Course: Electrophysiology of Heart

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Lecture 8: ECG-Physiological basis

Hello everyone. So, today we will start our first topic of ECG or electrocardiography. So, we will today discuss about the physiological basis of electrocardiography. So, the concepts we will cover that is the concept of a cardiac dipole, how this dipoles are formed in the heart and what are the different ECG waves particularly how this ECG waves are formed. We will discuss the technical aspects and how it is interpreted further in other lectures along with abnormal ECG. Today we will discuss only about the physiological basis of electrocardiography.

Now, ECG records the voltage between the dipoles which is produced by electrical activities of the heart. We are talking about heart particularly so, cardiac dipoles. So, ECG is the recording of the electrical activities which are generated by the heart. This is a summation of the action potentials of all the cardiac muscles.

Till now we had discussed the action potential which is generated from one cardiac muscle. That means, there are different phases of action potential there is a depolarization phase, there is first phase one of early repolarization and then we have the plateau phase and then we have the repolarization phase. So, these are the various phases of action potential we have seen in one cardiac muscle. Now, there are presence of gap junctions or electrical windows in between two cardiac muscles because of this electrical windows the action potential which is formed in one cardiac muscle or the wave of depolarization that gets shifted or that gets crossed from one cell to the other. So, in this way the whole muscle contracts or whole muscle acts as a syncytium this we had already discussed.

So, we will see how this extracellular recording of the summed up electrical events of all the cardiac muscle fibers this occurs with each heartbeat. Now, since ECG is the summation of all the action potentials of cardiac muscles. So, this is recorded extracellularly because our heart our body is a very nice conductor volume conductor. So, that is why this is recorded extracellularly. So, this is the ECG with various waves

mainly we have the here we have the P wave which is not given over here.

So, P wave QRS complex and the T wave these are the five basic waves of ECG. So, today we will see how this five basic waves are formed what are the physiological basis of this five waves. Now, first we should understand what do you mean by a dipole. Now, in dipole whenever we put a electrical charged solution and we attach the negative terminal of a battery to the charge solution at one end and the positive terminal to the other end. So, there is a flow of charges which occur this flow of charges occurs because of the voltage differences.

So, the combination of this two poles one the positive pole and the negative pole that constitutes a dipole in an electric field which results in the flow of current. So, the voltage if I want to measure what is this voltage across this dipole or associated with this dipole it can be measured with a galvanometer which can be measured with the voltmeter. So, that is what we do in case of heart also the voltage difference that exists that is determined by the influences of the positive and the negative ends of the dipole in other way the dipole determines the voltage. And the direction whenever we are talking about the dipole it acts as a vector also a dipole has got a direction it has got a magnitude, magnitude is the voltage. The similar we see in case of heart because our body is a volume conductor it is a very good conductor of electricity.

And the very good example is if you just put your hand in the socket you can understand how our body is a good conductor of electricity. So, the electrical activities in our heart that occur in our heart that creates too many dipoles as the heart creates many dipoles simultaneously the electrocardiography or the ECG recording will record that voltage that will give the net dipole voltage that will signify the all the record the voltage of the net dipole that is the average of all the dipoles. So, that is the concept of dipole in case of heart. Now that occurs because the differences in the charges at some point of the heart there is a depolarization occurring other part of the heart other part of that cardiac cell repolarization is occurring at there is a differences in the charges and that causes the dipole. So, we will see suppose this is our heart now this consist of we know right atrium left atrium right ventricle left ventricle.

Now this atria and ventricle musculature are usually separated by a fibrous band except at one point that is AV node. This fibrous band which is separating the atrial and the ventricular musculature are nothing that is fibrosis annulus. And the only portion which is conducting the impulse or which is serving as a connecting link between the atria and the ventricle that is AV node. And we had already discussed the impulse which gets carried this is the SA node which lies at near at the opening of the superior vena cava. Now whatever impulse will be generated from the SA node the SA node will generate

various impulse now whatever impulse will get generated from the SA node it does not means all the impulses will get traversed or get transmitted to the ventricles why because as we can see some impulses are hitting this fibrosis annulus also.

So, this fibrosis annulus is not a good conductor of electricity. So, it acts like an insulator. So, this will not conduct the impulses. So, whatever impulses are hitting this fibrosis annulus will get fed off or wear off only the impulses which is reaching the AV node or the average of the impulses which are reaching the AV node that will get transmitted through the AV node that also with the help of its significant mechanism of AV nodal delay to the ventricles. So, with this if we the basics of electrocardiography which lies on the which works on the principles of galvanometer that we will see suppose if I take a chunk of cardiac muscle.

So, this is the cardiac muscle tissue I have taken. So, we know this cardiac muscle tissue suppose I have attached one end to a negative pole the other end I have attached to the positive pole this portion is A this portion is B and I have attached this negative and positive terminal to a galvanometer. So, when I have attached this to a galvanometer we that means this galvanometer will deflect according to the charges or the detect whatever differences or whatever changes occurring in this cardiac muscle. So, initially when we talk about resting membrane potential that means whenever the cell is at rest when no stimulation is given which means the inside of the cardiac muscle which consists number of cardiac myocytes that will consist of negative charges. That means this cardiac muscle is electronegative throughout.

Now since from A to B end you can see from A to B end throughout there is a equal distribution of electronegativity or electronegative charges. So, there is no net flow of charge over here there is no potential difference hence this galvanometer will not get or it will not catch any deflection. So, it will remain static. So, the needle of the galvanometer will remain static. So, there will be no deflection of this galvanometer at this point that means when the cell is at rest that means no stimulation.

At the second condition suppose we stimulate this cell again we have stimulated this cell this is connected at one end negative the other end is positive this is A this is B and we have connected this terminal to a galvanometer to check for the deflections. So, we have stimulated at this part at the part A we have stimulated means obviously I have given a threshold stimulus. So, that there is an occurrence of action potential that means there will be formation of there will be influx of the cations whether it is sodium ions or calcium ions there will be influx of the cations. So, whenever there will be influx of the cations there is already electronegative charges which is distributed because of the resting membrane potential. But whenever I am stimulating at one end at that particular

end due to influx of the cations this part will become electropositive.

So, when this part is becoming electropositive the rest of the part is electronegative you can see a wave of depolarization is traversing from one end to the other that means here from A to B. A strong wave of depolarization which is getting carried forward towards the positive end of the electrode this is the positive end of the electrode. So, here the strong wave of depolarization whenever a strong wave of depolarization is getting carried out within the myocardium progressively because to make the whole myocardium depolarized. So, it will create an electromagnetic force and as we all know that electromagnetic force is always represented by a vector that means it has got a direction and a magnitude. In this case the direction of this vector will be the same as the direction of this depolarization wave that means towards B or towards the positive.

And the charge it will carry since it is the positive charges is going on. So, this vector is carrying positive charge at its head. So, positive charges moving towards the positive electrode this galvanometer this is positive this is negative here this is positive this is negative. Positive negative means the deflection is plus 10 plus 20 plus 30 here it is minus 30 minus 20 like this. So, whenever the deflection of the galvanometer we want to check in case of the wave of depolarization moving towards the positive electrode the deflection will be positive.

That means positive charges or depolarization towards positive electrode there will be the positive deflection. In case of ECG the way the paper rolls and the way the needle of the galvanometer occurs that is usually kept perpendicular to each other. So, that is why we get the deflection either upwards or downwards. So, the upward deflection is the positive deflection and the negative whenever the deflection is downward any waves we get downwards that means that is a negative deflections. So, in the second case what we have seen whenever a depolarization wave is moving from point A to point B that means towards the positive electrode there is positive deflection.

So, next we will see another example suppose because of this depolarization wave at one point of time it will completely polarize the myocardial cell. Complete polarization occur means there will be positive charges throughout this cell. Whenever there will be positive charges throughout this cell that means this myocardial cell is completely polarized which means from A to B again there is no net flow of charges. This is the same situation which was at during the resting membrane potential only difference was there was electronegativity inside and here it is electropositivity. So, when the cell gets completely polarized and when there is no net flow of charges again there will be no deflection picked up by the galvanometer.

Now, the second case if I want to increase the thickness of this myocardial cell suppose this myocardial cell is very much thick than the previous myocardial cell. So, the more thicker the myocardial cell and we give a stimulus at one end similar end. So, there will be more depolarization because of the more number of myocytes because of more number of gap junctions. So, more number of myocytes more number of gap junctions more strong will be the depolarization wave. So, in this case because of the stronger depolarization the stronger depolarization wave the force of the electromagnetic force is so strong that the vector will also be very much strong.

So, the deflection will also be very much strong in this case. The same we see in case of ventricles and as compared to the atrial musculature the ventricular musculature is very thick by atrial musculature is very thin. So, whenever depolarization occurs in case of ventricular musculature we see a very strong deflection, but in case of atrial musculature since it is thin we see a very slower as well as less strong deflections where the amplitude of the voltage is less compared to the ventricular depolarization which means the strength of the vector depends on the force of the the power of the force of the impulses or the electropositivity or the depolarization which is occurring. With this another example is in case of suppose this is again negative terminal this is again positive terminal a galvanometer is attached this is A point this is B point. Now this time instead of stimulating at the A point suppose there is a stimulation which is done at the B point.

So, obviously B point will be positive towards the B point there will be more electropositivity compared to the other part of the myocardial cell which is still electronegative or yet to get depolarized. So, here the depolarization wave is travelling from B to A not A to B that means here the vector will be directed as I already told you the depolarization wave the vector direction is the same as that of the wave of the depolarization direction. So, here the depolarization vector will be towards A that means negative terminal, but the charge since it is a wave of depolarization. So, charge it will bear positive only. So, wave of depolarization is moving towards the negative terminal of the electrode or when wave of depolarization is moving toward away from the positive electrode or positive terminal of the electrode the deflection will be negative.

This is negative and this is positive the deflection will be negative. So, till now we had read that whenever there is a depolarization or wave of depolarization when positive charge is moving towards the positive electrode the deflection will be positive. When the positive charge is moving away from the positive electrode or towards the negative electrode the deflection will be negative. Whenever there is total electronegativity or at rest or whenever the cell is completely polarized at that time there will be no deflection which is picked up by the galvanometer. And strength of the vector depends on the or the

length of the vector depends on the power of the force of the depolarization.

Atrial musculature will bear a less force while ventricular musculature will bear a strong deflection in the galvanometer. With this now we will come to the repolarization. Since I told you that in the conducting system the last part of the ventricles which gets depolarized is the first part to get repolarized because of the arrangement of the Purkinje cell layer and also the blood vessels. The depolarization occurs from inner side to the outer side that means from endocardium to epicardium, but the repolarization occurs just in the opposite direction that means from outer myocardium to inner myocardium that means from epicardium to endocardium. So, what we see suppose again we take this piece of myocardial cell which is again bearing the two terminals A and B negative and the positive terminal and it is also attached to the galvanometer.

Now I had told you this cell is initially depolarized that means the cell is now completely depolarized. Whenever the cell is depolarized the last part of the depolarization means the B is the last part of the depolarization that means this part will also be the first part to get repolarized. Repolarization means loss of positive ions there will be opening of the potassium channels and potassium ions will if fluxed that means will go out. When positive ions is getting out that means that part of the membrane or that part of the cell is becoming electro negative. So, whenever the repolarization will start this part suppose that this part is getting repolarized it will bear negative charges.

Now, this time when repolarization is occurring there is a wave of repolarization which is bearing negative charges which is moving towards the negative electrode. I told you the vector direction will always be towards the wave of depolarization or repolarization the direction in which the charges are moving. So, here the charges are moving from B to A. So, the vector will be moving from B to A bearing since it is repolarization bearing negative charges. So, what is it is happening negative charges is flowing towards the negative electrode.

So, when negative charge flows towards the negative electrode the similar charges are flowing towards the similar electrode there will be again positive deflection not negative deflection. This will again give positive deflection not negative deflection these are the basis of your 5 ECG waves that is P, Q, R, S, T from P to S we have the depolarization waves and T wave we have the repolarization waves. That is why T wave is always positive like that of the other depolarization waves even it is the phenomenon of repolarization question can come that repolarization is opposite that of depolarization, but still in ECG we see the T wave is positive. It is because of this because the repolarization occurs towards the epicardium the direction is from epicardium to endocardium and that is why the vector moves from the electromagnetic vector which

bears the negative charge it moves towards the negative electrode. So, negative charges moving towards the negative electrode will give a positive deflection.

Now with this basic principles if we just study the electrical impulse conduction in a heart. This is a positive terminal this is the negative terminal this positive terminal I have attached say suppose to the left foot. Now since our body is a volume conductor suppose I want to detect any charges from my left side from my right side. So, right side of the arm I want to detect. So, if I put any electrode over here or if I put any electrode over my right wrist it will detect the same charges.

So, it is convenient to put an electrode over here or the lead over here then obviously over the shoulder right shoulder. So, that is why we put the lead over the arms the wrist and the legs. So, similarly we it is very difficult to put if we want to check the electrode electrical charges or the dipoles which are occurring on the left side of the body. It is very difficult for us to put the electrode or the leads on the waist left waist it is not or the pubic region. So, that is why we put this electrode we connect the positive terminal of the electrode or the positive terminal to the left leg and negative terminal we usually connect to the right arm.

So, anyway this connections or technical aspects of the leads will discuss in the further lectures, but till now what is very important is the connection negative and positive is mainly for the deflection of the voltmeter or the galvanometer what we want to deflect. So, this is the galvanometer or the basic principle in which the ECG is working. This is the needle of the galvanometer and this is the ECG paper which is rolling at a certain speed. As I told you the technical aspects I will tell later the ECG's paper is rolling at a certain speed. This ECG paper will roll from this suppose if it is left this is right it will roll from left to right and this is the needle.

So, when the impulse will travel this is the positive electrode this is the negative electrode. So, when the impulse is travelling from S n node to heavy node you can see there is a positive the wave of depolarization is travelling from S n n to heavy node. That means, it is travelling towards the positive terminal. This wave of depolarization is towards the positive terminal. So, that is why this atrial depolarization is marked by P wave that is why we get P wave over here.

And P wave is slower in nature because of the conducting pathway which is comparatively slow as that of the ventricular musculature pathway as that of the Purkinje fibers ventricular depolarization. Now, this P wave denotes the atrial depolarization. So, we get the atrial depolarization. This impulse has reached the heavy node. Now, AV node conduction is so slow it is very slow because of the specialized modified myocardial

tissue which is present in the AV node it has already been discussed in the conducting system chapter.

So, because of the slow conduction ECG machine cannot detect any signals from the AV node it is very very slow because of the specialized type of cells and less number of gap junctions and there is a delay of 0.1 seconds. So, at this point of time though the electrical impulse is getting conducted through AV node, but ECG the galvanometer can is not able to detect any signals. So, it will it seems that the heart is electrically silent. So, at this time there will be a straight line in the ECG this is P wave this is a straight line.

Now, the soon AV node the impulse travels through the AV node the next it will come to the bundle of HES. Now, in the bundle of HES the first depolarization as I told you is a septal depolarization, next ventricular depolarization, third the basal portion of the heart. Now, in the bundle of HES suppose this is the bundle of HES the depolarization the septal depolarization occurs from left to right. Now, you can say this is a positive electrode, but the depolarization here we have the positive electrode, but the depolarization is occurring from left to right. That means, the depolarization is moving the wave of depolarization is moving away from the positive electrode.

So, that is why this will give a small this will give a small this is a Q wave deflection in the galvanometer. Why small? Because septal musculature is very small. So, as compared to the ventricular or the atrial musculature. So, that the so this will give a small negative deflection in the ECG. Now, the next depolarization is the ventricular depolarization.

Ventricular depolarization as I told you it occurs from the endocardium because of the Purkinje fibers the Purkinje fibers runs over here. Because of the Purkinje fibers the ventricular depolarization is like this. The left ventricle has got very increased amount of thickness in the musculature. So, it will impart very strong vector of depolarization as compared to the right ventricle. But still the heart will give an average of the left ventricular depolarization and the right ventricular depolarization.

And final deflection will be towards left and downwards which is also towards the positive electrode. So, depolarization wave towards the positive electrode means it will give rise to a rapid R wave. It will give rise to the rapid R wave. Now, this R wave is very rapid and the deflection is very rapid and because of the strong because of the strength of the musculature. The thickness of the ventricular as I already told you the vector strong vector depends on the length and the thickness of the musculature.

So, now the last portion of the heart to get depolarized is the posterobasal portion of the heart which is again opposite to the direction of the electrode terminal which is moving away from the positive electrode. Hence this will also give a small deflection negative deflection since posterobasal portion of the heart is also thin. So, it will give a small deflection this will give rise to S wave. Now, after this there is a complete depolarization of the heart. The ventricles have gone into complete depolarization and I told you when a cell is completely depolarized again the heart will become electrically silent.

So, this will give rise to a straight line again. Now, then after the depolarization there will be repolarization. The repolarization will give rise to a positive deflection in the T wave because the repolarization starts from as I told you the last part of the depolarization. The last portion to get depolarized is the first portion to get repolarized which means the epicardium will get repolarized first. So, the repolarization of the epicardium will occur first and a negative vector or a negative electromagnetic force is moving towards the negative terminal it will give a positive deflection that is T wave.

That is why T wave is positive in deflection. Now, the question can comes that in ventricular depolarization we have got three types of depolarization in three segments that means there is a septal depolarization, there is a ventricular depolarization and there is a basal portion depolarization. But repolarization we have got only one wave it is because the repolarization process is very slow. The repolarization process is very slow because of the nature of the potassium channels. The potassium channels are the delayed rectifier potassium channels which are very slow as compared to that of the calcium channels or sodium channels. So, the septal muscles will get repolarized by that time the ventricles will also get repolarized and by that time the basal portion of the heart will also start repolarizing.

So, each portion get repolarization overlap each other. So, we net we get only one wave in case of repolarization as compared to the three simultaneous wave QRS we get in the ventricular depolarization. So, in this way we get the five waves of ECG three positive waves PRT and two negative waves that is Q and S. So, the basic principles of ECG outreach lies in depolarization when positive charges moving towards the positive electrode, there will be upward deflection. When positive charges is moving towards a negative electrode there will be downward deflection or negative deflection. When repolarization means when negative charges moving towards the positive electrode there will be a negative deflection.

Opposite charges I mean the opposite charges moving towards the opposite electrode. The repolarization towards the negative electrode that means the negative charges moving towards the negative electrode again there will be a positive deflection. This is the basics we have to remember and this I had already explained keeping in mind the

terminal of the ECG and the direction of the impulse conduction SA node. This is the septal depolarization, this is the ventricular depolarization which is towards the positive electrode and we can see this is the basal portion of the depolarization which is away from the positive electrode giving rise to the various waves. This is the P wave because of the atrial depolarization, this is the Q wave because of the septal depolarization which is moving from left to right.

This is the R wave because of the ventricular depolarization, net ventricular depolarization because there is left side and right side also. So, the net ventricular depolarization is towards the positive electrode. So, we get R wave then we get S wave because of the posterior basal portion the last part of the heart to get depolarized that is the basal portion of the heart which is also away from the positive electrode. And the last wave that is T wave we get this is a wave of repolarization which is moving towards the negative electrode. Negative charge moving towards the negative electrode will give again positive deflections.

So, these are the waves, these are the physiological basis of waves which is very important until you understand this you would not be understanding what are the abnormalities occurring in the ECG. So, these 5 waves are very important and we have seen how these are correlated with the ECG in terms of conduction. So, in this way we I would like to conclude today's topic of the physiological basis of ECG. Thank you.