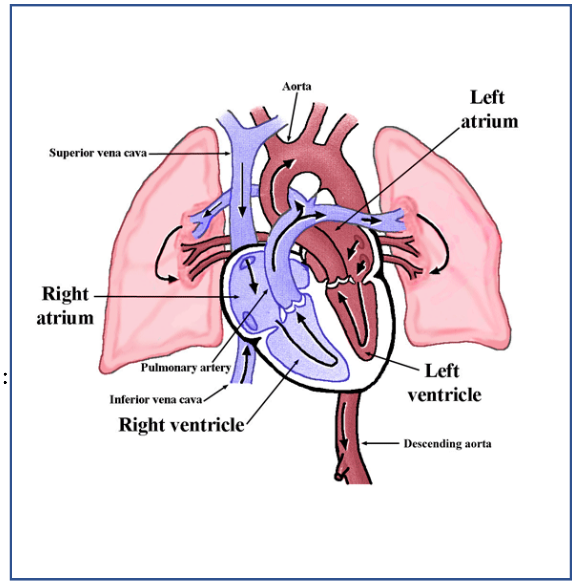
Circulatory system

Heart

Heart is a four-chambered muscular central pumping organ that receives and pumps out blood to whole body. It is basically conical or heart shaped organ with 12 cm (5 in) in length, 8 cm (3.5 in) wide, and 6 cm (2.5 in) in thickness.

Situation:

It is situated in the middle mediastinum in between the two lungs and obliquely placed behind the body of sternum. About one third of it is on the right side and two third of it is on the left side of the middle.



Layer of the heart:

Three layers of tissue form the heart wall.

1. Epicardium: The outer layer of the heart wall
2. Myocardium: The middle layer of the heart
3. Endocardium: The inner layer of the heart.

Chamber of heart:

The internal cavity of the heart is divided into four chambers:

1. Right atrium
2. Right ventricle
3. Left atrium
4. Left ventricle

The two atria are thin wall chambered that receive blood from veins. The ventricles are thick walled chambers that forcefully pump blood out of the heart. This differences in thickness is due to the presence of myocardium in chambers. The right atrium receives deoxygenated blood form systemic veins and left atrium receives oxygenated blood from pulmonary veins.

Valves of the heart:

There are four valves in heart.

1. Right atrioventricular valve
    a. It is situated between right atrium and right ventricles
    b. It is also called tricuspid valves.
    c. Is has three cups
        i. Anterior or infundibular
        ii. Posterior or marginal
        iii. Medial or septal
2. Left atrioventricular valve
    a. It is situated between left atrium and left ventricles
    b. It is also called bicuspid valves or mitral valves
    c. It has two cups

    i. Anterior or aortic
    ii. Posterior
3. Semilunar valves
    a. They are situated at the base of large vessels leaving the ventricles
    b. They are two types: pulmonary and aortic.
    c. Pulmonary semilunar valve is situated between the right ventricle and pulmonary trunk.
    d. Aortic semilunar valve is situated between the left ventricle and the aorta.

 # Circulation of heart:

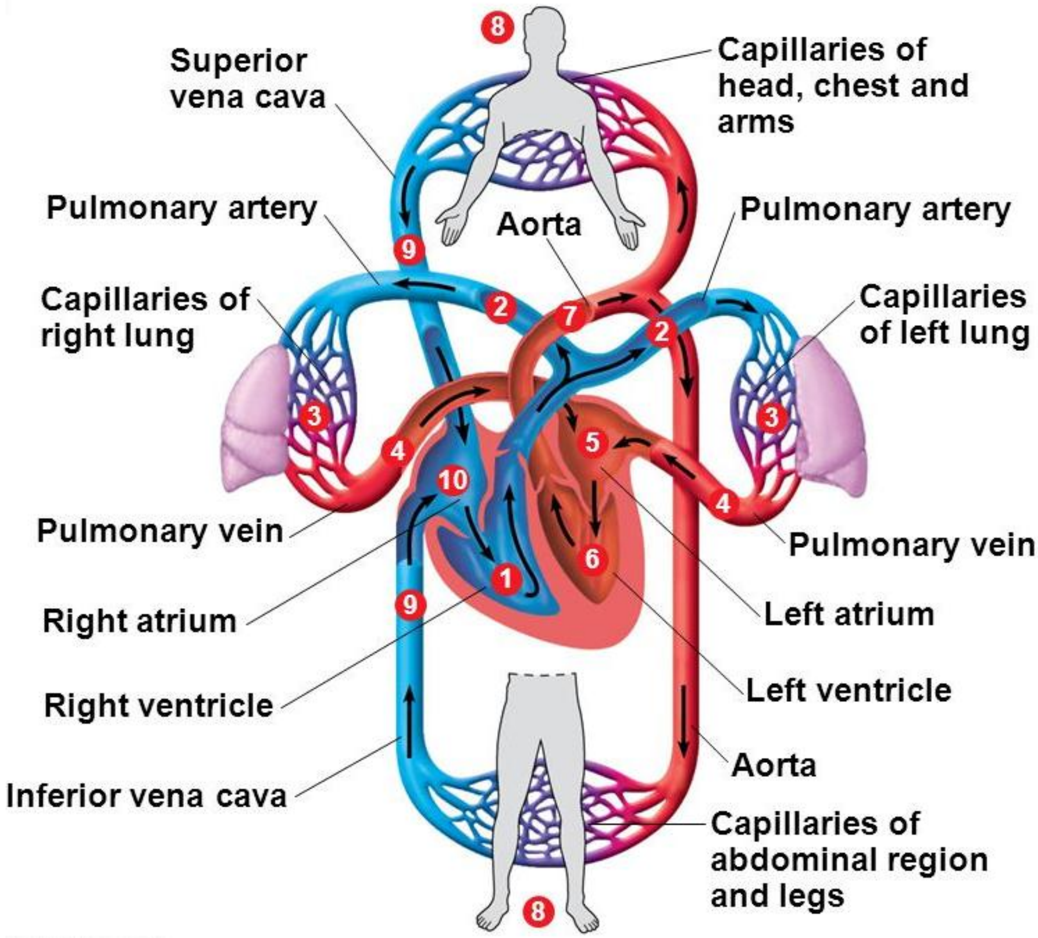
The human circulatory system has two-part systems (**systemic** and **pulmonary**) whose purpose is to bring oxygen-bearing blood to all the tissues of the body. In the **systemic loop**, the blood circulates into the body's systems, bringing oxygen and collecting carbon dioxide waste. In the **pulmonary loop**, the blood circulates to and from the lungs, to release the carbon dioxide and pick up new oxygen.

The Pulmonary loop (Controlled by right side of heart)

1. From the **right atrium (10)** the oxygen poor blood reaches into the **right ventricle (1)** through the **tricuspid valve**.
2. During ventricle contraction, the blood is pushed into the **pulmonary artery** (2) that divided into two main parts: one to the **left lung (3)** and one to the **right lung (3)**.
3. Here, in lungs carbon dioxide rich blood is converted into oxygen rich blood.
4. The fresh, oxygen-rich blood returns to the **left atrium (5)** of the heart through the **pulmonary veins (4)**.

The **systemic loop** (Controlled by left side of heart)

1. The **oxygen-rich** blood coming from the **lungs** (3) enters the **left atrium** (5) of heart through **pulmonary vein (4)**.
2. As the chamber fills, it presses open the **mitral valve** and the blood flows down into the **left ventricle (6)**.
3. During the ventricle **contraction**, the blood on the left side is forced into the **aorta (7)**.
4. The blood leaving the aorta brings oxygen to all the body's cells through the network of **arteries** and **capillaries (8)**.
5. The used blood from the body returns to the heart through **veins**.
6. All of the blood from the body is eventually collected into the two largest veins: the **superior vena cava (9)**, which receives blood from the **upper body**, and the **inferior vena cava**, which receives blood from the **lower body** region.
7. Both veins, reach the blood into the **right atrium (10)** of the heart.



Heart muscles

It is also called cardiac muscles, made up of involuntary striated muscles, called myocardium. The heart muscles are composed of three major types of cardiac muscles.

1. Atrial muscles
2. Ventricular muscles
3. Specialized excitatory and conductive muscles fibers-
    a. The sinus node (SA node)
    b. The intranodal pathway
    c. The Atrio-ventricular node (AV node)
    d. The AV bundles
    e. Purkinje fibers

Functional anatomy of heart muscles:

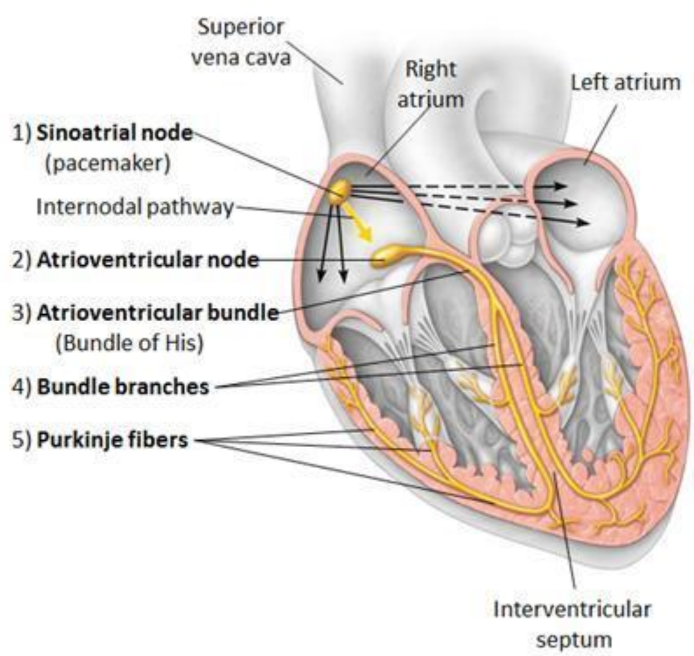
a. **Myocardial cells** or **Myocytes** are the functional unit of myocardium.
b. They are about 100µm long with branched manner.
c. They contain bundle of parallel **myofibrils**.
d. Each myofibril is made up of a series of **sarcomeres.**
e. A sarcomere is bound by two transverse Z lines.

f. The **actin** filaments attached with Z lines and overlap with thicker parallel protein filaments known as **myosin**.
g. Actin and myosin are attached by to each other by cross bridges that contain **ATPase.**
h. Sarcomere is the contractile unit of myocardium.
i. The muscle fibers cells are extensively branched and are connected to one another at their ends by **intercalated discs.**
j. Intercalated discs are part of the sarcolemma and contain two structures: **gap junctions** and **desmosomes.**
k. A **gap junction** forms channels between adjacent cardiac muscle fibers that allow the
l. current to flow from one cardiac muscle cell to the next.
m. A **desmosome** is a cell structure that anchors the ends of cardiac muscle fibers together so the cells do not pull apart during the stress of individual fibers contracting.
n. Myocardium are grouped into two population:
   1. Pace maker and conducting cells
      a. SA node
      b. AV junctional tissue
      c. Bundle of His
      d. Purkinje fiber
   2. Working myocardial cells
      a. Actin
      b. Myosin
      c. Troponin
      d. Tropomyosin

Junctional Tissues of Heart

Cardiac muscle consists especially of certain specialized structures which are responsible for initiation and transmission of cardiac impulses at a regular and faster rate than rest of the muscles. These are called junctional tissue of heart.

1. The sinus node (Sino-atrial node or SA node)
2. The internodal atrial pathway
3. The Atrio-ventricular node (AV node)
4. The bundle of His and branches
5. Purkinje Fiber



1. SA node

- It is one of the major elements in the cardiac conduction system, that controls the heart rate.
- It is a banana-shaped structure that varies in size, usually between 10-30 mm long, 5–7 mm wide, and 1–2 mm deep.
- The SA node is the heart's natural pacemaker.
- It consists of a cluster of cells that are situated in the upper part of the wall of the right atrium at the junction of superior venacava.
- It generates electrical impulses and conducts them throughout the muscle of the heart, stimulating the heart to contract and pump blood.
- These cells contract at a rate of about 70-80 times per minute, which make up the natural heartbeat.

2. Internodal atrial pathway

- It is the pathway that conduct the impulse from the SA node to AV node and left atrium.
- These internodal tracts contain Purkinje fibers.
- There are three pathways
  i. Anterior internodal tract of Bachman
  ii. Middle internodal tract of Wenckebach
  iii. Posterior internodal tract of Thorel
- Anterior internodal tract, after coming out from SA node, curved around the superior venacava and divided into two parts.
- Bachman bundle, providing impulse to left atrium, and another merged into AV node.
- Middle internodal tract, arises from the SA node merged into the AV node.
- Posterior internodal tract passes to reach the AV node.
- Combinedly, they serve as peripheral pathway for impulse conduction from SA node to AV node and left atrium.

3. AV node

- It is situated at the posterior and right border of the interatrial septum.
- It is normally conducting impulse between atria and ventricle.
- The cells are basically cardiac muscle fiber with less myofibril.
- They transmit impulse to the ventricle from SA node through bundle of His and its branches at a rate of 0.1 m/sec
- The rate of AV nodal impulse 40-60 impulse/min.
- In case of failure of SA node, AV node can produce impulse and that is why it is also called reserve pacemaker.

4. Bundle of His or AV bundle

- It extends from AV nodes and going across the inter ventricular septum.
- At the top of the inter ventricular septum, it is divided into left and right branches.
- The left bundle is further divided into anterior and posterior fascicle.

- All the fascicle and branches are merged into Purkinje fibers.
- It is the system that conduct impulse from atrium to ventricles.
- In case of failure of SA or AV nodes, these bundles of His may generate impulse at rate of 30-36 impulse/min.

5. Purkinje fiber

- The Purkinje fibers are specialized conducting fibers with fewer myofibrils and a large number of mitochondria.
- They are able to conduct cardiac action potentials more quickly and efficiently than any other cells in the heart.
- It arises from the branches of the Bundle of His, spread from the intraventricular septum to the papillary muscles of the heart.
- The fibers are spread over the all parts of the ventricular myocardium.
- It can initiate impulse at a rate of 15-40 impulse/min.

Properties of heart muscles

The properties of Heart muscles are:

1. Autorhythmicity
2. Conductivity
3. Excitability & contractility
    a. All or none law
    b. Frank Starling law
4. Refractory period
5. Tonicity

A. Autorhythmicity

1. Heart muscles does not require any external stimulation to produce impulse (automaticity) at regular interval (rhythmicity).
2. Heart muscles produce impulse at regular interval without any external stimuli by its junctional tissues.
3. The SA node and junctional tissues produce the impulse rather than myocardial cells.
4. SA node generates the impulse and other junctional tissues propagate them to the whole myocardial cells.

B. Conductivity

1. It is the ability to transmit the generated impulse from SA node to the rest of the heart muscles.
2. Impulse generated from the SA node at a rate of 70-80 impulse/min, passes to the junctional fibers of AV node through the internodal pathway at a speed of 0.04 sec.
3. From the junctional fibers, the impulse reaches to AV nodal fibers at a speed of 0.06 sec.
4. The impulse than travels to transitional fibers with a 0.1 sec delay before excitability.

C. Excitability and contractility

1. Heart muscles response to a stimulus of adequate strength and duration.
2. The minimum potential for excitation is -90mV.
3. The stimulus and response both are may be electrical, mechanical or thermal.
4. Heart muscles shows excitability, when subjected to a stimulus and it develops an action potential.
5. This propagated action potential is responsible for initiating contraction.
6. This contraction is due to the chemical and mechanical change in actin and myosin.
7. All contractions generate force and produce squeeze on the blood in ventricle to eject from these cavities.
    a. *All or none law*

        If an adequate stimulus is applied to heart muscle, the muscles responds to its maximum, but if the stimuli is not adequate, it does responds at all.

    b. *Frank starling law*

        Within the physiological limit, the greater the length of cardiac muscle fiber, the greater will be the force of contraction.

D. Refractory period

1. It is the period during which heart muscle is nonresponsive to external stimuli.
2. The refractory period of heart is 0.30 sec.
3. It is two types: Absolute and relative.
4. In absolute RFP, heart muscle is refractory to any stimuli and it about 0.25 sec.
5. In relative RFP, heart muscle is responsive slightly to any strong stimuli and it is about 0.05 sec.

E. Tonicity

It is the partial contraction of heart muscle over the contained blood.

* Pace maker (SA node)

In general sense, Pace maker is that rider that sets the pace of any race. SA node is called the pacemaker of heart because it produces 70-80 impulse/min. Impulses are first generates at SA node and it maintain the whole cardiac rhythm. As the rate and rhythm is higher than any other junctional tissues of heart, SA node is called pace maker of heart.

Cardiac cycle

The cardiac events that occur from the beginning of one heart beat to the beginning of the next are called the cardiac cycle. The cardiac cycle is inversely proportional to the heart rate. If the normal heart rate is 75, then cardiac cycle would be 60/75 seconds or 0.8 sec.

Events of cardiac cycle

In atria

1. Atrial systole

   Systole is the period of contraction of heart muscles. Atrial systole initiates the cardiac cycle as the pace maker (SA node) is in the atria. The duration is about 0.1 sec. It propels some blood (30%) into the ventricles.
2. Atrial diastole

   Diastole is the period of relaxation of heart muscles. At the end of atrial systole, atrial diastole occurs. During this period, blood enters into atria from great veins. The duration is about 0.7 sec. About 70% of ventricular filling occurs during this time.

In ventricle

3. Ventricular systole

   It starts at the end of atrial systole and last for 0.3 sec. At the beginning of this phase, AV and semilunar valves are closed and produced the 1^{st} heart sound. The pressure arises to 120 mm-Hg, and semilunar valves open. This results the ejection of blood from ventricles.
4. Ventricular diastole

   It starts at the end of ventricular systole and lasts for 0.5 sec. It starts with the closure of semilunar valves. As the diastole starts, pressure of ventricles falls to 80 mm-Hg and produce the second sound of the heart.

Heart sound

The vibratory motion of heart produced during the different events of cardiac cycle through the heart structure and produced special audible sound called heart sound. Heart sound is four in number. 1^{st} and 2^{nd} heart sound is audible through stethoscope but 3^{rd} and 4^{th} is detected by phonocardiograph.

Clinical significance:

1. Diagnosis of valvular heart diseases
2. Diagnosis of cardio-dynamic status
3. Diagnosis of congenital heart disease
4. Differentiating the murmur whether it is systolic or diastolic in origin.

Pulse

Pulse is the rhythmic dilation and elongation of atrial wall as a result of pressure changes created by the ejection of blood from heart to the periphery. The normal range of pulse is 60-90/min.

Cardiac output

The amount of blood that ejected by each ventricle or pumped into the aorta per minute by heart is called cardiac output.

Cardiac output CO= stroke volume* heart rate = 70*72 ml = 5042 ml/minute = 5.04 liter/min.

As, stroke volume is 70 ml/beat and heart rate is 72 beats/min (average).

 # Factors affecting cardiac output

1. Physiological
   a. Age: CO increase with ages
   b. Sex: Due to less body weight and surface area, female has 10-20% less CO than male.
   c. Surface area: More the surface area, more the CO.
   d. Posture: CO is greater in sitting and lying than erect posture.
   e. Exercise: CO markedly increase in severe exercise.
2. Pathological
   a. Hyperthyroidism: CO increase due to high body metabolism.
   b. Fever: CO increase as temperature and metabolism increases.

 # Cardiac index

The cardiac output per minute per square meter of body surface area is called cardiac index. The average value is 3.5 liter/min/Sq.m

 # Stroke volume

The amount of blood pumped out by each ventricle in each beat is called stroke volume. It is about 70 ml.

Stroke volume= end diastolic volume – end systolic volume.

 # End systolic volume

The volume of blood which remains in each ventricle at the end of the ventricular systole. It is about 40-50 ml.

 # End diastolic volume

The volume of blood which remains in each ventricle at the end of the ventricular diastole. It is about 110-120 ml.

 # Venous return

It is the amount of blood that come from periphery to right atria of heart in each minute. It is equal to cardiac output. It is about 5 liter/min.

 # Total Peripheral resistance

It is the resistance in which blood has to overcome while passing though the periphery. It is expressed as TPR= P/Q, where p is the pressure and Q is flow of blood.

Heart rate

The number of heart beat per minute is called heart rate. The normal range is, 60-90/min for adult with an average of 72 beat/min.

Factors affecting heart rate

1. Respiration: HR increases during inspiration and decrease while expiration.
2. Cardio-vascular reflexes: Stimulation of baro receptor decrease and stimulation of Brain Bridge increases the HR.
3. Temperature: Increasing temperature increase the HR by stimulating SA node.
4. Intra cranial pressure: Increase intra cranial pressure slows down the HR.
5. Muscular exercise: It increase HR by decreasing O2 and increasing Body temperature.
6. Age: From infancy to old age, it progressively decreases.
7. Gender: Female has slight faster HR than male.
8. Surface area: HR in inversely proportional to surface area.

Tachycardia

The term, tachycardia means fast heart rate. The increase of HR above 100 beats/min is usually referring to as tachycardia.

Bradycardia

The term, bradycardia means slower heart rate. The decrease of HR below 60 beats/min usually refer to as bradycardia.

ECG (electrocardiogram)

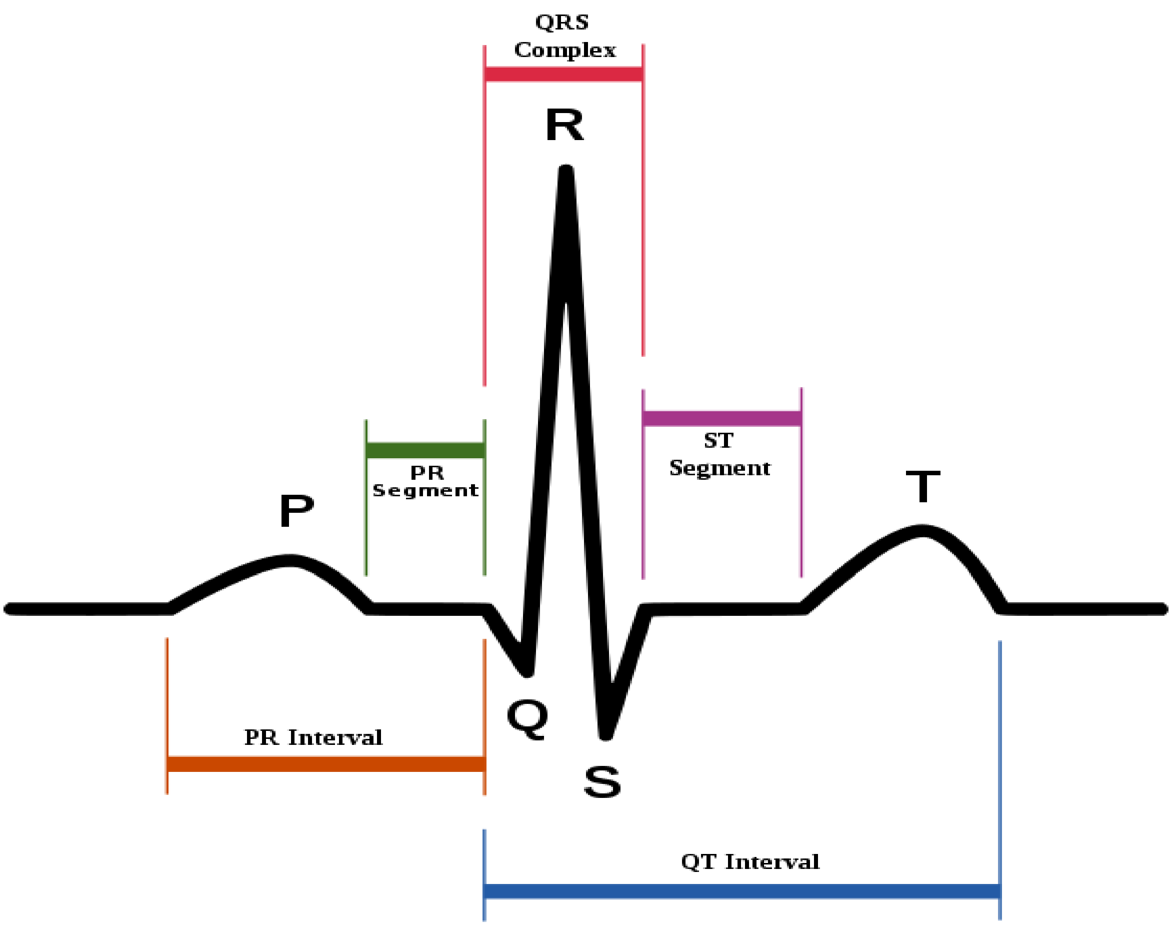
It records the electrical changes of heart from the surface of the body in each cardiac cycle.

A typical normal ECG

A normal ECG shows five consecutive waves PQRST. Of these there are three positive waves, P, R, T and two negative waves, Q, S and a complex QRS.

1. P wave:
    a. It is the first upward deflection with small constant wave.
    b. This represents the sequential activation of left and right atria (atrial depolarization).
    c. This impulse is originated in SA node with 0.10 sec duration and at 25 mv voltage.
    d. It indicates that SA node function properly.
2. Q wave:
    a. It is a downward, small deflection.
    b. It represents septal depolarization from left to right as it is caused by septal activity.
    c. It normally represents the left ventricular functions.
    d. Q wave greater than 1 small square in width and deeper than 2 mm, indicates the myocardial infraction.

3. R wave:
    a. It is an upward deflection with hith constant and conspicuous tallest peak.
    b. It follows immediately after Q wave.
    c. It indicates the apical left ventricular depolarzation.
4. S wave:
    a. It is the downward deflection next to R wave.
    b. It represents the posterior basal left ventricular depolarization.
5. QRS complex:
    a. QRS complex represents the activation of right and left ventricles.
    b. It is produced by ventricular depolarization and atrial repolarization.
    c. The total duration is 0.08-0.10 sec.
    d. Due to large ventricular mass, the peak is larger than P wave.
6. T wave:
    a. It is a slow and low wave produced by ventricular repolarization.
    b. It has the duration of 0.13 sec with 0.2-0.4 mV voltage.
    c. Inversion of T wave seen in ischemia, heart block or digoxin toxicity.



7. ECG intervals:
    a. P-R intervals
        i. It is the length of the time from the start of P wave to the start of QRS complex.
        ii. Duration is 0.12-0.20 sec.
        iii. 0.4 sec interval indicates that heart block can occur at any time.
    b. QT intervals
        i. It extends from the start of the QRS complex to the end of the T wave.
        ii. Duration is < 0.44 sec.
        iii. The lengthened of QT interval indicates the incident of sudden death.
    c. R-R intervals
        i. It is the interval of between two successive R waves.
        ii. Same R-R intervals indicates the rhythmic ventricle depolarization.
        iii. Duration is 0.80-0.83 sec.
    d. P-P intervals
        i. It is the interval between two successive P waves.
        ii. Same P-P intervals indicates the rhythmic atrial depolarization.
    e. S-T segments
        i. It is the duration between the end of the QRS and the start of T wave.
        ii. This segment should be isoelectric and straight line.
    f. T-P intervals
        i. Alteration of this interval reveals the change of heart rate

 # Depolarization and repolarization of heart muscles

- Cardiac cells at **rest** are considered **polarized**, meaning no electrical activity takes place.
- Myocardial cell has a negative membrane potential when at rest.
- Electrical **impulses** are generated by automaticity of specialized cardiac cells.
- Once an electrical cell generates an electrical impulse, this electrical impulse causes the ions to cross the cell membrane, called **action potential.**
- Stimulation above a threshold value induces the opening of **voltage-gated ion channels** and a flood of cations into the cell.
- The **positively charged ions** entering the cell cause the **depolarization** characteristic of an action potential.
- The movement of ions across the cell membrane through **sodium, potassium and calcium** channels, cause **contraction** of the cardiac cells/muscle **(systole).**
- Depolarization with corresponding contraction of myocardial muscle moves as a **wave** through the heart.
- **Repolarization** is the return of the ions to their previous resting state, which corresponds with **relaxation** of the myocardial muscle (**diastole**).
- After a delay, **potassium channels** reopen, and the resulting flow of K+ out of the cell causes **repolarization** to the resting state.
- **Depolarization** and **repolarization** are electrical activities which cause muscular activity.

- The **action potential** curve shows the **electrical changes** in the myocardial cell during the depolarization – repolarization cycle.
- This **electrical activity** is what is detected on ECG, not the **muscular activity**.

 # Action potential

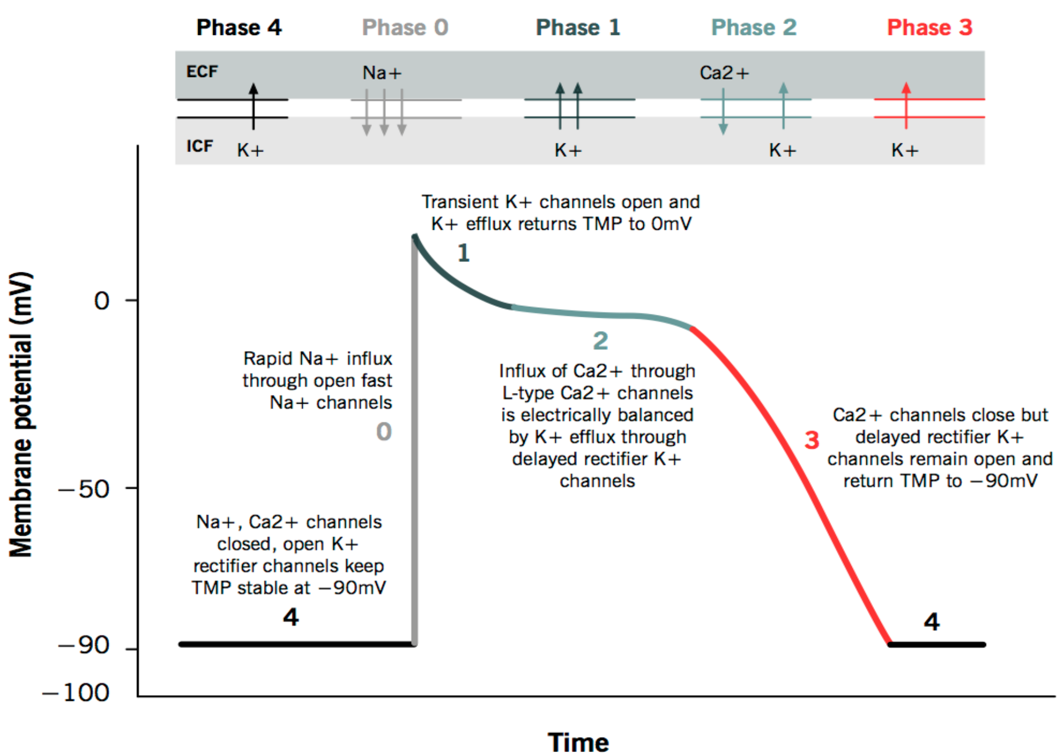
The cardiac action potential is a brief change in voltage (membrane potential) across the cell membrane of heart cells. This is caused by the movement of ions between the inside and outside of the cell, through ion channels.

NB: The leakage of these ions, across the membrane is maintained by the activity of pumps which serve to keep the intracellular concentration more or less constant.

1. The **sodium (Na+)** and **potassium (K+)** ions are maintained by the **sodium-potassium pump** which uses energy (in the form of adenosine triphosphate (ATP)) to move three Na+ out of the cell and two K+ into the cell.
2. The **sodium-calcium exchanger** which, removes one Ca2+ from the cell for three Na+ into the cell.

 # Phases of action potential

The resting membrane potential of myocardial cells, is around -90 millivolts. That is inside of the membrane is more negative than the outside. The main ions found outside the cell at rest are: sodium (Na+), and chloride (Cl−), whereas inside the cell it is mainly potassium (K+).



Myocyte action potential

Phase 4: Resting Phase

1. Phase 4/ diastole occurs when the cell is at rest, with a constant voltage of -90mV.
2. During this phase the membrane is most permeable to K+.
3. Na+ and Ca2+ channels are closed at resting phase.
4. The membrane potential slowly becomes more positive, until it reaches a set value of around -40mV.

Phase 0: Depolarization

1. An action potential triggered in a neighboring cardio myocyte, causes the membrane potential to rise above −90 mV.
2. Na+ channels start to open one by one and Na+ leaks into the cell, further raising the membrane potential.
3. Membrane potential approaches to −70mV, at this point, enough fast Na+ channels have opened to generate a self-sustaining inward Na+ current.
4. The large Na+ current rapidly depolarizes the MP to 0 mV.
5. As Na+ channels are time-dependent, Na+ channels are closed.
6. L-type ("long-opening") Ca2+ channels open when the TMP is greater than −40 mV.

Phase 1: Early repolarization

1. This phase begins with the rapid inactivation of the Na+ channels.
2. At the same time potassium channels open and close rapidly, allowing for a brief flow of potassium ions out of the cell, making the membrane potential slightly more negative.

Phase 2: The plateau phase

1. Ca2+ channels are still open and there is a small, constant inward current of Ca2+.
2. K+ leaks out down its concentration gradient through K+ channels.
3. These two countercurrents are electrically balanced, and the membrane potential is maintained at a plateau just below 0 mV throughout phase 2.

Phase 3: Repolarization

1. Ca2+ channels are gradually inactivated.
2. Persistent outflow of K+, brings membrane potential back towards resting potential of −90 mV to prepare the cell for a new cycle of depolarization.