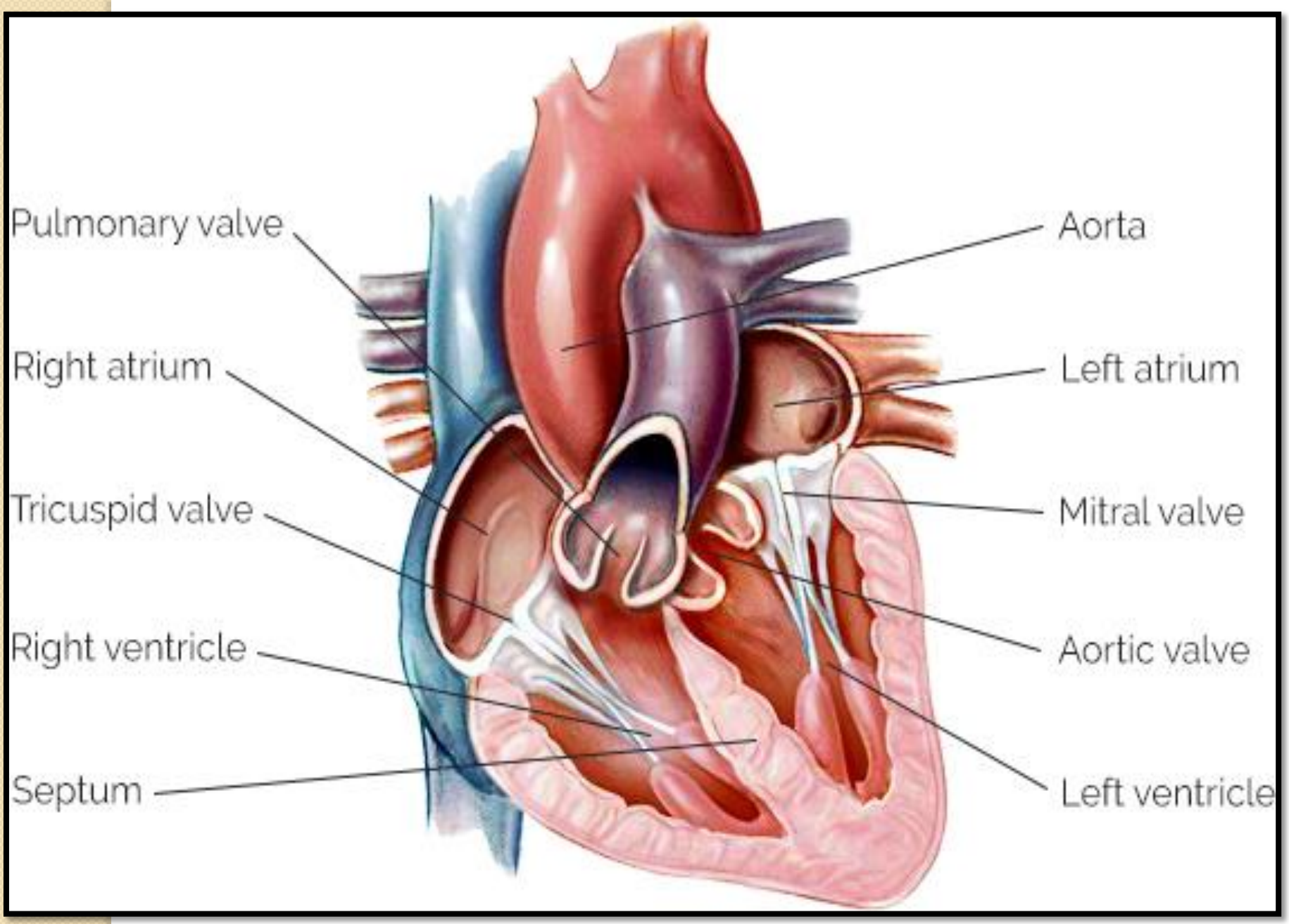


FIGURE 2 : Valves of the heart

Cardiovascular system

Right Side of the Heart:-

- Right side of the heart has two chambers, the upper right atrium and lower right ventricle.
- Right atrium is a thin walled and low pressure chamber.
- Sinoatrial node: that produces cardiac impulses.
- Atrioventricular node: that conducts the impulses to the ventricles.
- It receives venous (deoxygenated) blood via two large veins(figure 1):-

1. Superior vena cava that returns the venous blood from the head, neck and upper limbs

2. Inferior vena cava that returns the venous blood from lower parts of the body

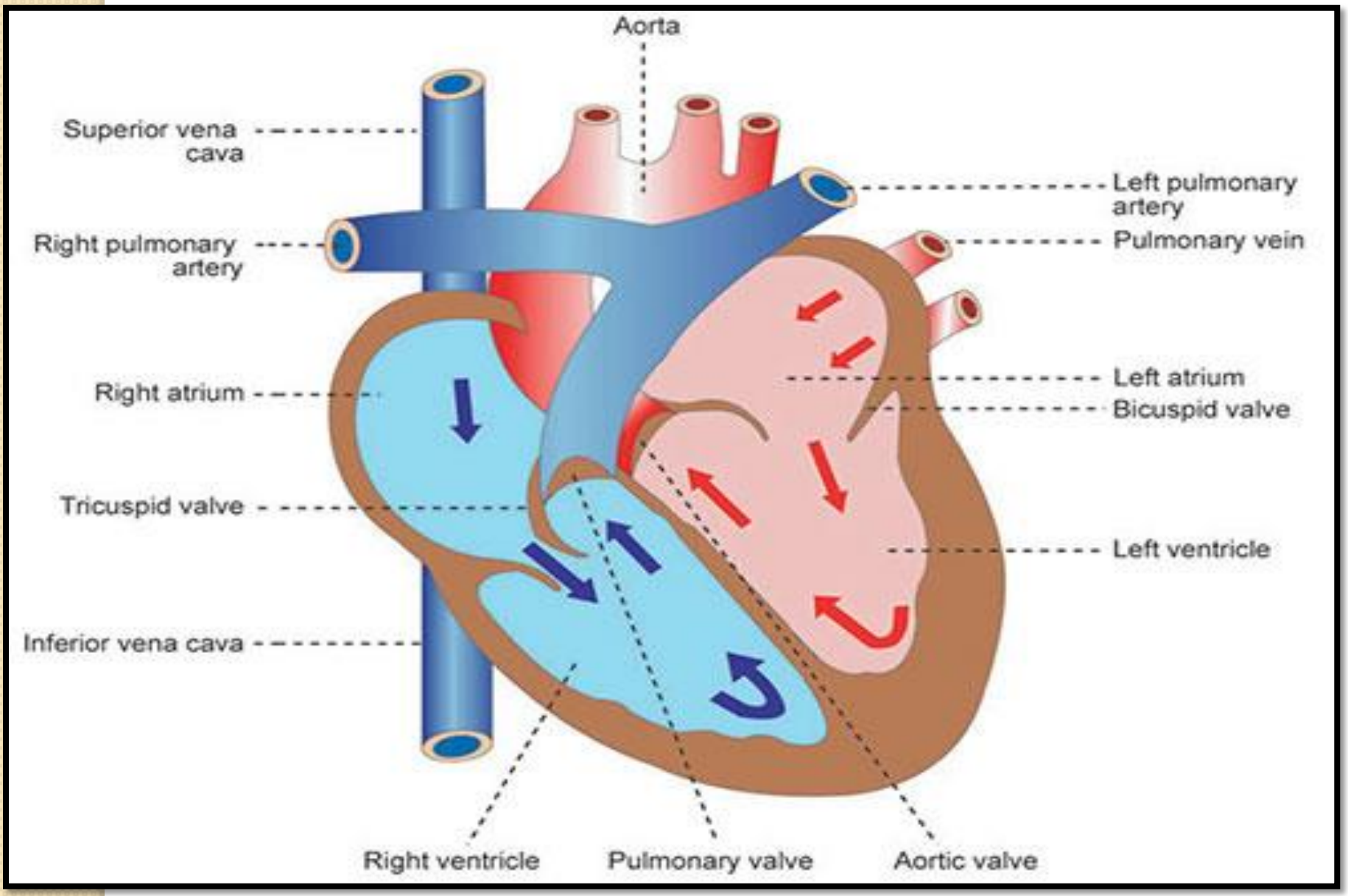


Figure1: Section of the heart

Cardiovascular system

(Left side of the Heart)

Left side of the heart has 2 chambers :-

1- The upper left atrium:-Is a thin walled and low pressure chamber. It receives oxygenated blood from the lungs through pulmonary veins.

This is the only exception in the body where an artery carries venous blood and vein carries the arterial blood.

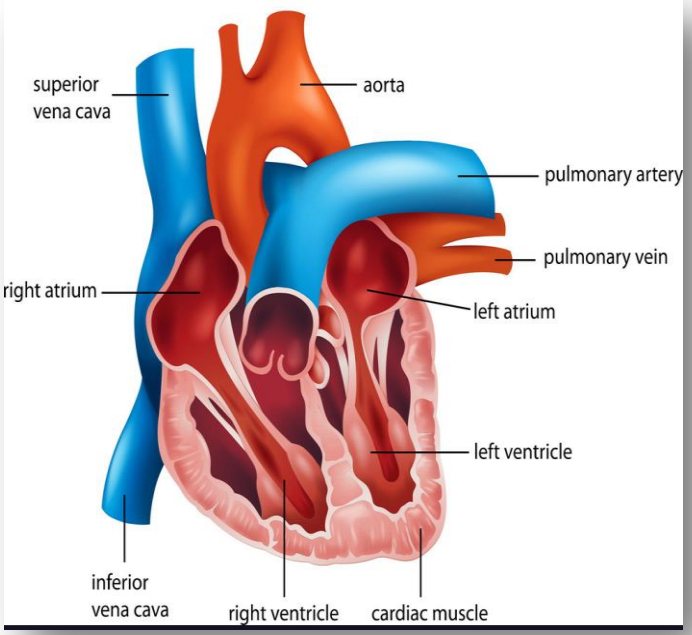
Blood from left atrium enters the left ventricle through the mitral valve

2-The lower left ventricle. :-Left ventricle pumps the arterial blood to different parts of the body through systemic aorta

Cardiovascular system

Septa of the Heart:-

Right and left atria of the heart are separated from one another by interatrial septum. The ventricles are separated from one another by interventricular septum.



The Cardiac muscle

Myocardium is formed by three types of cardiac muscle fibers:

i. Muscle fibers which form the contractile unit of the heart

ii. Muscle fibers which form pacemaker

iii. Muscle fibers which form the conductive system.

i. Muscle Fibers which Form the Contractile Unit of the Heart

- These cardiac muscle fibers are striated fibers and are similar to the skeletal muscles in structure.
- But, unlike the skeletal muscle fibers, the cardiac muscle fibers are involuntary in nature.
- The cardiac muscle fiber is covered by sarcolemma. It has a centrally placed nucleus.
- The myofibrils are embedded in the sarcoplasm.
- The sarcomere of the cardiac muscle has muscle proteins namely, actin, myosin, troponin and tropomyosin.
- The important difference between skeletal muscle and cardiac muscle is that the cardiac muscle fiber is branched and the skeletal muscle is not branched.

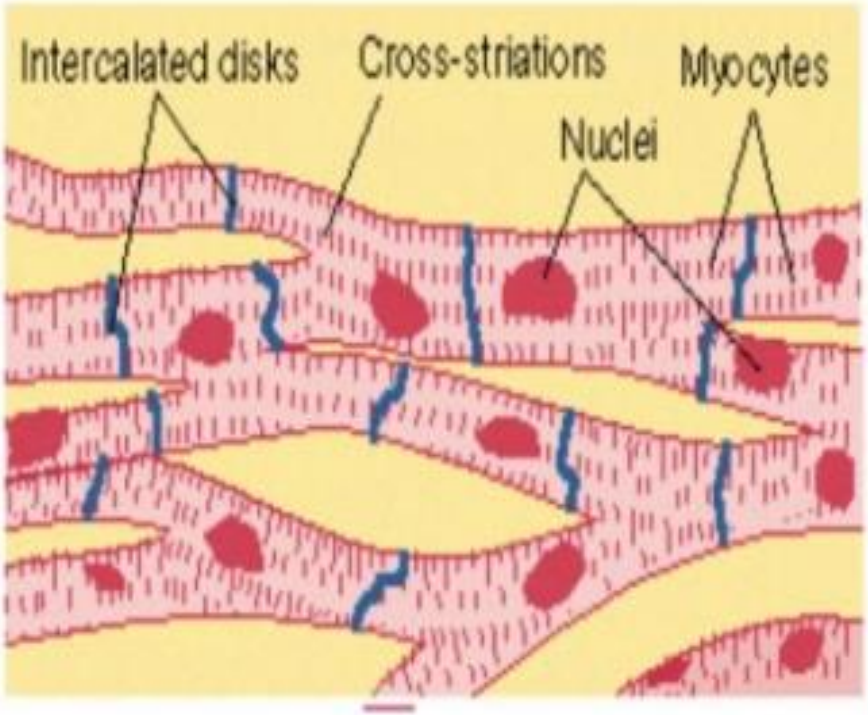
- Exhibit branching
- Adjacent cardiac cells are joined end to end by specialized structures known as intercalated discs

- Within intercalated discs there are two types of junctions
  - Desmosomes
  - Gap junctions that allow action potential to spread from one cell to adjacent cells

- Heart function as syncytium
  when one cardiac cell undergoes an action potential, the electrical impulse spreads to all other cells that are joined by gap junctions so they become excited and contract as a single functional syncytium

Atrial syncytium and ventricular syncytium

Cardiac Muscle Tissue



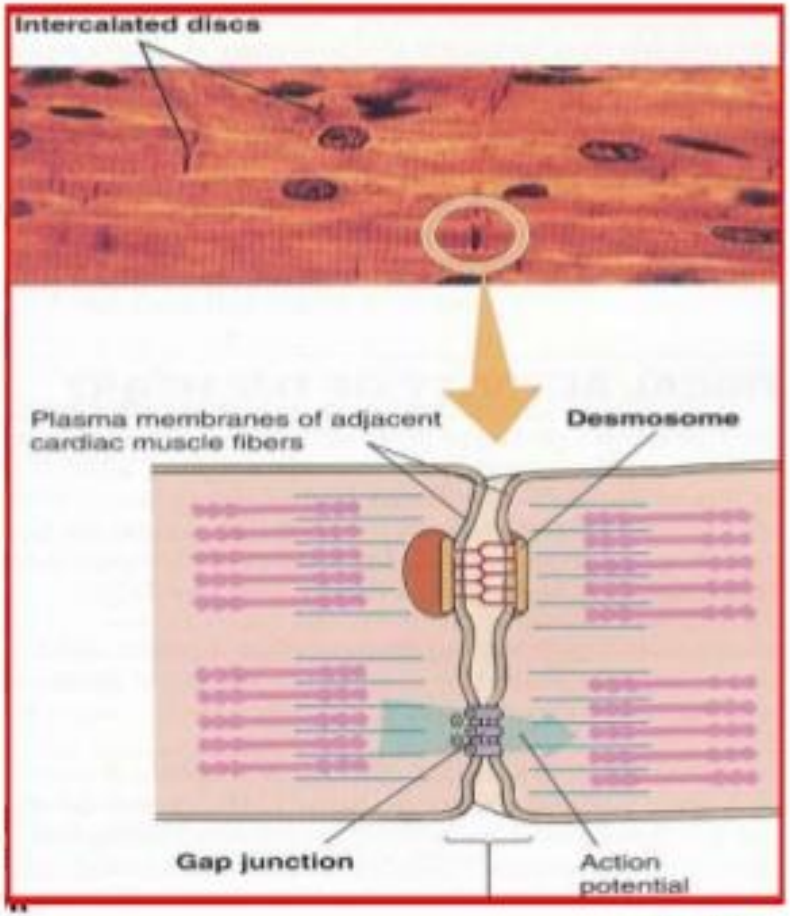
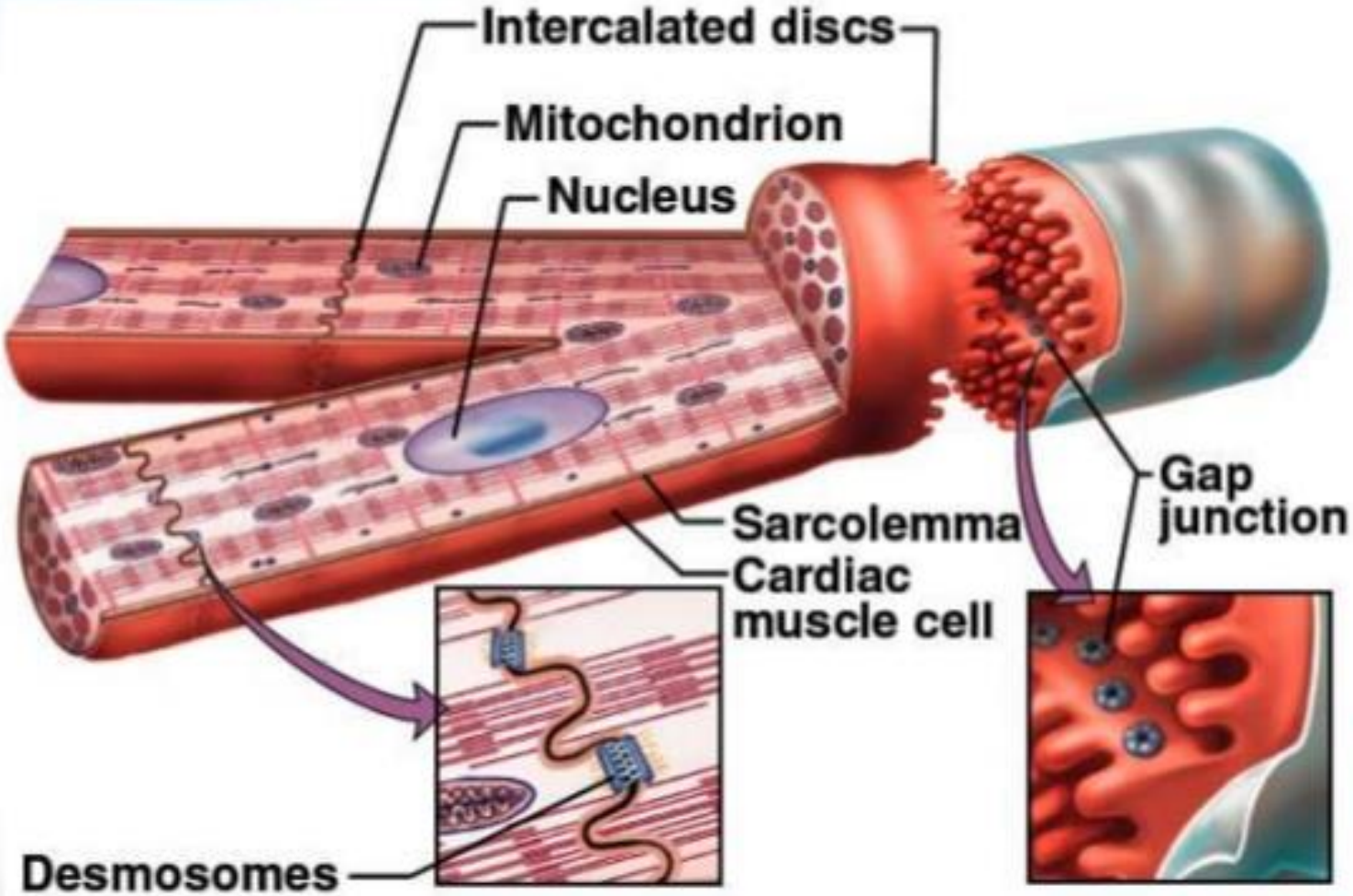
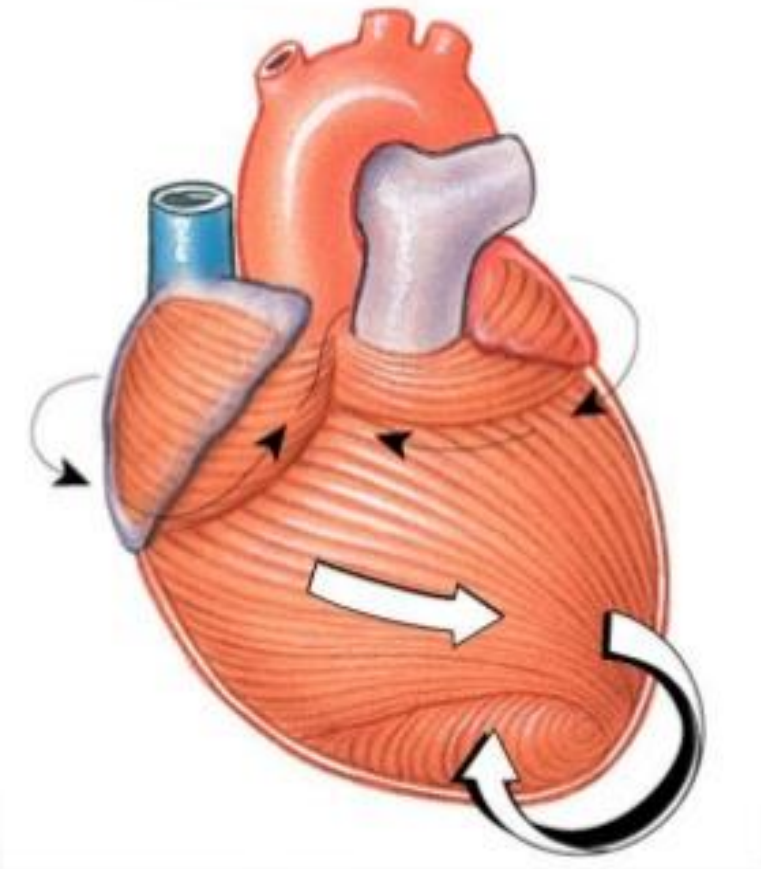


Figure 10.10a

Structure of Cardiac Muscle Cell



Orientation of cardiac muscle fibres:



Unlike skeletal muscles, cardiac muscles have to contract in more than one direction.

Cardiac muscle cells are striated, meaning they will only contract along their long axis. In order to get contraction in two axis, the fires wrap around.

Muscle Fibres which Form the Pacemaker

- Some of the muscle fibres of heart are modified into a specialized structure known as pacemaker.
- These muscle fibres forming the pacemaker have less striation.
- They are named **pacemaker cells** or **P cells.**
- Sino-atrial (SA) node forms the pacemaker in human heart.

Muscle Fibres which Form Conductive System

- Conductive system of the heart is formed by modified cardiac muscle fibres

- Impulses from SA node are transmitted to the atria directly. However, the impulses are transmitted to ventricles through various components of conducting system

Conducting system of heart

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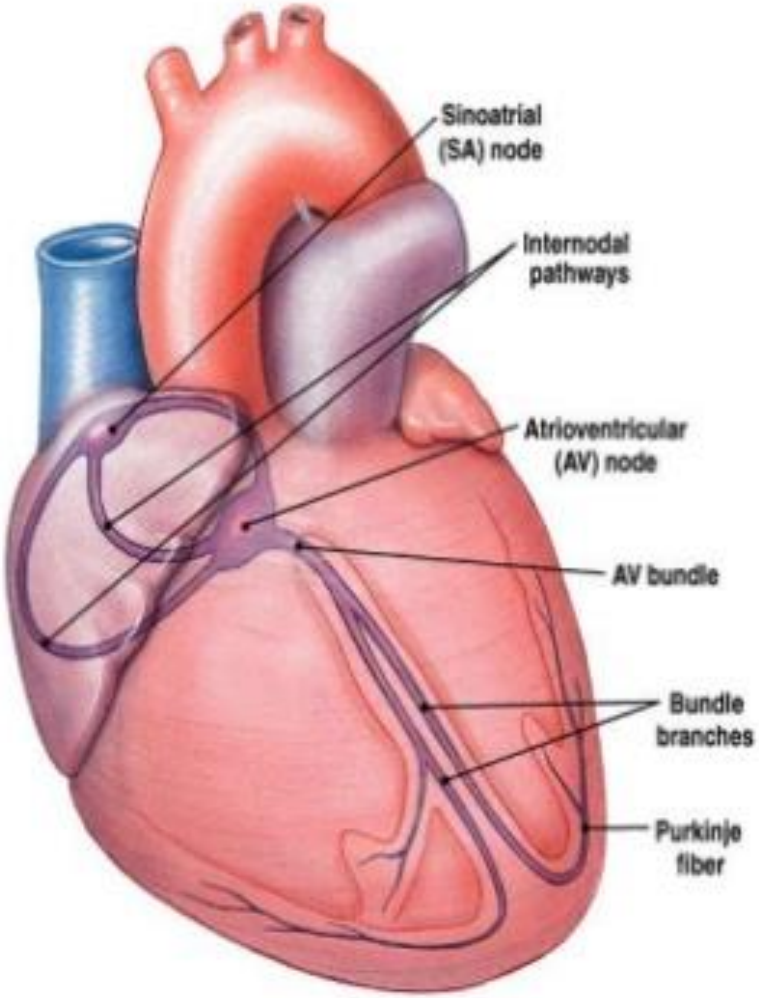
Cardiac Conduction System Overview

Sinoatrial node
↓
Atrial syncytium
↓
Junctional fibers
↓
Atrioventricular node
↓
A-V bundle
↓
Bundle branches
↓
Purkinje fibers
↓
Ventricular syncytium



The conducting system

Properties of cardiac muscle

- Electrical
  - Excitability (Bathmotropic action)
  - Auto rhythmicity
  - Conductivity (Dromotropic action)

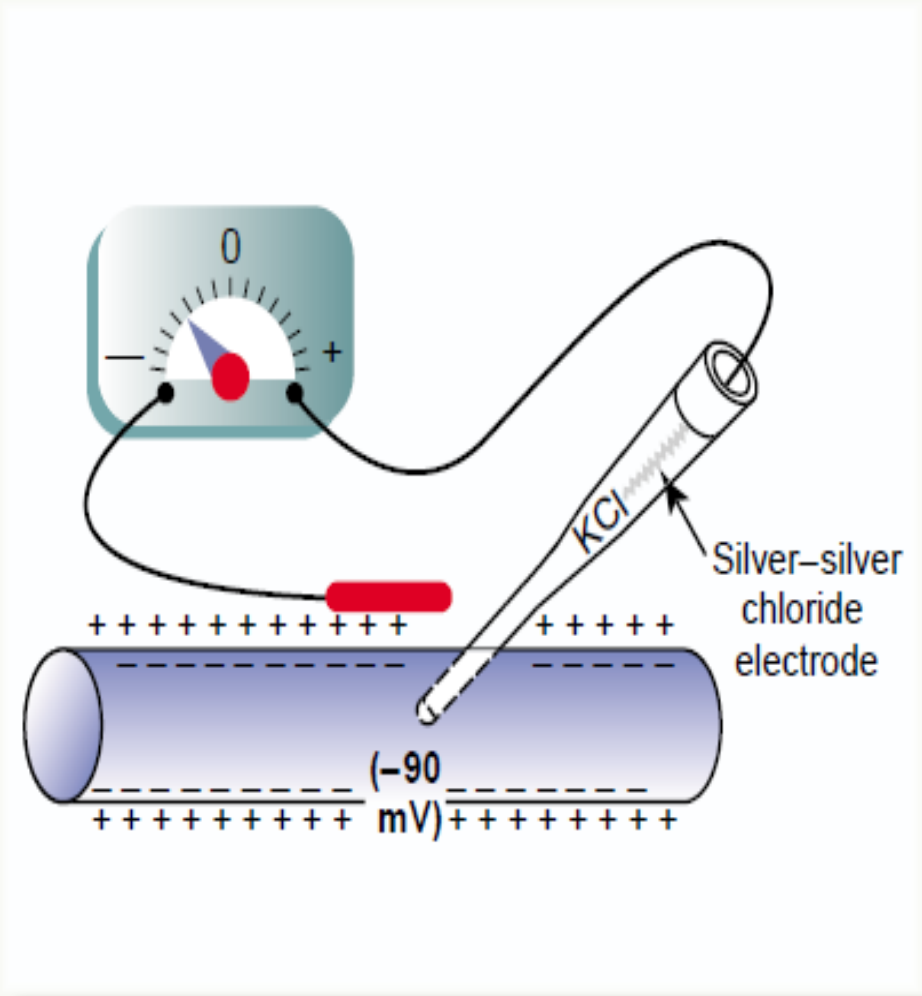
- Mechanical
  - Contractility (Inotropic action)
  - Refractory period
  - Staircase / treppe effect

Resting Membrane Potential

- **Definition**: it is the potential difference across cell membrane at rest:
- it is negative inside with respect to outside.

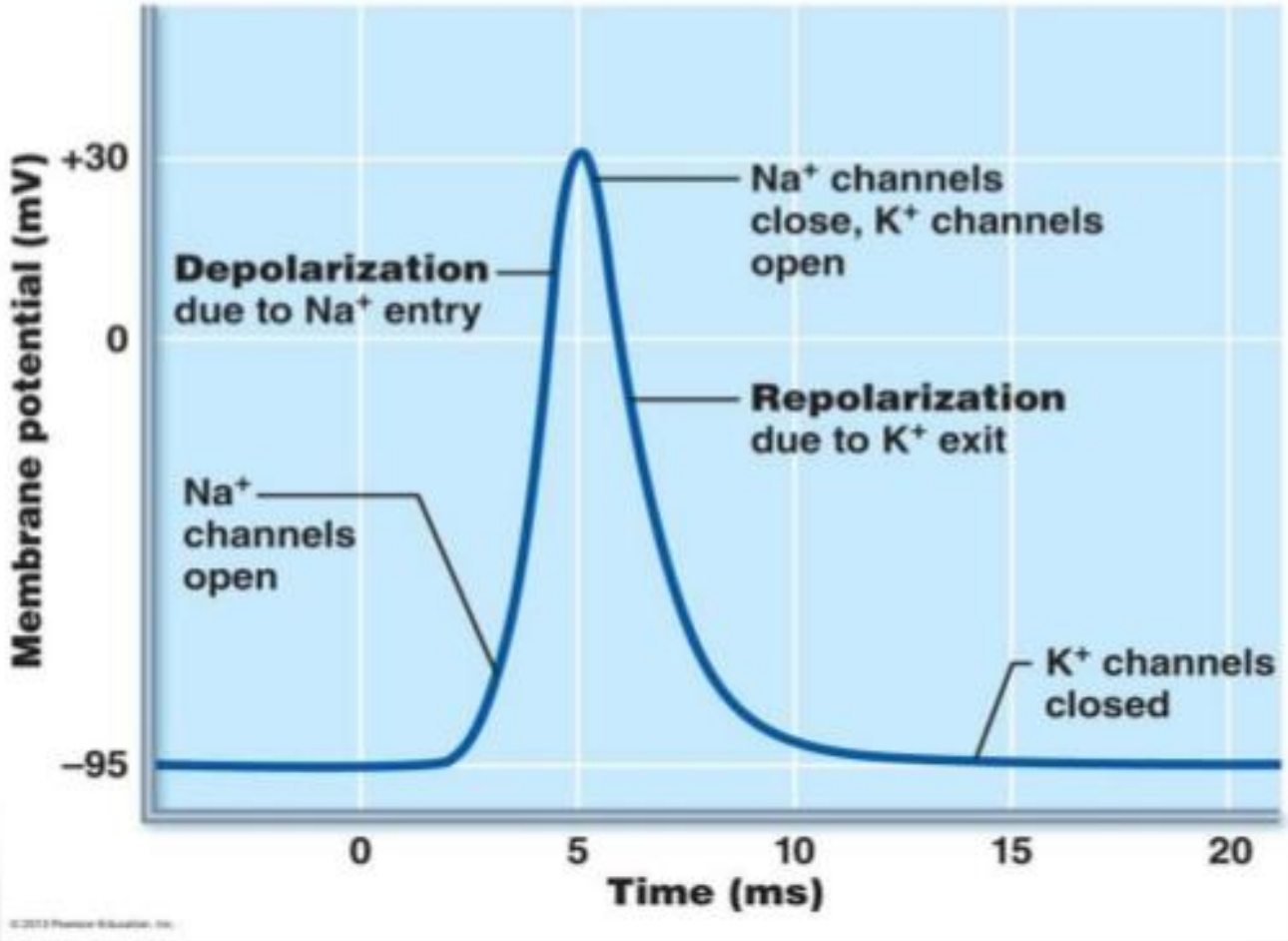
Potential

- values of RMP vary in various excitable tissues:
- In nerve fiber: -90 mV
- In skeletal muscle: -90 mV
- In cardiac muscle: -85 mV
- SA node: -55 mV
- In nerve cell body: -70 mV
- In smooth muscle: -55 mV to -60 mV



Measurement of the membrane potential of the nerve fiber using a microelectrode

Action potential- the change in electrical potential associated with the passage of an impulse along the membrane of a muscle cell or nerve cell.



1- Autorhythmicity

Definition: the ability of the heart to initiate its beat continuously and regularly without external stimulation

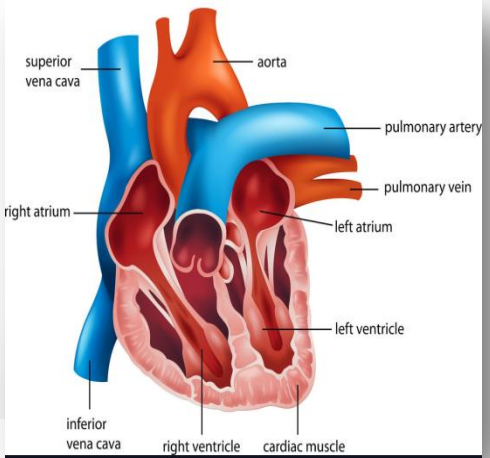
- ❖ **myogenic** (independent of nerve supply)
- ❖ due to the **specialized excitatory & conductive system** of the heart

↓

intrinsic ability of self-excitation (waves of depolarization)

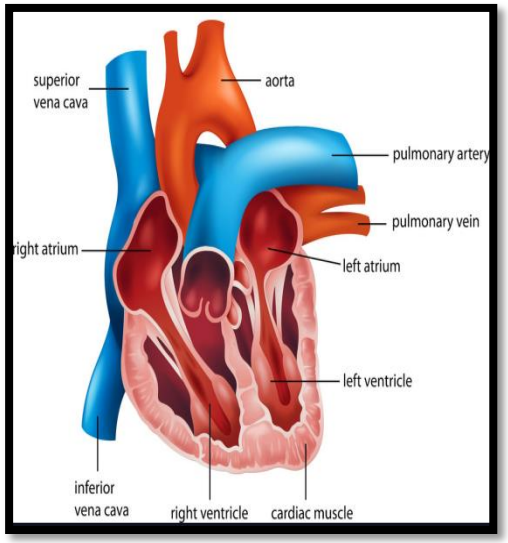
↓

cardiac impulses



Autorythmic fibers

Autorythmic fibers



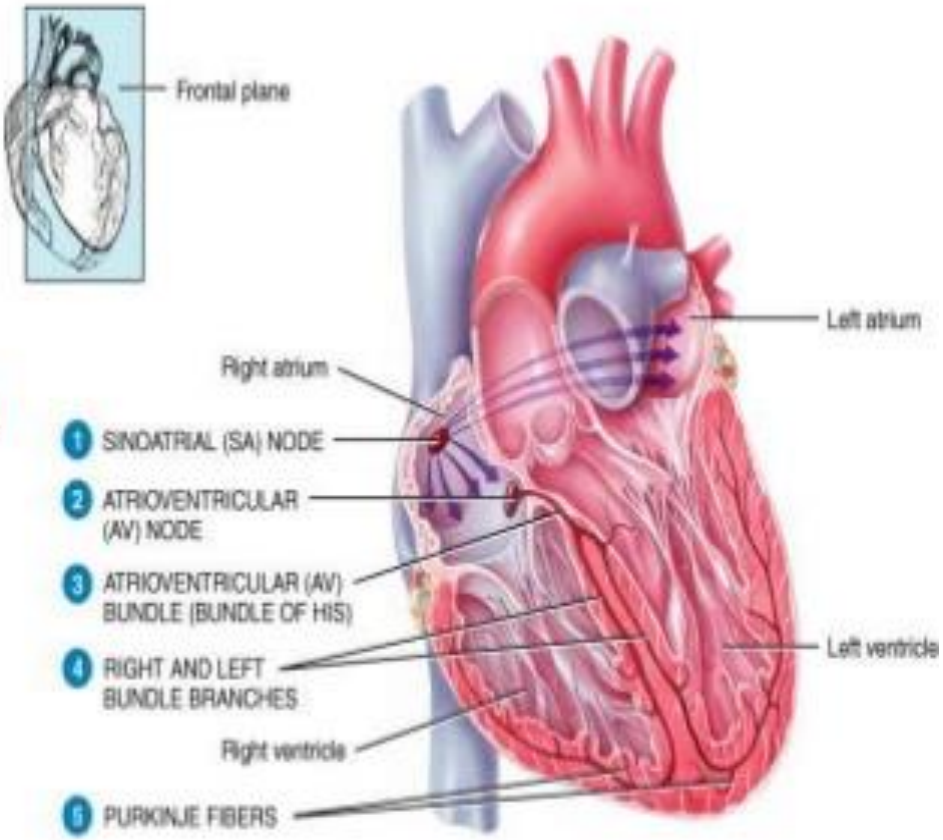
Forms 1% of the cardiac muscle fibers

Have two important functions

1. Act as a pacemaker (set the rhythm of electrical excitation)
2. Form the conductive system (network of specialized cardiac muscle fibers that provide a path for each cycle of cardiac excitation to progress through the heart)

Locations of autorhythmic cells

- Sinoatrial node (SA node)
  Specialized region in right atrial wall near opening of superior vena cava.
- Atrioventricular node (AV node)
  Small bundle of specialized cardiac cells located at base of right atrium near septum
- Bundle of His (atrioventricular bundle)
  Cells originate at AV node and enters interventricular septum
  Divides to form right and left bundle branches which travel down septum, curve around tip of ventricular chambers, travel back toward atria along outer walls
- Purkinje fibers
  Small, terminal fibers that extend from bundle of His and spread throughout ventricular myocardium

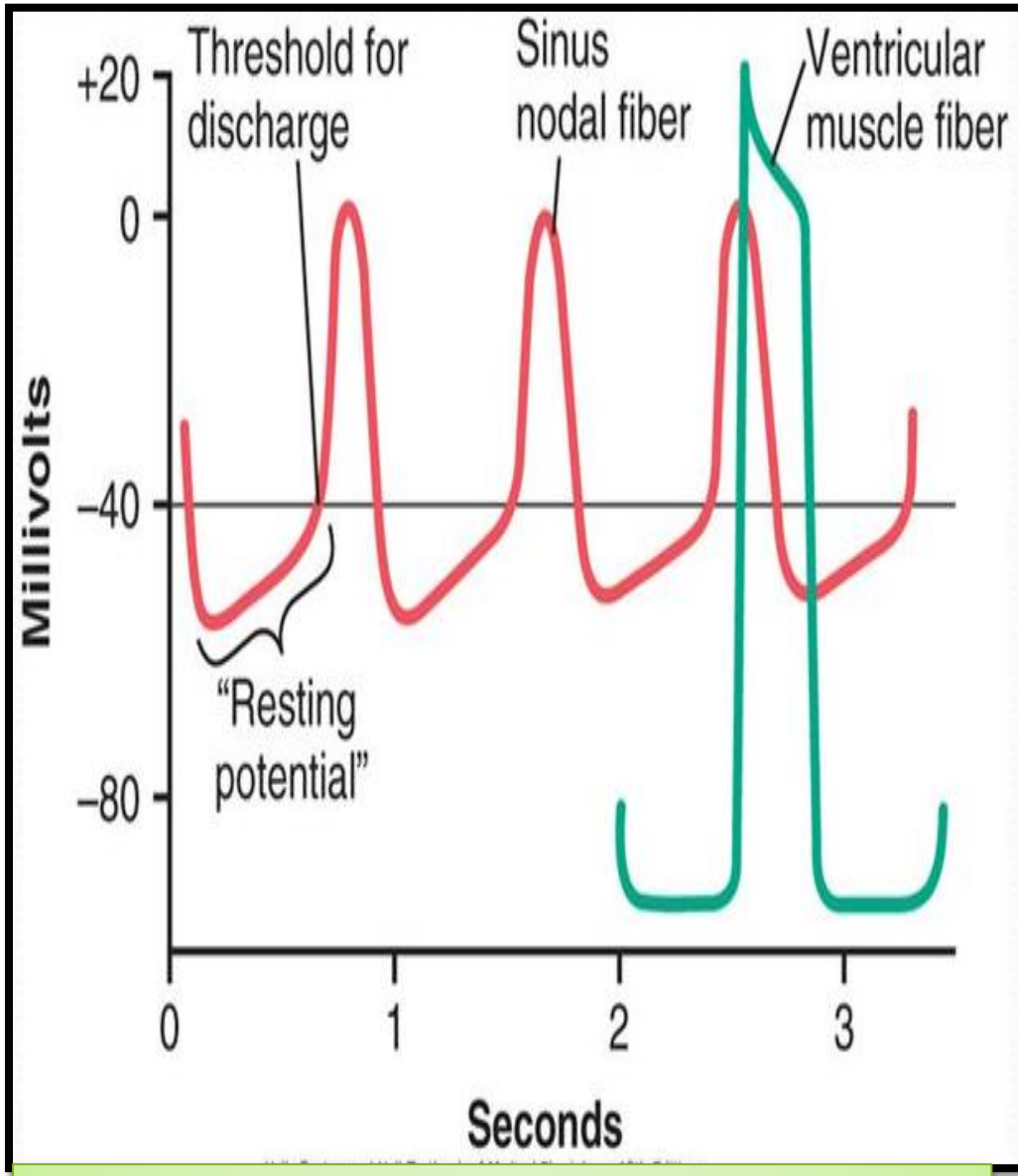


(a) Anterior view of frontal section

20.10a

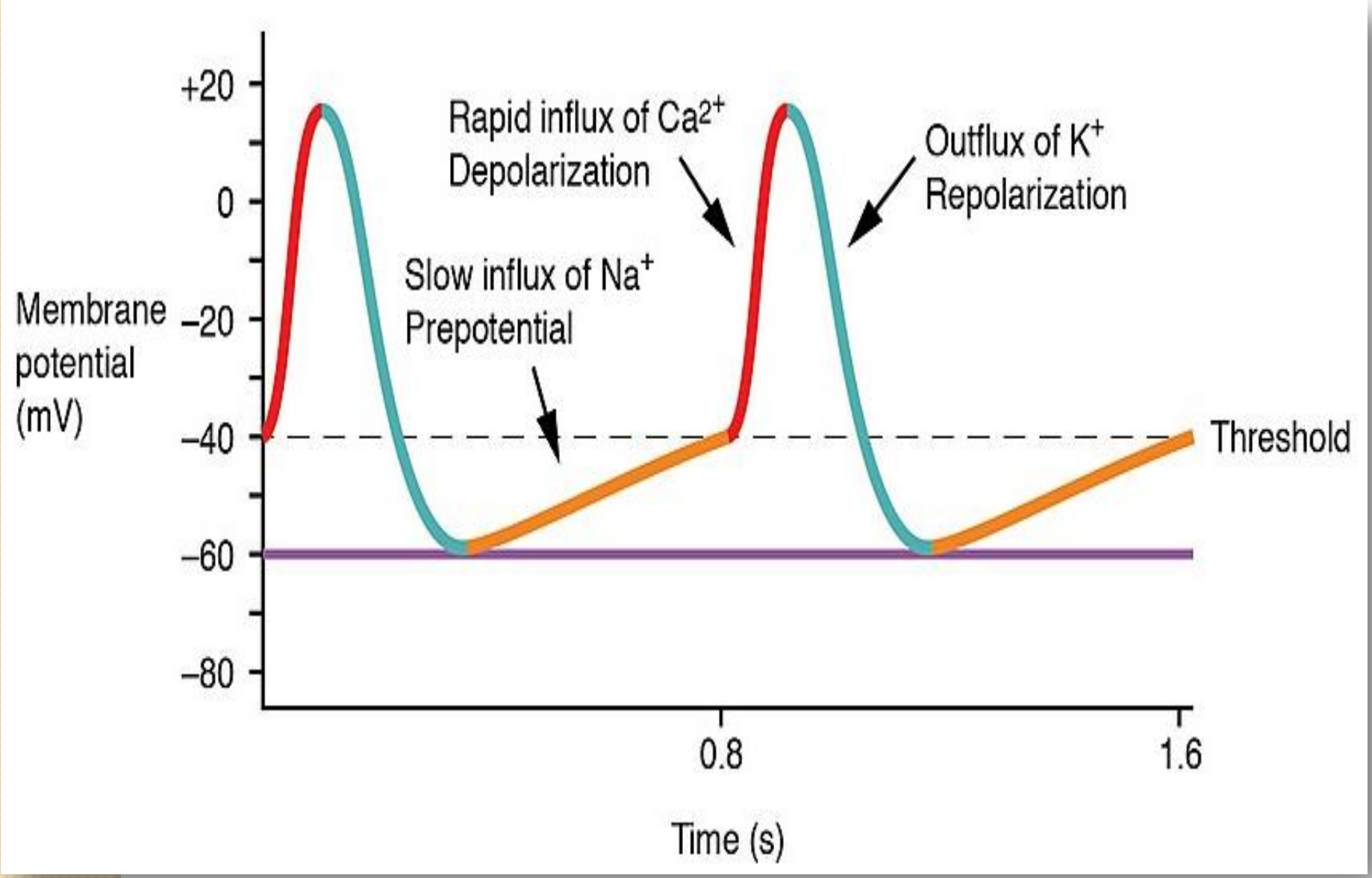
Mechanism of Autorhythmicity

- Autorhythmic cells do not have stable resting membrane potential (RMP)
- Natural leakiness to Na & Ca→ spontaneous and gradual depolarization
- Unstable resting membrane potential (= pacemaker potential)
- Gradual depolarization reaches threshold (-40 mv) → spontaneous AP generation



Rhythmical discharge of sinus node fiber

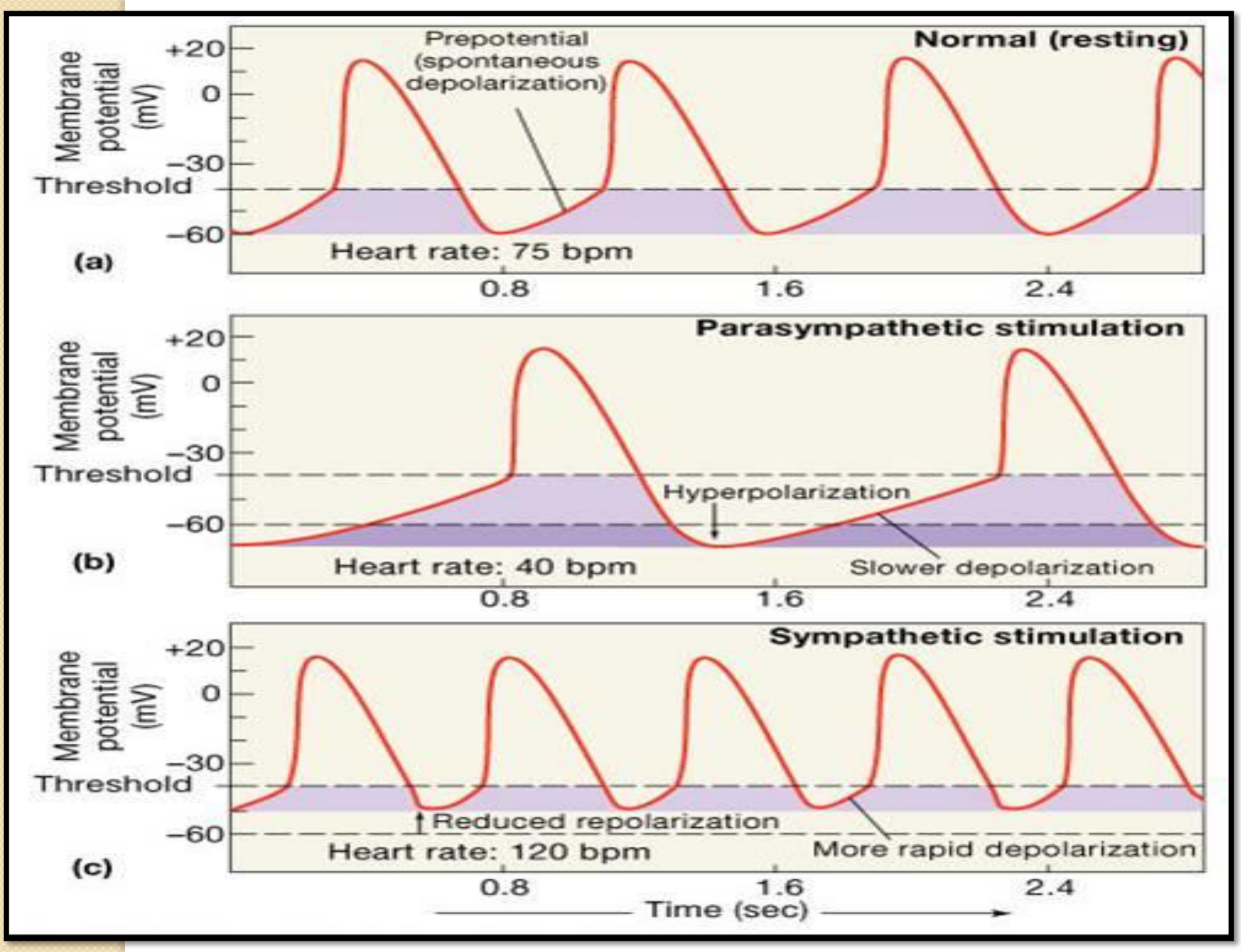
Prepotential , Pacemaker potential , Diastolic potential

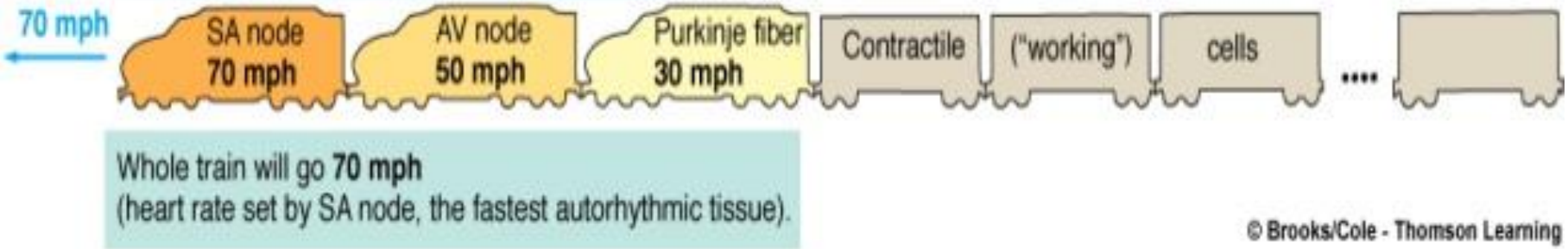


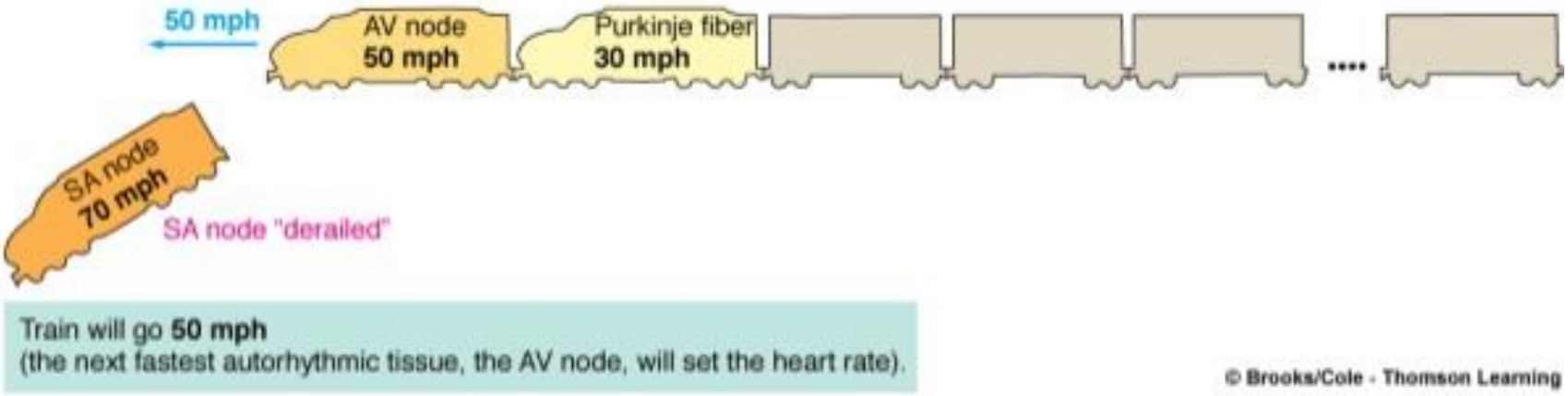
Rate of generation of AP at different sites of the heart

SITE	RATE (Times/min)
SA node	70 - 80
AV node	40 - 60
AV bundle, bundle branches,& Purkinje fibres	20 - 35

- SA node acts as heart pacemaker because it has the fastest rate of generating action potential
- Nerve impulses from autonomic nervous system and hormones **modify** the timing and strength of each heart beat but do not establish the fundamental rhythm.


Normal (resting)
Prepotential (spontaneous depolarization)
Membrane potential (mV)
+20
0
−30
−60
Threshold
Heart rate: 75 bpm
(a)
0.8
1.6
2.4
Parasympathetic stimulation
Hyperpolarization
Slower depolarization
Heart rate: 40 bpm
(b)
Sympathetic stimulation
Reduced repolarization
More rapid depolarization
Heart rate: 120 bpm
(c)
Time (sec)





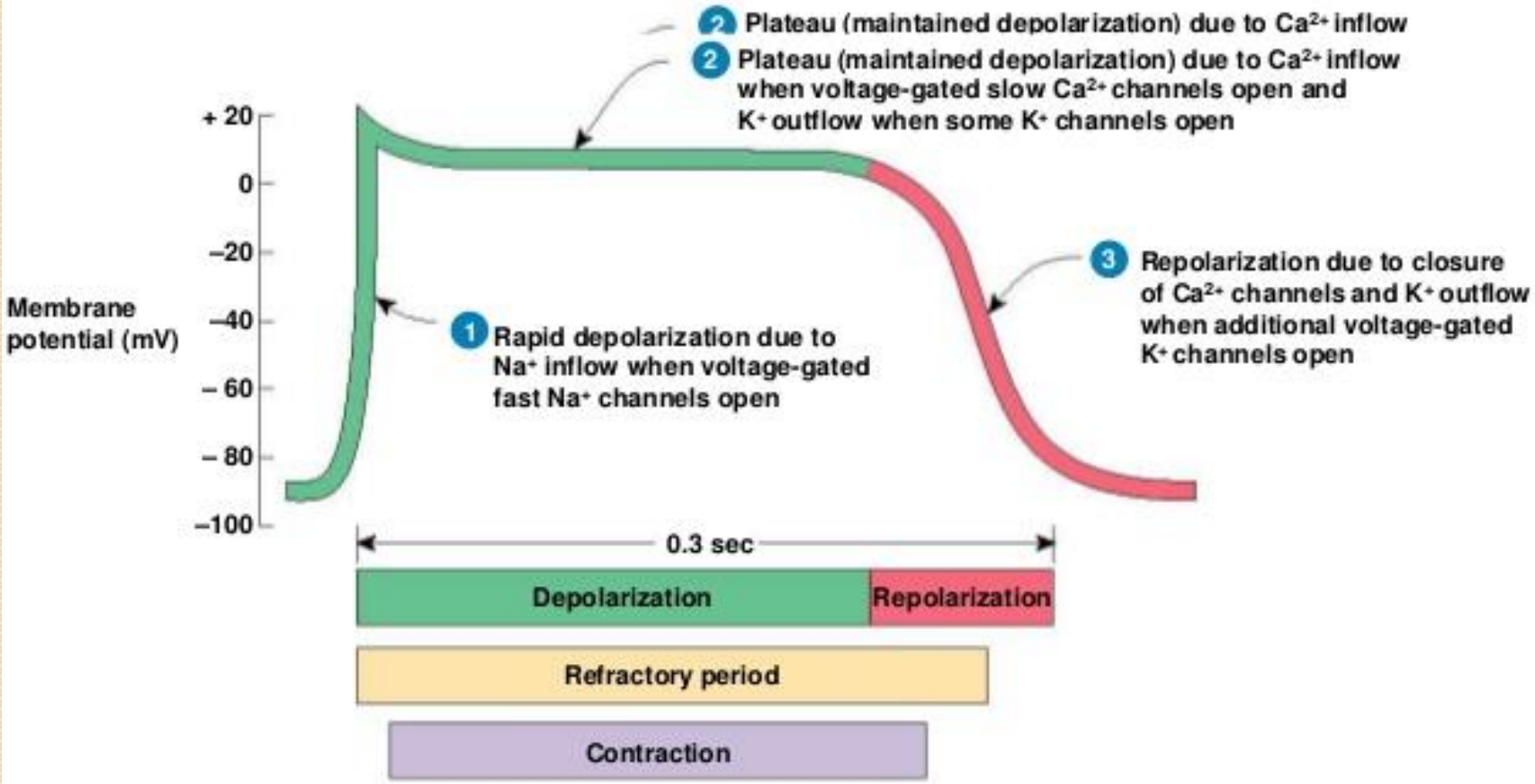
- ∴Non-SA nodal tissues are ***latent pacemakers*** that can take over (at a slower rate), should the normal pacemaker (SA node) fail

2. Excitability

Definition: The ability of cardiac muscle to respond to a stimulus of adequate strength & duration by generating an AP

- AP initiated by SA node→ travels along conductive pathway→ excites atrial &ventricular muscle fibres

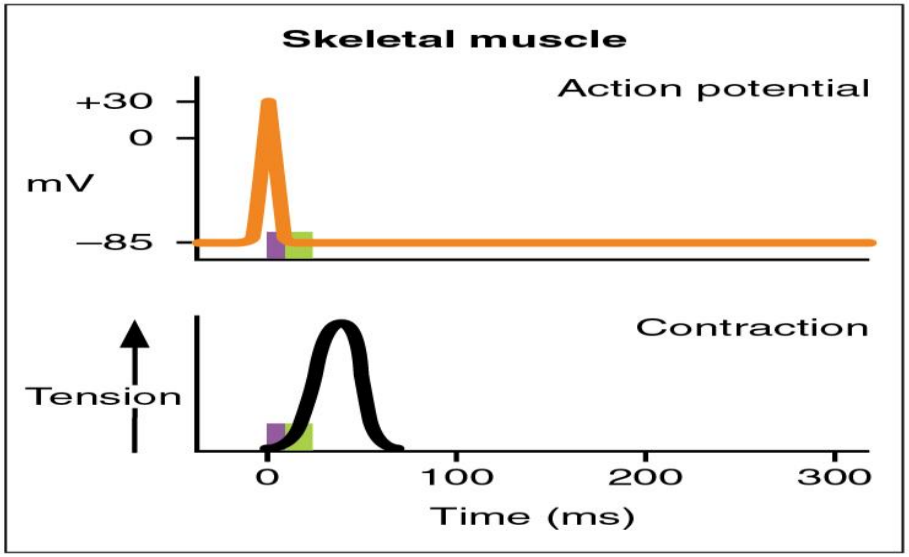
Cardiac Muscle Action Potential

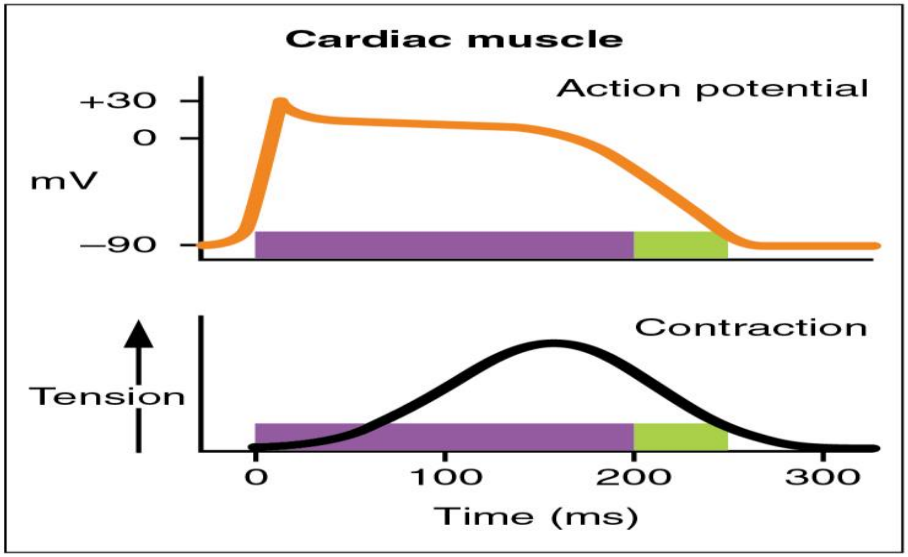


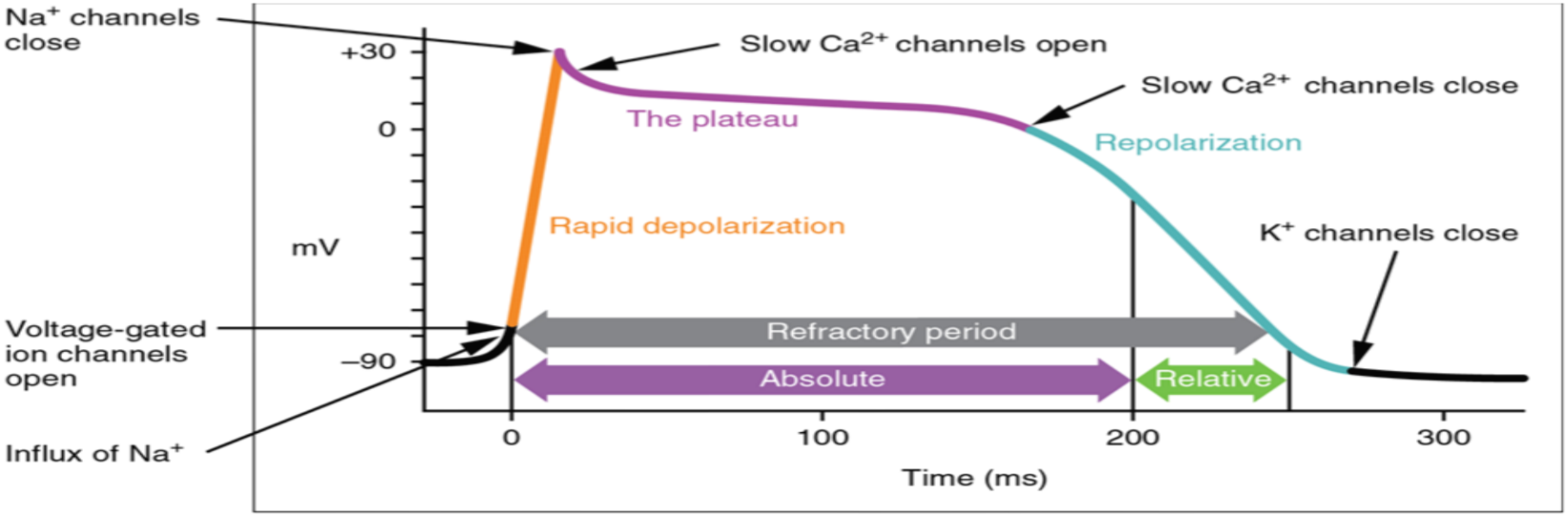
AP-contraction relationship

- AP in skeletal muscle is very short-lived-AP is basically over before an increase in muscle tension can be measured

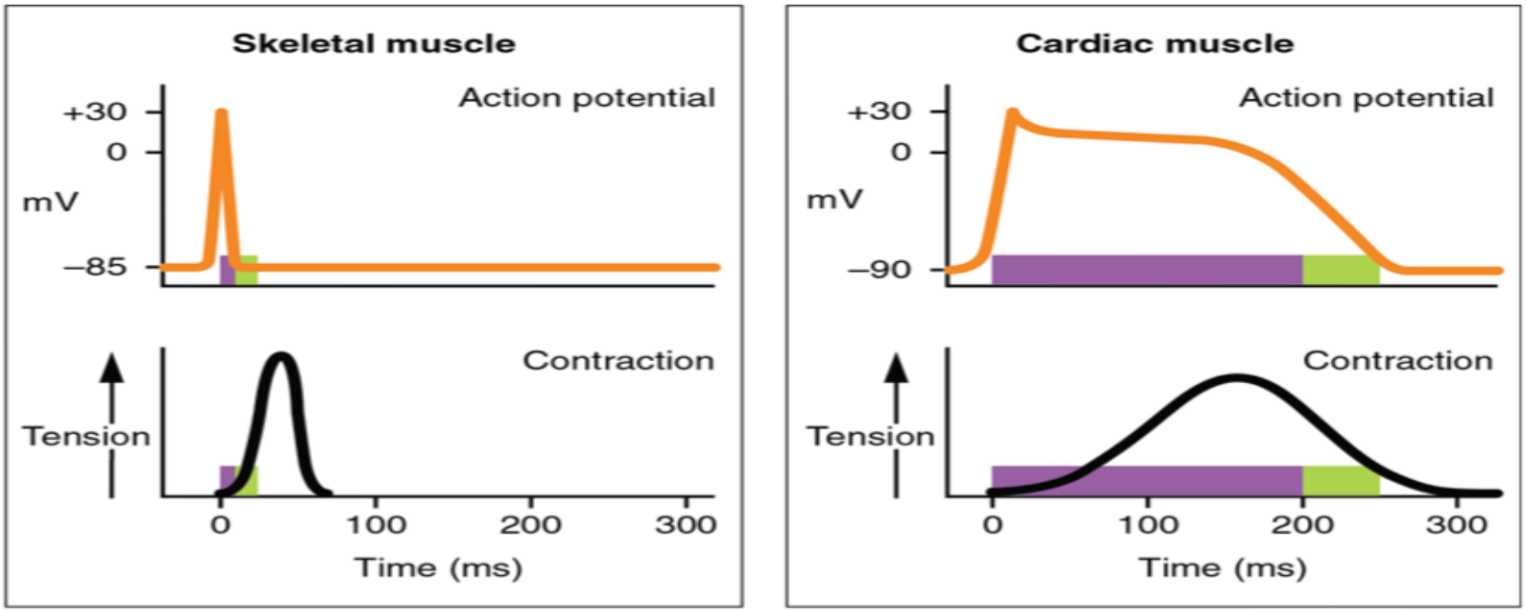
- AP in cardiac muscle is very long-lived
  - AP has an extra component ,which extends the duration .
  - The contraction is almost over before the action potential has finished



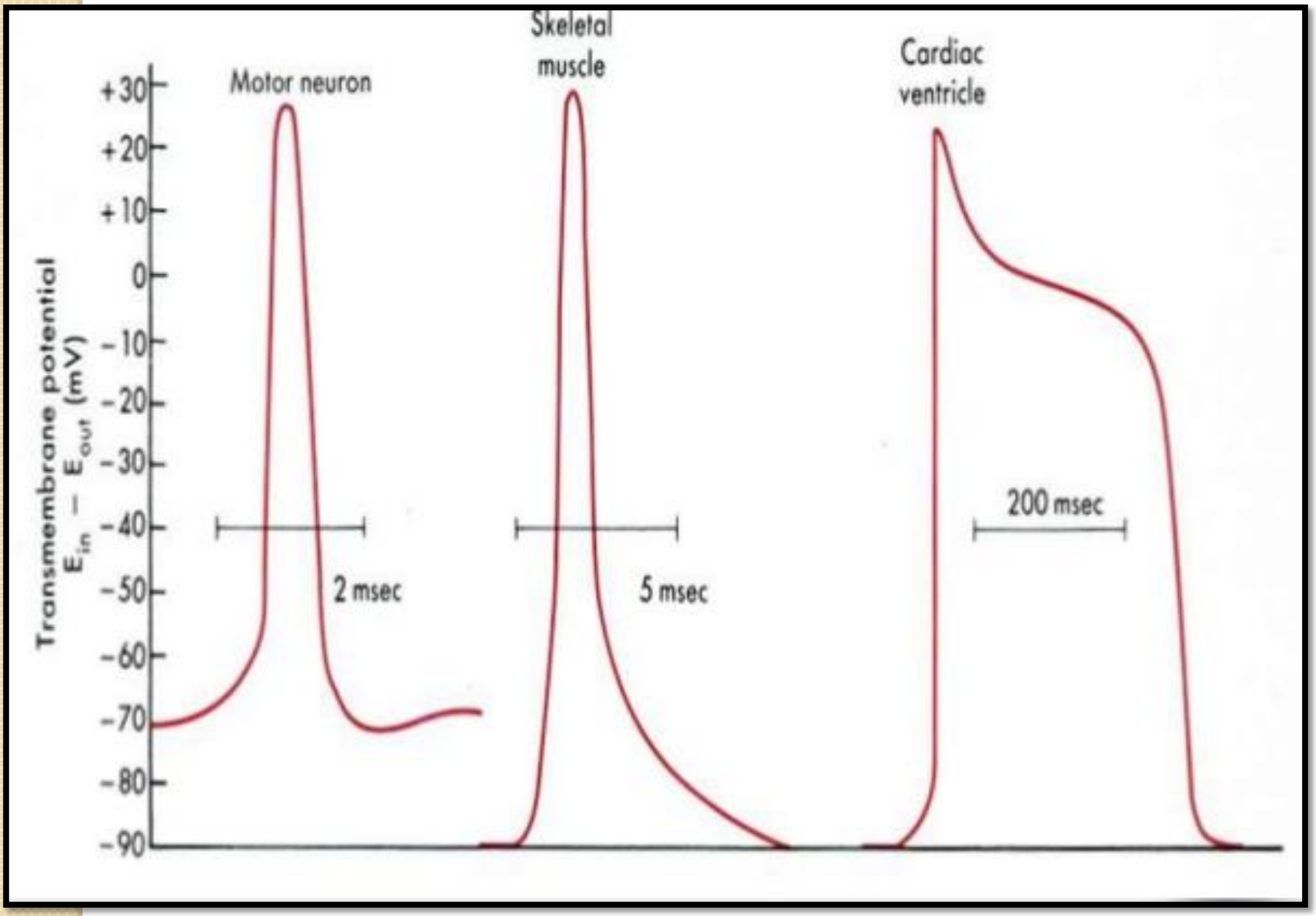



Na+ channels close
Slow Ca2+ channels open
Slow Ca2+ channels close
The plateau
Repolarization
Rapid depolarization
K+ channels close
Voltage-gated ion channels open
Influx of Na+
Refractory period
Absolute
Relative
+30
0
mV
–90
0
100
200
300
Time (ms)

(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)

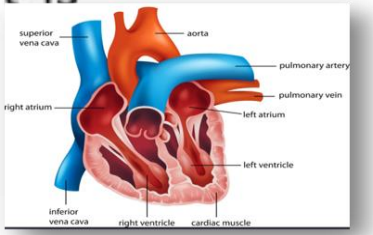

Motor neuron
Skeletal muscle
Cardiac ventricle
Transmembrane potential
$E_{in} - E_{out}$ (mV)
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2 msec
5 msec
200 msec

Refractory period

- It is that period during which a second stimulus fails to evoke a response.

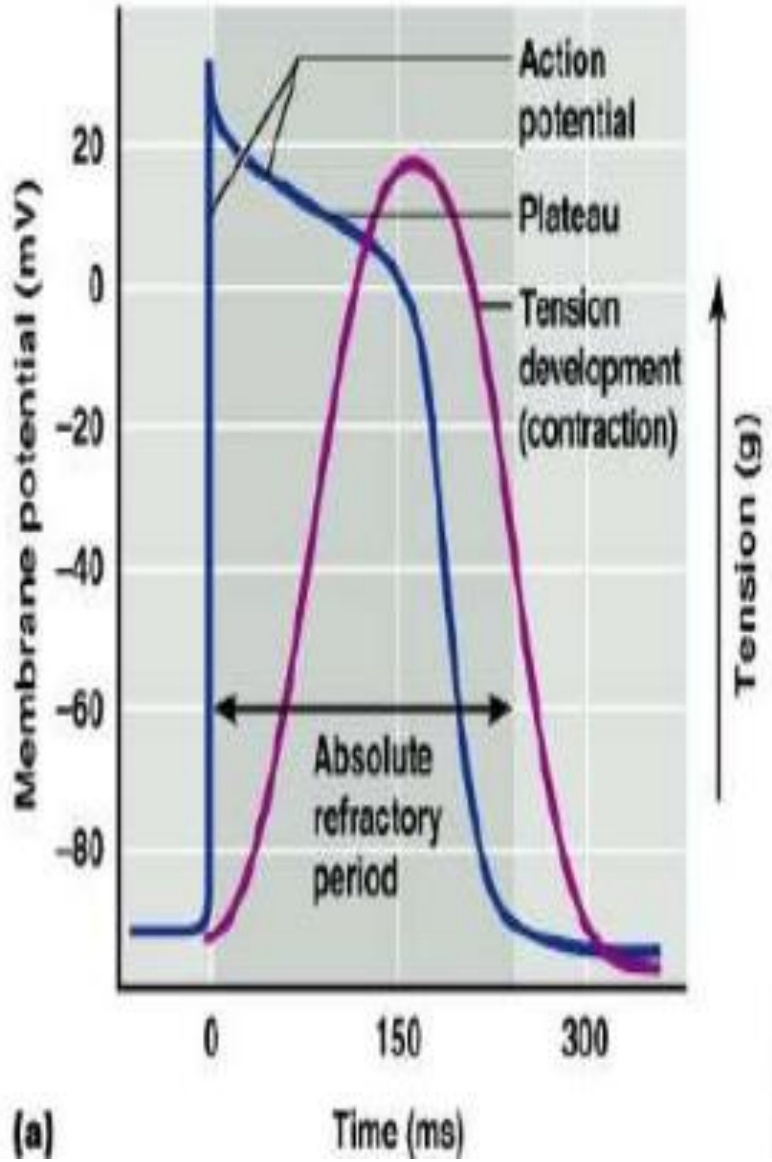
- Absolute Refractory Period : It is that period during which a second stimulus however high it is fails to evoke a response.

- Relative Refractory Period : It is that period during which a second stimulus evokes a response if it is sufficiently high.



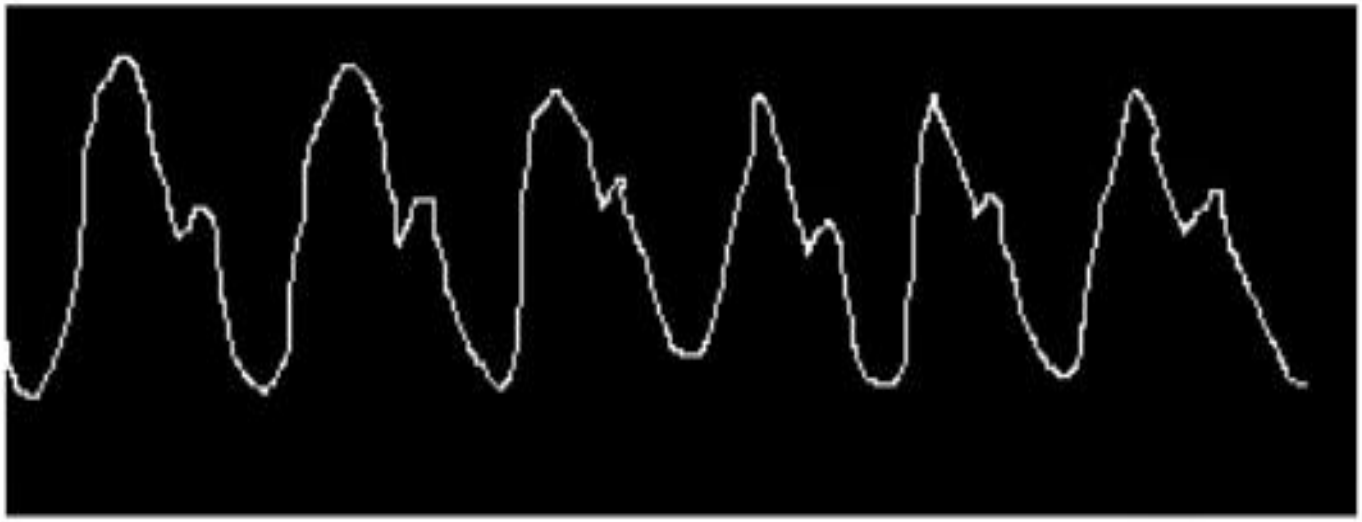
Refractory period

- Long refractory period (250 msec) compared to skeletal muscle (3msec)
- During this period membrane is refractory to further stimulation until contraction is over.
- It lasts longer than muscle contraction, prevents tetanus
- Gives time to heart to relax after each contraction, prevent fatigue
- It allows time for the heart chambers to fill during diastole before next contraction



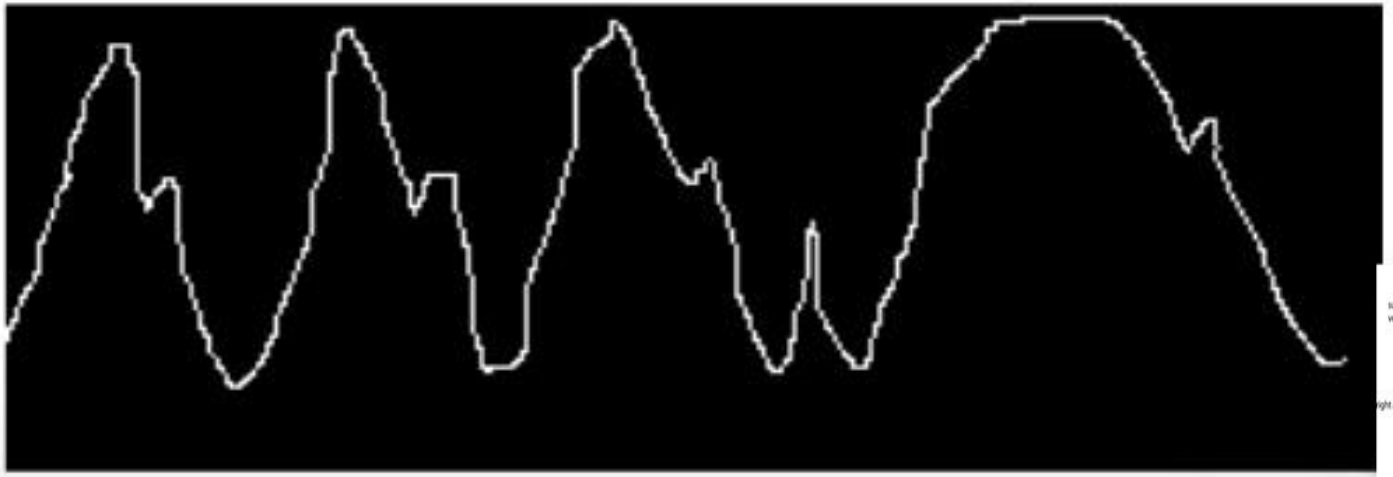
Normal Cardiogram

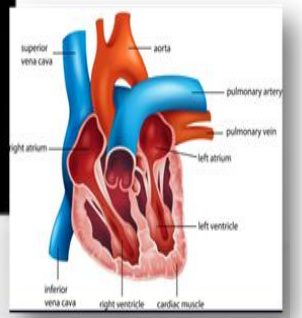
- It is a recording of the mechanical activity of the heart
- Systole- Contraction Diastole- Relaxation



Extra systole

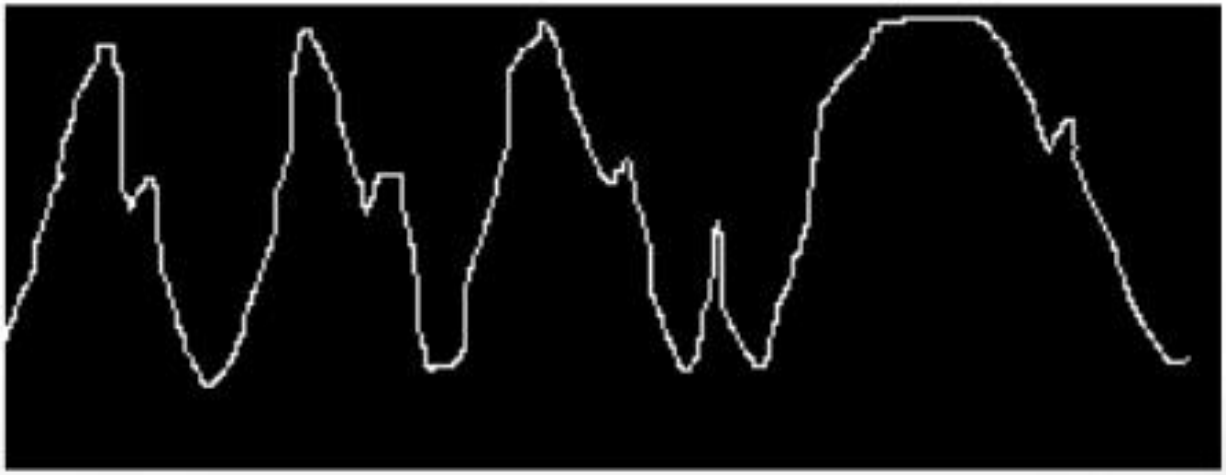
- It is an extra contraction seen when the second stimulus falls during the relative refractory period.
- Systole-Down stroke
- Diastole-Up stroke

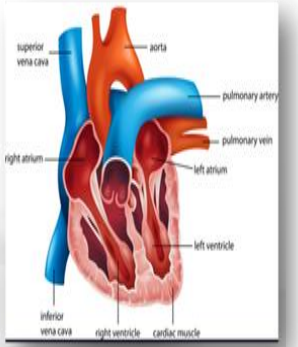




Compensatory Pause

- When an external stimulus is applied during the later 2/3 of diastole an extra contraction is observed.
- This is followed by a compensatory pause.
- Extra systole + Compensatory pause = 2 cardiac cycles





3. Contractility

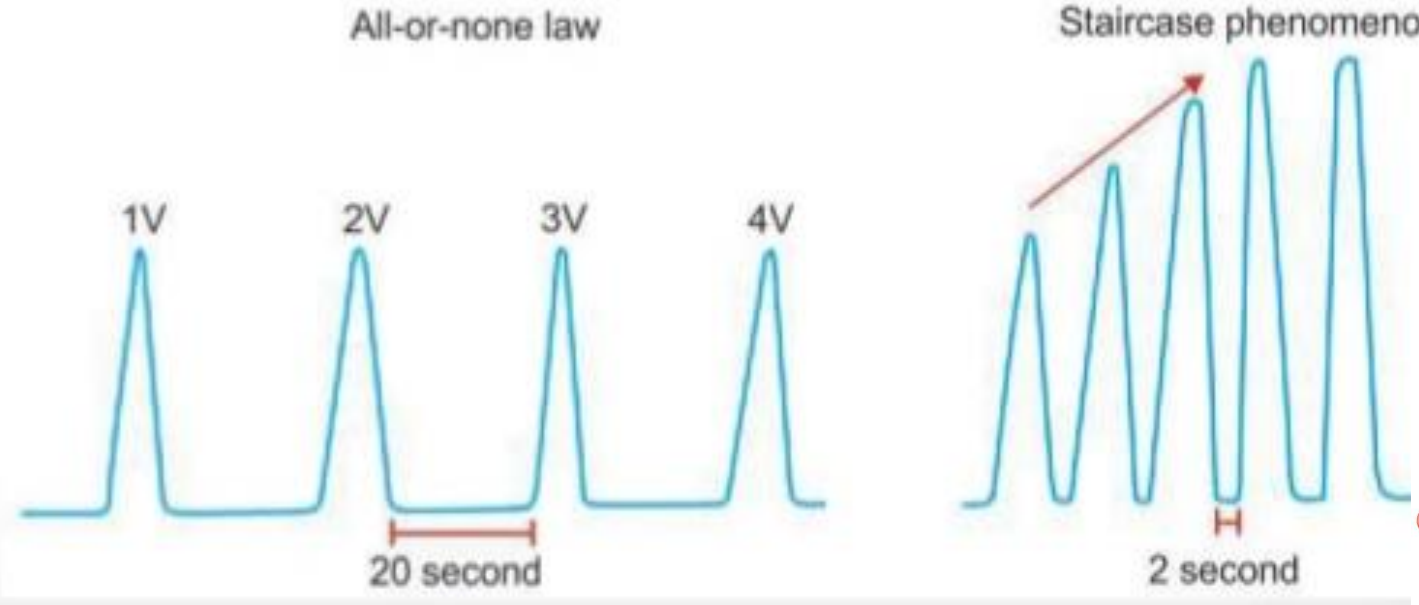
Definition: ability of cardiac muscle to contract in response to stimulation

All Or None Law

- The response to a threshold stimulus is maximal. If the stimulus is below threshold there is no response provided the physiological conditions remain constant
- The cardiac muscle follows the all or none law as a whole.
- In the case of skeletal muscle, all-or-none law is applicable only to a single muscle fiber.

Treppe or Stair-case Phenomenon

- When stimuli of same strength are applied at short intervals, an increase in the height of contraction is observed.
- This is due to the **BENEFICIAL EFFECT** - decrease in viscosity, mild increase in temperature and increase in the level of calcium ions.



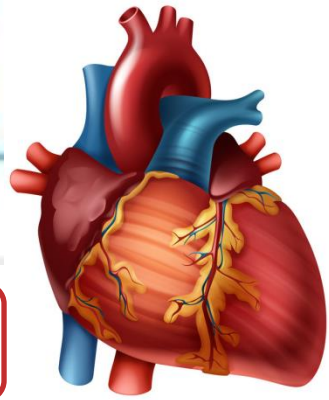
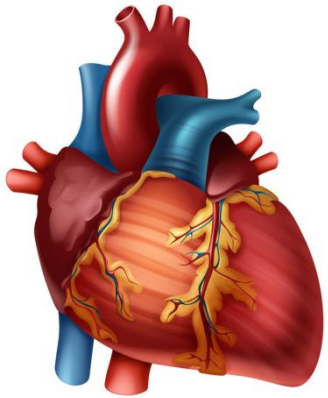


Figure: All or none law and staircase phenomenon in cardiac muscle

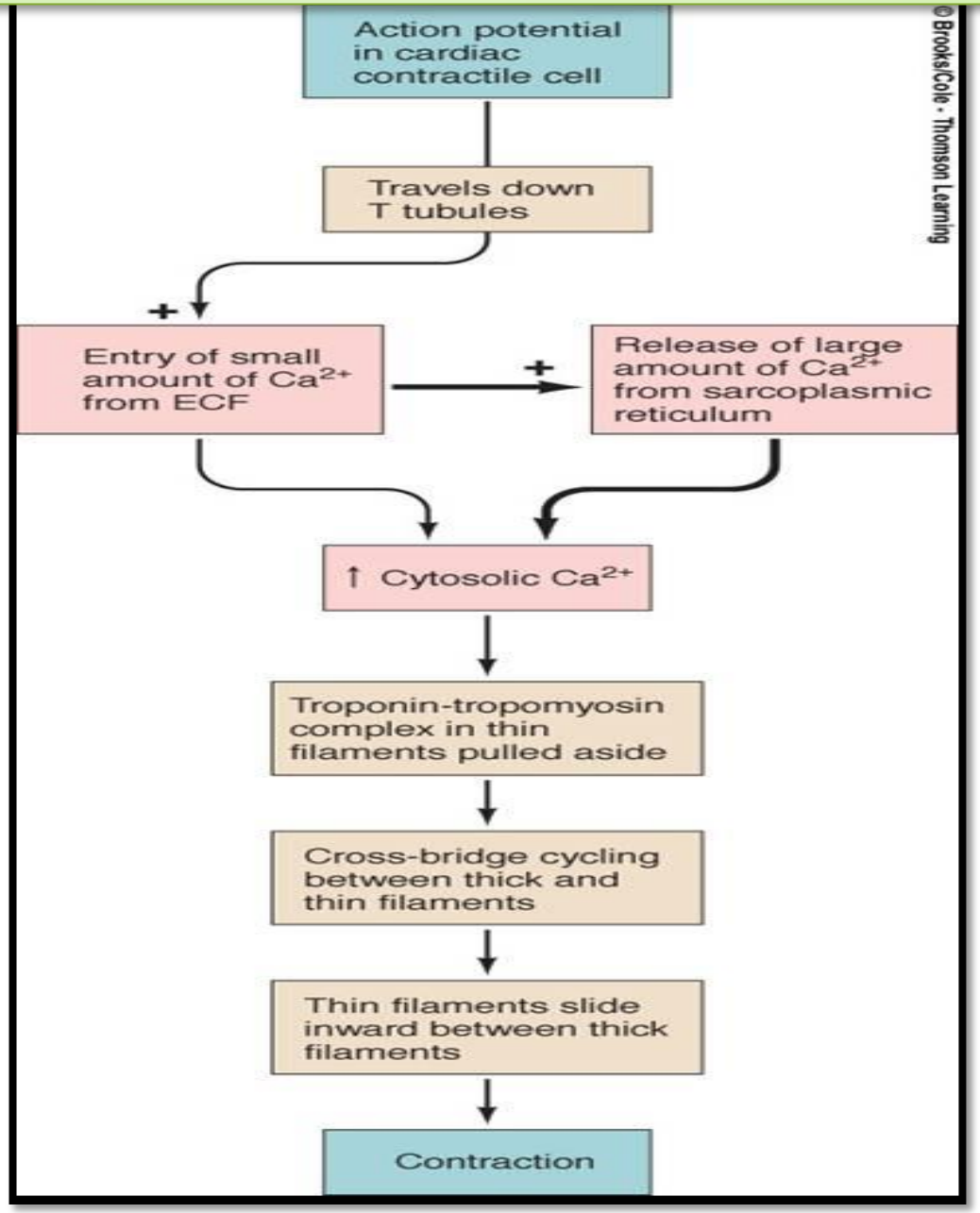
Summation of Sub-minimal Stimuli

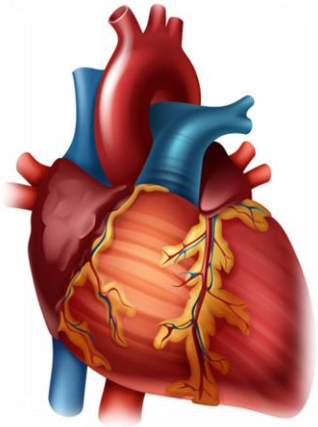
When a series of sub-minimal stimuli are applied to the cardiac muscle, it responds with a contraction once all the sub –minimal add up to produce a threshold stimulus.



Excitation-Contraction Coupling in Cardiac Contractile cells

Similar to that in skeletal muscles





The cardiac muscle stores much more calcium in its tubular system than skeletal muscle and is much more dependent on extracellular calcium than the skeletal muscle.

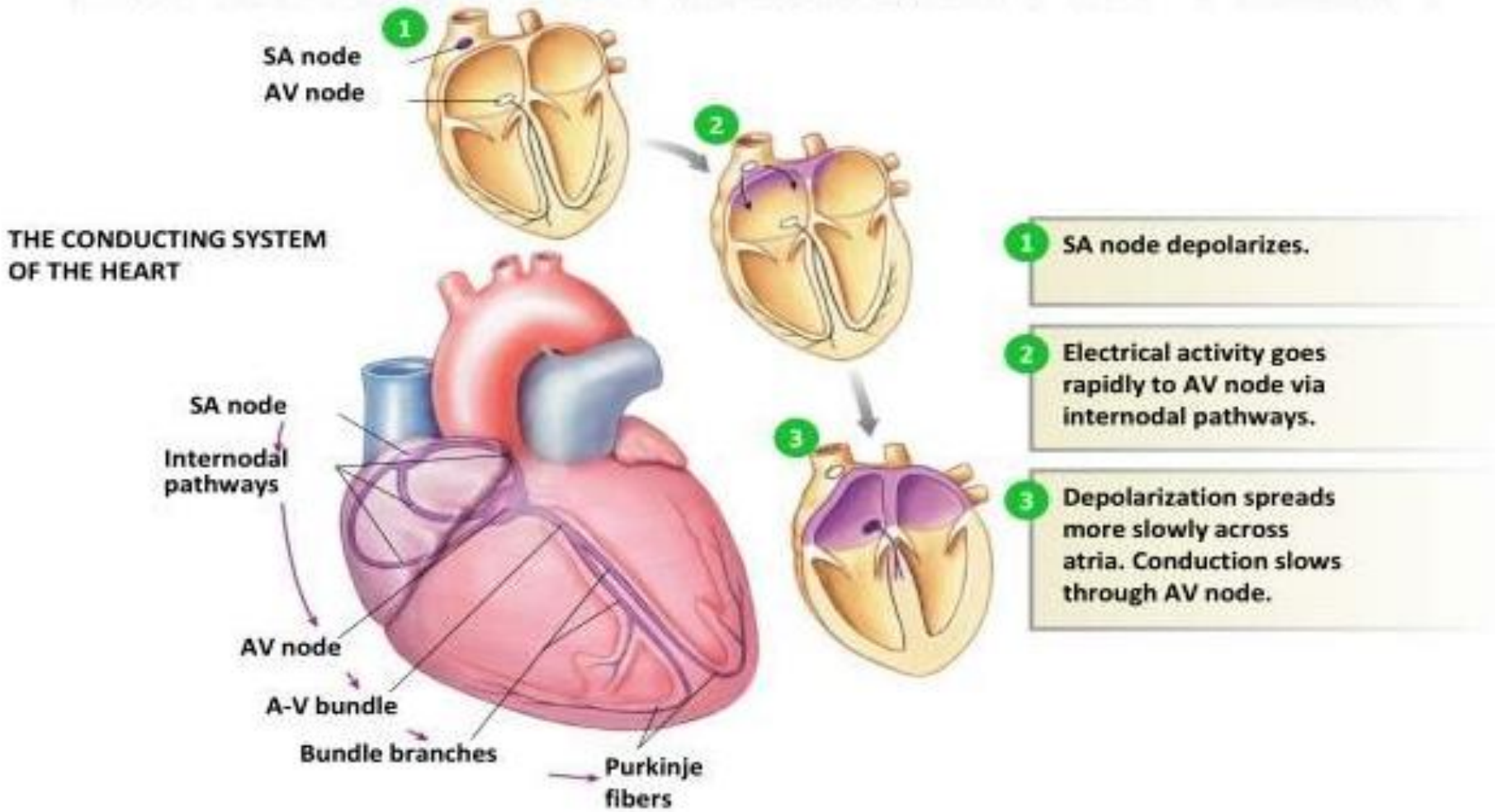
An abundance of calcium is bound by the mucopolysaccha -rides inside the T-tubule.

This calcium is necessary for contraction of cardiac muscle, and its strength of contraction depends on the calcium concentration surrounding the cardiac myocytes.

At the initiation of the action potential, the fast sodium channels open first, followed later by the opening of the slow calcium channels.

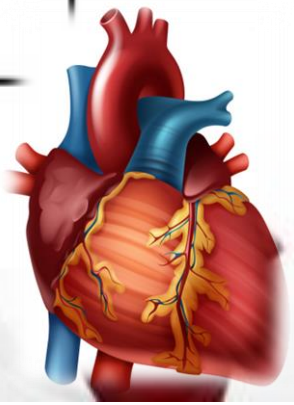
4. Conductivity

Definition: property by which excitation is conducted through the cardiac tissue



Tissue	Conduction rate (m/s)
Atrial muscle	0.3
Atrial pathways	1
AV node	0.05
Bundle of His	1
Purkinje system	4
Ventricular muscle	0.3-0.5

Thus, the velocity of impulses is maximum in Purkinje fibers and minimum at AV node



The atrial and ventricular muscles have a relatively rapid rate of conduction of the cardiac action potential, and the anterior internodal pathway also has fairly rapid conduction of the impulse.

However, the A-V bundle myofibrils have a slow rate of conduction <u>because their sizes are considerably smaller</u> than the sizes of the normal atrial and ventricular muscle.

Also, their slow conduction is partly caused by <u>diminished numbers of gap junctions between successive muscle cells in the conducting pathway</u>, causing a great resistance to conduction of the excitatory ions from one cell to the next.

Cardiac Cycle

The cardiac events that occur from the beginning of one heartbeat to the beginning of the next are called the *cardiac cycle*.

- The cardiac cycle consists:
  - Period of relaxation - ***diastole***,
    - during which the heart fills with blood,
  - Followed by a period of contraction called ***systole.***
    - **during which heart ejects blood**

Cardiac Cycle

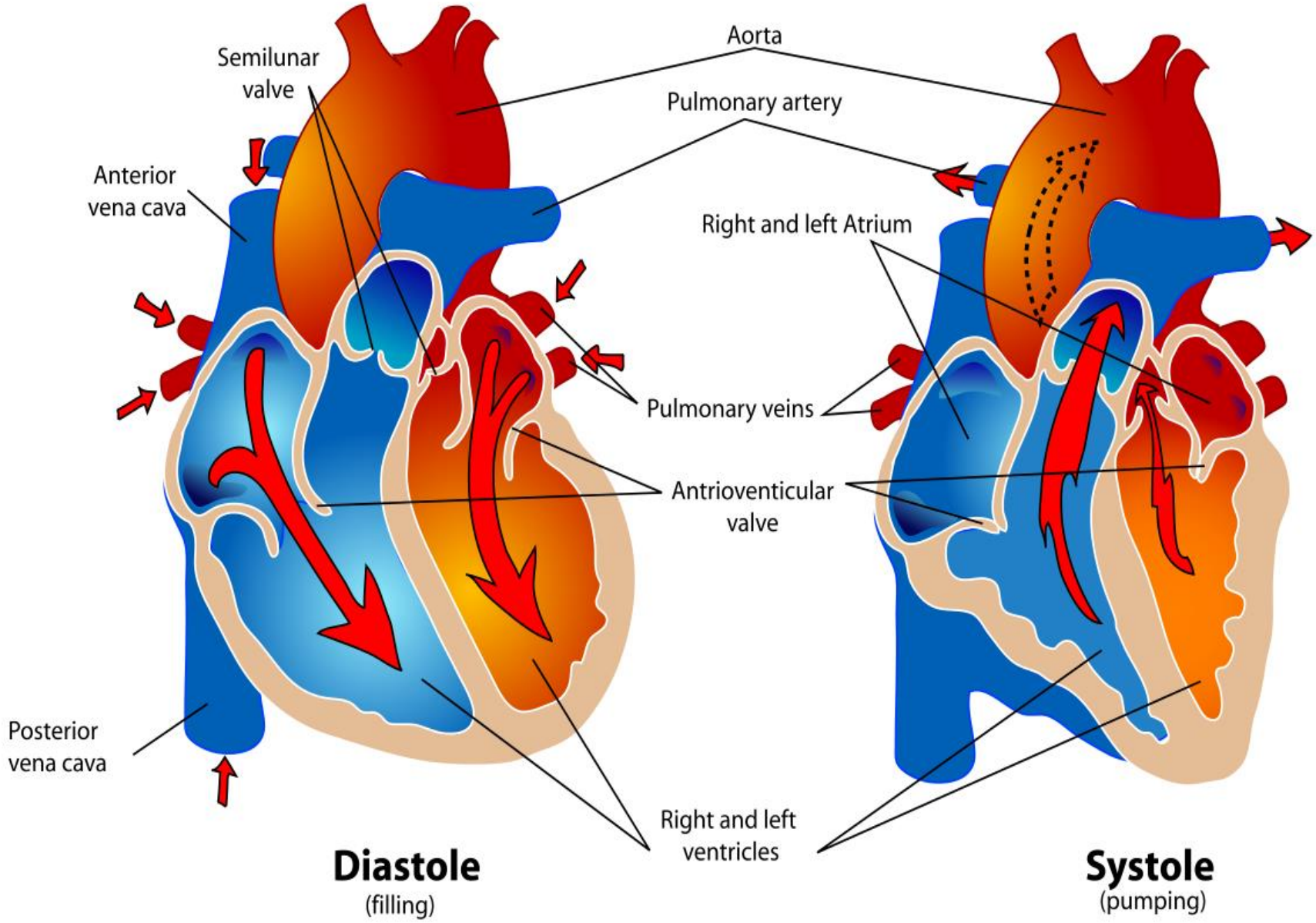
- During systole there is contraction of the cardiac muscle and pumping of blood from the heart through arteries.
- During diastole, there is relaxation of cardiac muscle and filling of blood.
- Various changes occur in different chambers of heart during each heartbeat. These changes are repeated during every heartbeat in a cyclic manner.
- Each cycle is initiated by spontaneous generation of action potential in the S.A node.

Divisions of cardiac cycle

- The cardiac cycle consists of a period of relaxation called **diastole**, during which the heart fills with blood this period is followed by a period of contraction called **systole**.

- The contraction and relaxation of atria are called atrial systole and atrial diastole respectively.

- The contraction and relaxation of ventricles are called ventricular systole and ventricular diastole respectively.


Semilunar valve
Aorta
Pulmonary artery
Anterior vena cava
Right and left Atrium
Pulmonary veins
Antrioventicular valve
Posterior vena cava
Right and left ventricles
Diastole
(filling)
Systole
(pumping)

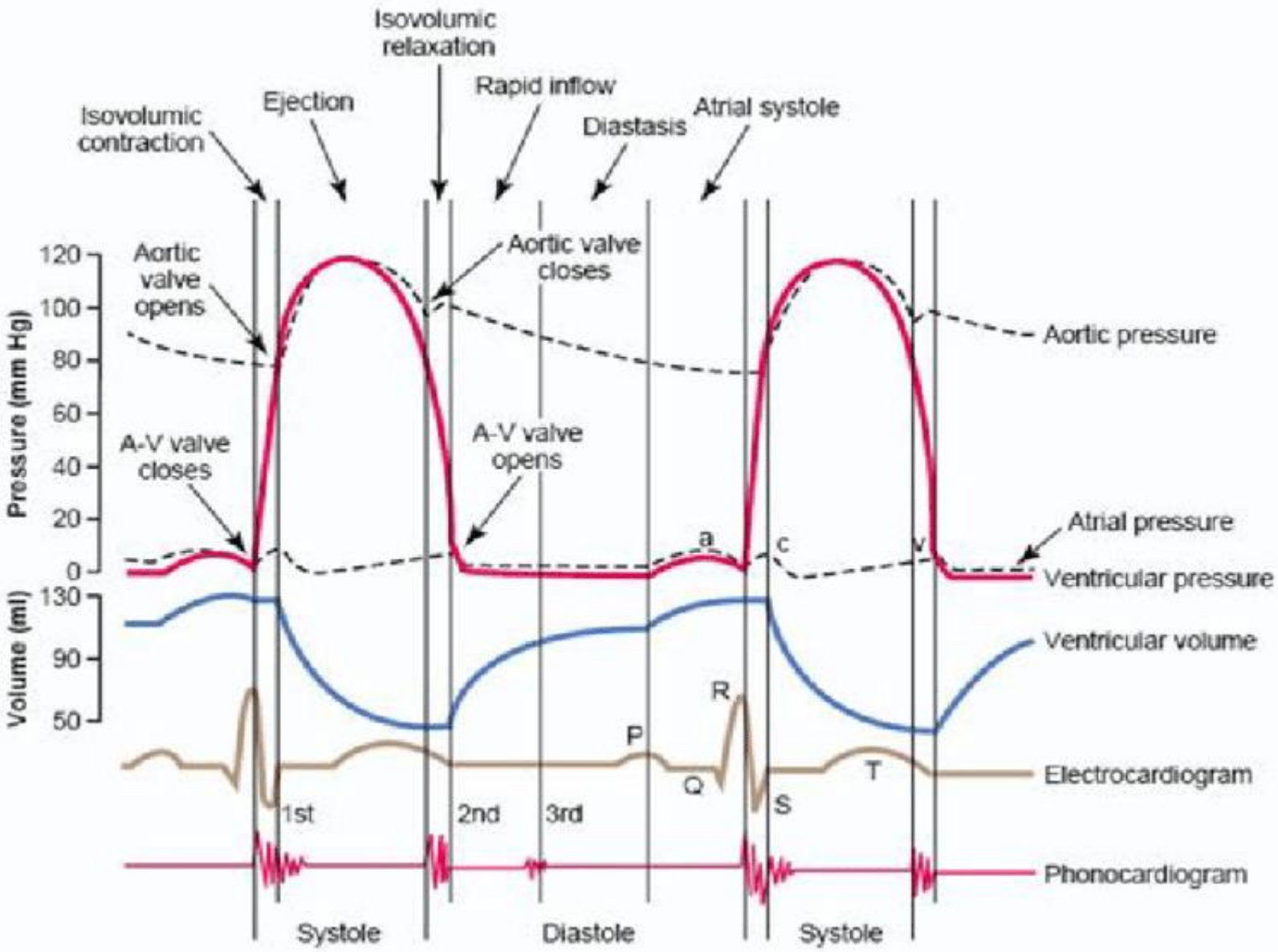
Requirements for Efficient Cardiac Contraction

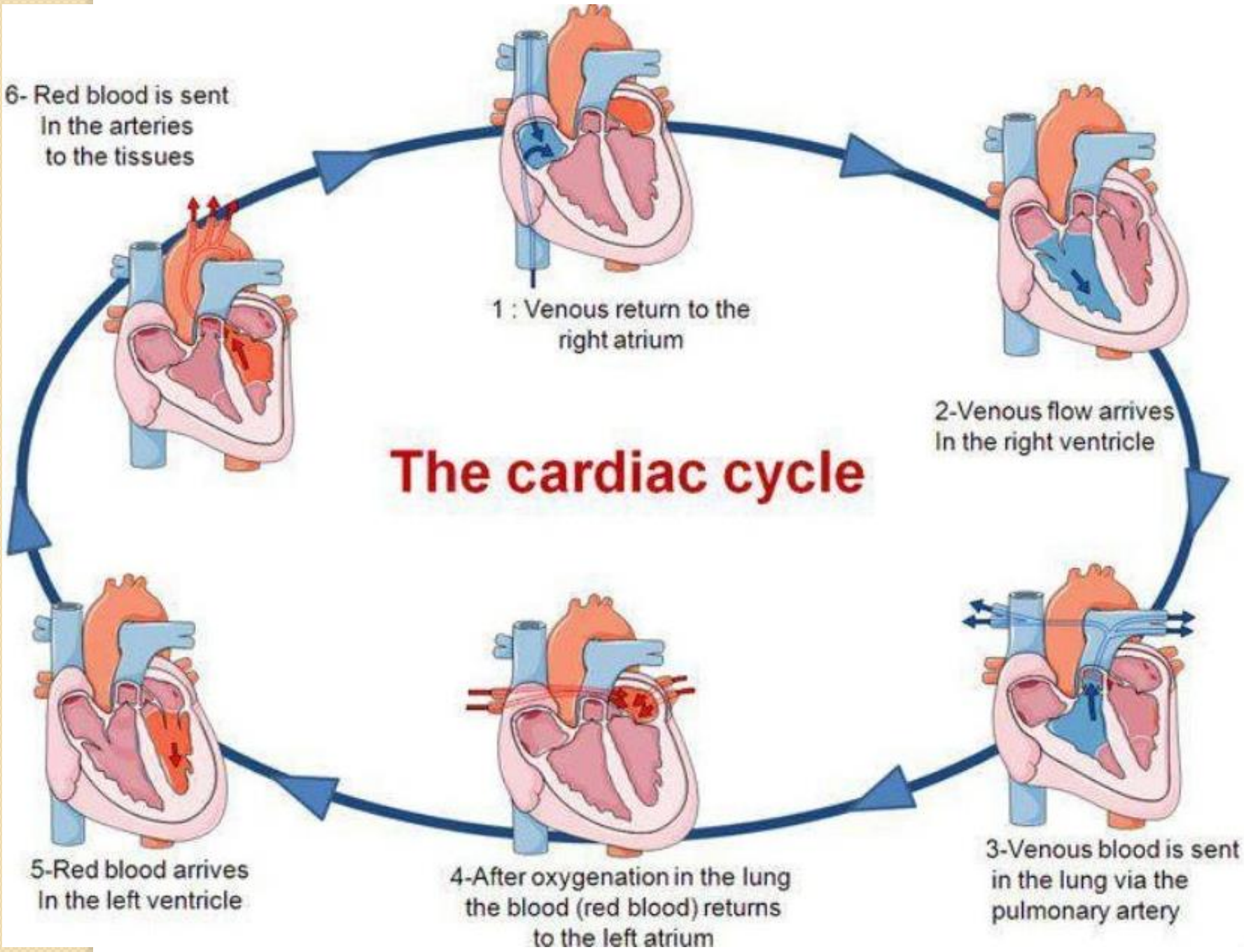
1. Atrial excitation and contraction need to be complete before ventricular contraction occurs.
2. Excitation of cardiac muscle fibers should be coordinated so that each chamber contracts as a unit.
3. Pair of atria and pair of ventricles should be coordinated so that both members of the pair contract simultaneously.

Cardiac cycle

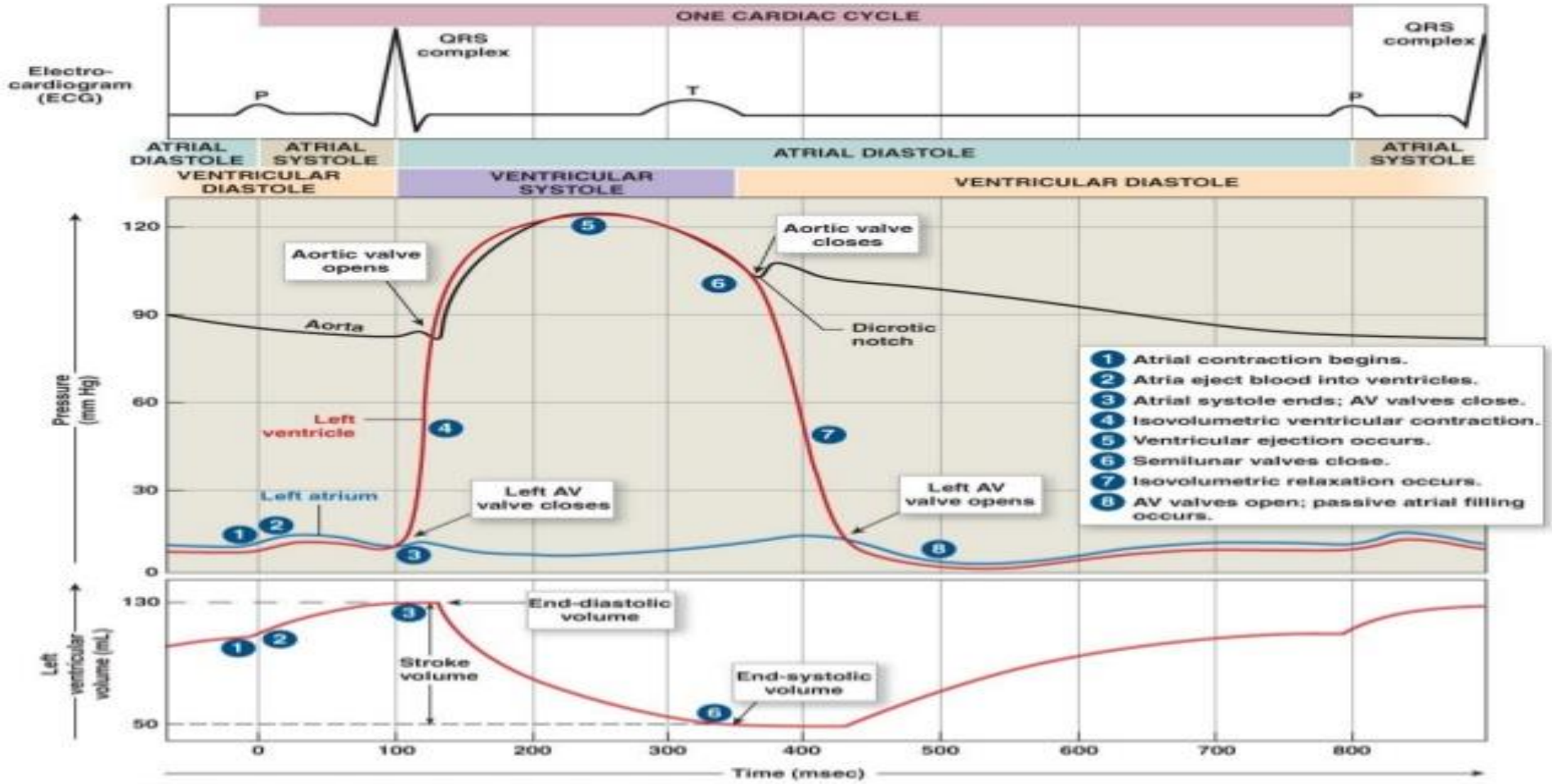
- First assembled by Lewis in 1920 but first conceived by Wiggers in 1915
- It is named after Dr. Carl J. Wiggers, M.D.
- A Wiggers diagram is a standard diagram used in cardiac physiology
- The X axis is used to plot time, while the Y axis contains all of the following on a single grid:
- Blood pressure Aortic pressure
  Ventricular pressure
  Atrial pressure
- Ventricular volume
- Electrocardiogram
- Arterial flow (optional)
- Heart sounds (optional)

Wiggers Diagram




The cardiac cycle
1 : Venous return to the right atrium
2-Venous flow arrives In the right ventricle
3-Venous blood is sent in the lung via the pulmonary artery
4-After oxygenation in the lung the blood (red blood) returns to the left atrium
5-Red blood arrives In the left ventricle
6- Red blood is sent In the arteries to the tissues

- Cardiac Cycle and Heart Rate
  - At 75 beats per minute
    - Cardiac cycle lasts about 800 msecs
  - When heart rate increases
    - All phases of cardiac cycle shorten, particularly diastole



The Cardiac Cycle

Eight Steps in the Cardiac Cycle

1. **Atrial systole**
   - Atrial contraction begins
   - Right and left AV valves are open
1. **Atria eject blood into ventricles**
   - Filling ventricles
3. **Atrial systole ends**
   - AV valves close
   - Ventricles contain maximum blood volume
   - Known as end-diastolic volume (EDV)
4. **Ventricular systole**
   - Isovolumetric ventricular contraction
   - Pressure in ventricles rises
   - AV valves shut
5. **Ventricular ejection**
   - Semilunar valves open
   - Blood flows into pulmonary and aortic trunks
   - Stroke volume (SV) = 60% of end-diastolic volume

6. Ventricular pressure falls

- Semilunar valves close
- Ventricles contain end-systolic volume (ESV), about 40% of end-diastolic volume

7. Ventricular diastole

- Ventricular pressure is higher than atrial pressure
- All heart valves are closed
- Ventricles relax (isovolumetric relaxation)

8. Atrial pressure is higher than ventricular pressure

- AV valves open
- Passive atrial filling
- Passive ventricular filling
- Cardiac cycle ends

1-Essentials of Physiology for Dental Students. K Sembulingam and Prema Sembulingam ,2016, four Edition , Jaypee Brothers Medical Publishers.

2- Human Physiology. Stuart Ira Fox., TWELFTH EDITION,2017. Published by McGraw-Hill


Thank
you