ELECTROCARDIOGRAPY (ECG)

DR. NAJEEB LECTURE NOTES

BY FATIMA HAIDER

KGMC

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In ECG, electrical activity of heart is graphically presented.

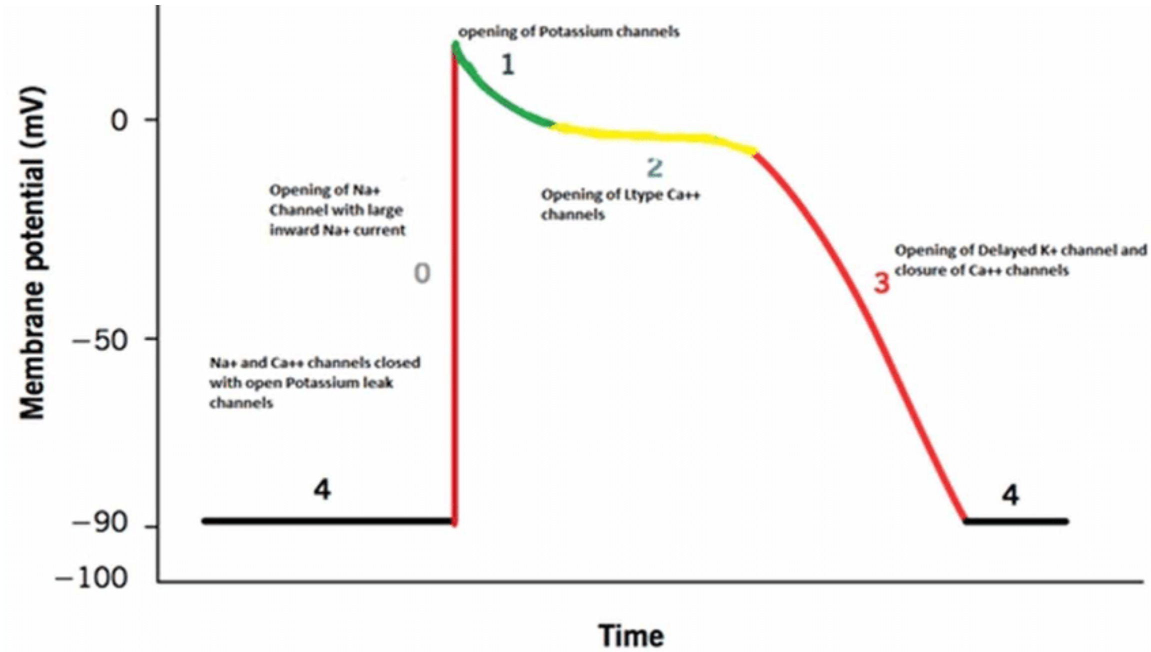
ELECTRICAL ACTIVITY OF HEART

Normally resting cells of ventricular myocardium are electrically negative inside having resting membrane potential of -90mV

As soon as cell is stimulated, RMP will reach to threshold potential. At threshold potential, voltage gated sodium channels open and sodium ions enter inside cell, making the cell electropositive and hence we say the cell is depolarized.

The depolarization sensitive calcium and potassium channels start to open. K^+ ions efflux takes place. As soon as potential reach around 0V, calcium channels also open. For a brief duration, K^+ ions are lost and Ca^{+2} ions are gained, so loss and gain of cations balances the potential. But as time passes, calcium channels close and potassium channels become more active and hence cell becomes progressively electronegative until RMP is reached.

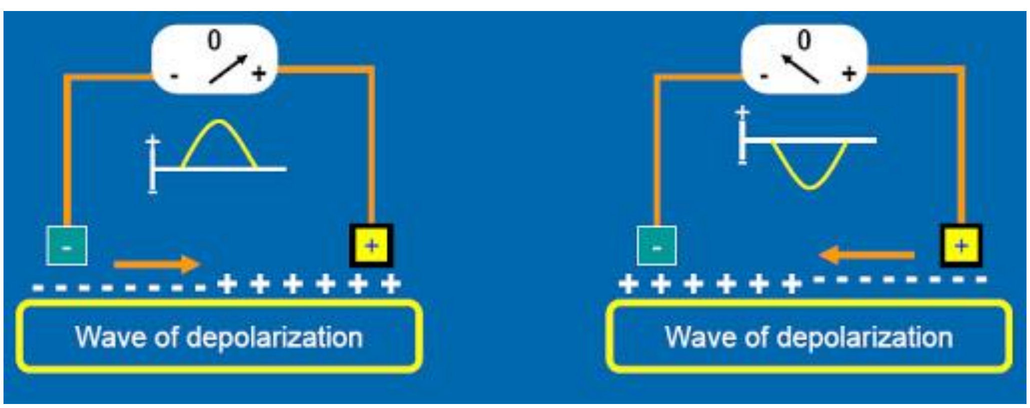
One myocardium cell can stimulate action potential in adjacent cells through gap junctions. During depolarization in one cell, sodium ions enter the interior of cell. Some of sodium moves into adjacent cells through gap juctions and action potential travels to adjacent cell.



PRINCIPLE OF ECG

ECG machine works on the principle of galvanometer.

To understand the basic principle of ECG, we take an experiment in which we connect a segment of myocardium to electrodes of galvanometer.



As resting membrane potential, the deflection in galvanometer remains neutral as no electrical activity is detected.

When myocardial segment is is stimulated at negative end of electrode, wave of depolarization start moving towards positive electrode. If wave of depolarization moves towards positive electrode, deflection of needle will be positive (as shown in above diagram in first left figure)

If the segment of myocardium is completely depolarized, there is no further movement of current and vector is no more available so needle will come back to neutral position.

Now myocardial segment is stimulated from positive end of electrode. Wave of depolarization is moved from positive end to negative end. Positive charges are moving away from positive electrode so deflection in galvanometer needle should be negative. (as shown in above diagram in right figure)

If thicker myocardium is stimulated, wave of depolarization will be stronger and vector will ultimately be stronger. Atrial myocardium (thin) will produce weak positive deflection while ventricular myocardium (thick) will produce strong positive deflection.

ELECTRICAL EVENTS IN HEART DURING ONE CARDIAC CYCLE

1. Atrial depolarization
2. Stimulation of AV node
3. Depolarization of ventricle

ATRIAL DEPOLARIZATION

At beginning of cardiac cycle, SA node fires, thereby generating a wave of depolarization in cells adjacent to SA node. This wave of depolarization travels to adjacent cells through gap junctions.

The wave of depolarization sweeps over atrial myocardium downward and towards left due to position of SA node on upper right side of atrium. Electrical waves spread simultaneously in both right and left atrium.

All the vectors of electrical wave passing through atria add together to form a single vector moving downward and towards left.

This vector is small due to two reasons:

1. The atrial myocardium is thin
2. Atria donot have specialized and fast conducting system i.e. they conduct at moderate speed.

STIMULATION OF AV NODE

When both atria are completely depolarized, depolarizing waves from atria will hit the fibrous annulus present between atria and ventricles. This fibrous tissue is not a good conductor and hence most of the waves hitting this fibrous tissue will die out.

The only single area from where the depolarizing wave can go from atria down to the ventricles is AV node.

AV node is a modified myocardium which is specialized in slow conduction. It conducts the depolarizing wave very slowly and the wave takes 0.1 second to move from atria to the ventricles. This slow conduction holds the depolarizing wave for a while so atria can complete their contraction.

The purkinje fibers, however, are specialized in fast conduction. Due to fast conduction the whole ventricle is stimulated simultaneously so that septum of ventricle, medial part and basal part of ventricle contract simultaneously for effective ventricular output.

AV NODE VS. PURKINJE FIBERS

AV NODE	PURKINJE FIBERS
1. AV node is specialized in slow conduction	1. Purkinje fibers are specialized in fast conduction
2. The cells of AV nodes are small and arranged at right angle to direction of current	2. Cells of purkinje fibers are large
3. Number of gap junctions are less	3. Number of gap junctions are more
4. Depolarization of AV node is dependent on calcium hence conduction is slower	4. Depolarization of purkinje fibers is dependent on sodium hence conduction is faster
5. Cells of AV node have less diameter so provide more resistance to conduction	5. Cells of purkinje fibers have large diameter so provide less resistance to conduction
6. The resting membrane potential of AV node is -60mV	The RMP of Purkinje fibers is -90mV As purkinje cell is more electronegative so cations will move readily into purkinje cells than AV node

AV node is very small, hence electrical vector is very small when AV node is undergoing repolarization and due to this small electrical vector, ECG will not detect electrical activity of AV node.

VENTRICULAR DEPOLARIZATION

From AV node, through bundle of His, current will move to right and left bundle branch. These bundle branches are made of specialized myocardial cells called purkinje fibers.

Ventricle depolarizes in three stages:

1. Ventricular septum depolarization
2. Major ventricular depolarization
3. Basal depolarization

VENTRICULAR SEPTUM DEPOLARIZATION

The upper part of interventricular septum is fibrous while the lower part is muscular.

Septal myocardium is stimulated by left bundle branch. It is not stimulated by right bundle branch. Hence wave of depolarization is produced in ventricular septum in lower left portion of interventricular septum which sweeps further from left to right and from down to up.

Septal depolarization is a small vector which is directed upwards and towards right.

MAJOR VENTRICULAR DEPOLARIZATION

The wave moves along right and left bundle branches and the purkinje fibers which are in the deeper myocardium (inner myocardium which is just under the endocardium) and depolarizing waves are generated in the ventricles and this depolarizing current moves from inner myocardium to outer myocardium.

Left ventricle is three times thicker than right ventricle, so depolarizing vectors are produced stronger in left ventricle than those produced in right ventricle. Due to this reason, the major depolarizing vector produced by addition of right and left ventricular vector, is directed downward and slightly more towards left.

BASAL DEPOLARIZATION OF VENTRICLE

The depolarizing wave moves towards basal area. These vectors are moving upward and rightward.

When ventricular depolarization begins, atrial repolarization take place. Atrial repolarization activity is masked by ventricular depolarization.

ELECTRICAL VECTORS OF HEART

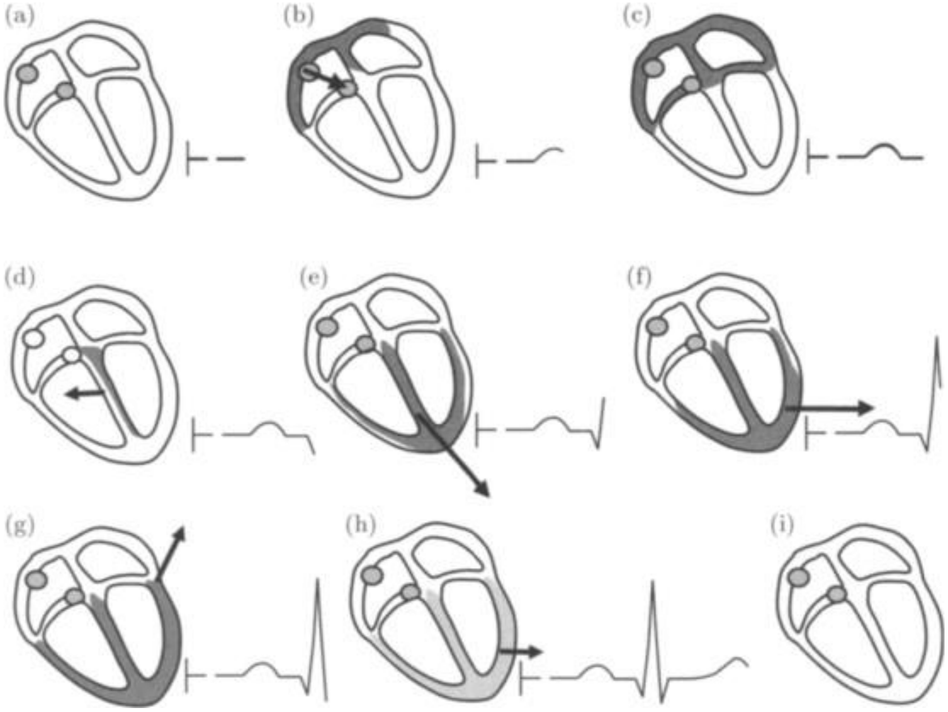


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Figure (b) represent atrial depolarizing vector

Figure (d) represent septal depolarizing vector which is upwards and rightwards

Figure (e) represent major depolarizing ventricular vector formed by addition of right and left ventricular vectors and this vector is directed downward and towards left

Figure (g) represent basal ventricular vector which is directed upward and rightward

ELECTRICAL VECTORS AND ECG

We suppose an experiment in which a galvanometer is connected to heart. Positive electrode is placed on left foot while negative electrode is placed on right arm and deflection in galvanometer is noted. A rolling paper is attached to galvanometer to record the graph.

The electrical vectors produced in one cardiac cycle are conducted to the body surface through body fluids. So applying electrode on body surface can help us to detect electrical activity of heart.

When SA node fires, the atrial vector is produced. This atrial depolarizing vector is moving towards positive electrode (placed at foot) so deflection should be positive. The needle will move positively upward with moderate speed and a small deflection called **P wave** is marked on paper.

When AV node undergoes depolarization, electrodes do not pick any activity and needle will remain straight.

As soon as current is released into purkinje fibers, ventricular depolarization start.

Ventricular septal depolarization vector is moving away from positive electrode, so deflection will be negative. Needle will move with fast speed, deflect a little downward and then come back. As it is a fast vector so it suddenly goes down after a sudden upward deflection. This is represented by **QRS wave**.

When depolarizing currents reach basal ventricles, these vectors are moving away from positive electrode and as these are small vectors so small deflection is produced.

At the end of QRS, when all the ventricle is completely depolarized, reading will move in a straight line called **ST segment**.

After some time, repolarization process will begin. In ventricles, the part which is depolarized in the end is repolarized first. The outer myocardium (which is under epicardium) will repolarize first and spread to inner area. So direction of repolarization is opposite to depolarization. This net repolarizing vector will be directed rightward and upward.

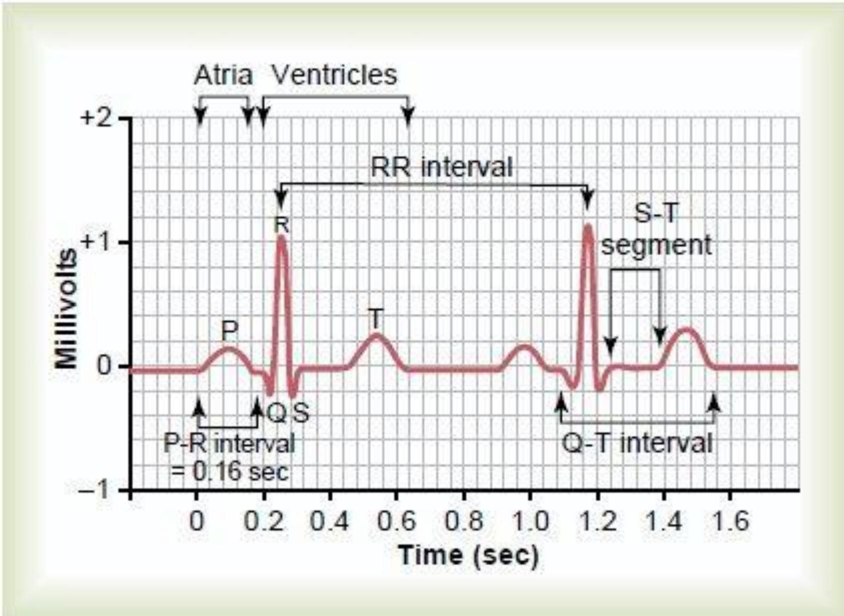
Why repolarization begins from outer myocardium?

Answer: the blood flow/ capillary beds are in inner, middle and outer myocardium. During ventricular systole, outer myocardium compresses the middle and inner myocardium. Hence blood flow to inner myocardium will stop and blood flow to outer myocardium will be better than inner myocardium. Due to this reason repolarization will begin from outer myocardium.

When ventricles are repolarizing, negative vector moves toeards negative electrode so needle will move positively but gradually as it is a slow vector. The wave produced on graph is called **T wave**.

Atrial repolarization is not presented on ECG

OVERVIEW

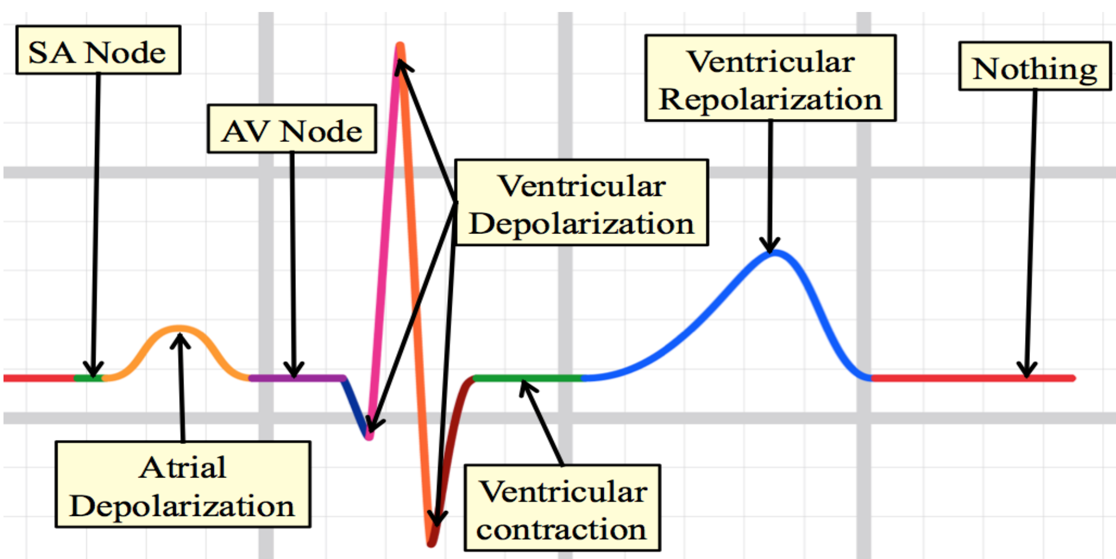


- P wave – atrial depolarization
- PR interval – this straight line indicates AV nodal silence
- QRS Complex

  Q wave represent ventricular septal depolarization

  R wave represent major ventricular depolarization

  S wave represent basal ventricular depolarization
- ST Segement – Depolarized ventricle
- T wave – ventricular repolarization



WAVES IN EKG

Waves are the pattern made on ECG recording due to fluctuations of needle

- P Wave – atrial contraction
- Q wave – ventricular septal depolarization
- R wave – major ventricular depolarization
- S wave – basal ventricular depolarization
- T wave – ventricular repolarization
- U wave – comes after T wave and may not always be observed due to its small size

SEGMENTS IN EKG

Segments are isoelectric lines drawn when needle is not fluctuating

- PR Segment – Ideally PR segment should be called PQ segment but when we change position of electrodes for different leads, sometimes Q wave is not formed so it is called PR segment.
- ST Segment – End of S wave and beginning of T wave

INTERVALS IN ECG

Some part of wave plus segment is called interval.

- PR Interval – beginning of P wave to beginning of QRS interval, or
  P wave + PR segment is called PR interval
- QRS Interval – interval during which current is spreading over ventricular tissue
- QT interval – Beginning of Q wave to end of T wave
  QT interval begins from onset of ventricular systole to end of ventricular diastole

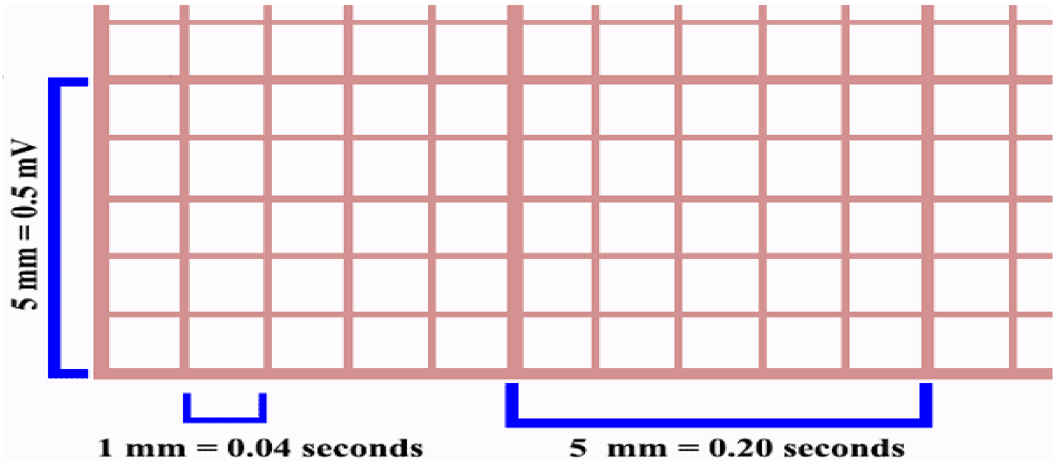
EKG PAPER

The EKG paper is a graph paper where for every five small (1mm) squares, we can find a heavier line forming a larger 5mm square.

During one minute 300 large squares pass under the pointer.

The horizontal axis measures time. On a standard EKG paper, speed is 25mm/s. Therefore, each 1mm square on the horizontal axis equals 0.04s, and each large square, 0.20s.

The vertical axis measures the amplitude of the heart's electrical current. It is measured in mV. Therefore each 1mm square on the vertical axis equals 0.1mV and each large square, 0.5mV.



TIMINGS AND DURATION ON EKG PAPER

P Wave – 2 and ½ small squares = 0.1s

PR Segment - 2 and ½ small squares = 0.1s

PR Interval = P wave + PR segment = 5 small squares = 0.2s

QRS Complex = 2 and ½ small squares = 0.1s

QT Interval = 10 small squares = 0.4s