Animal Physiology
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Module - 1
Lecture - 6

Welcome back to the lecture series in Animal Physiology in the NPTEL section. So we are into the section 3, and today we will be talking about the third lecture in section 3, which is pretty much the concluding lecture about the heart.

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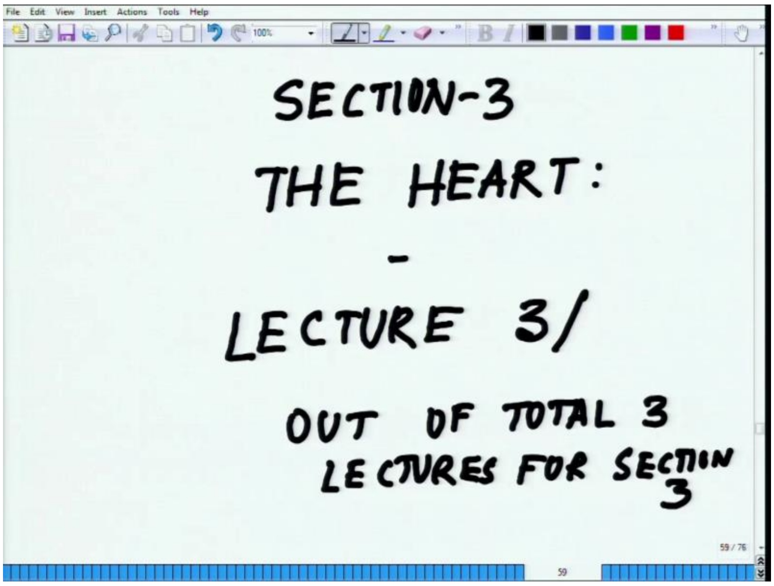

So, we have talked in the 1st lecture about the structure of the heart and the cellular details, how the tissues are arranged in the heart, what are the different valves, what are the different chambers. And how the blood flows from one chamber to another and likewise, and the second section we introduce the conduction system and the contraction system of the heart.

And in depth we talked about the pacemaker which are part of the conduction system and the contractile element which are part of the cardiac myocytes, which are part of the contractile element and we talked about the action potentials and everything. And in the last class, we concluded last class talking about how the ECG is been generated and in this class what we will do, we will talk about the conduction circuit.

And how that circuit exactly determines, how the signals will move from one end of the heart to the other end of the heart.

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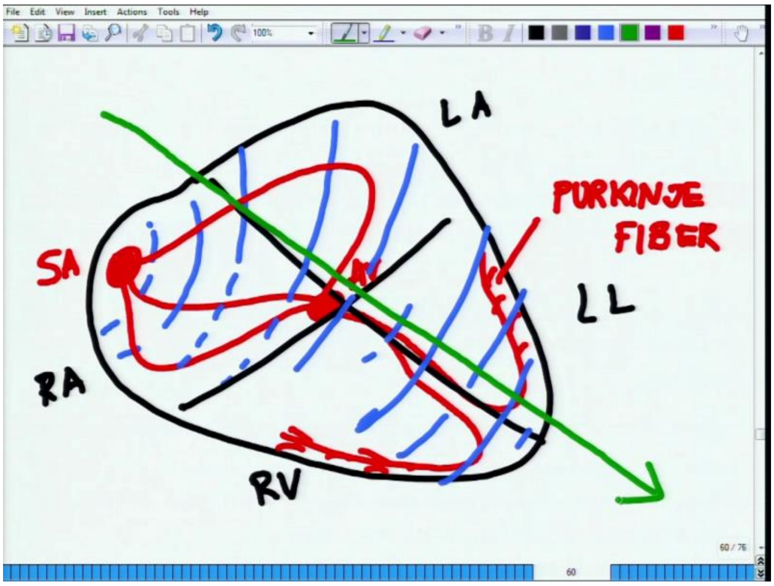

So, moving back if I redraw the circuit of the, so these are the right atrium, right ventricle, left atrium, left ventricle and this is where in the last class we talked about the SA node and SA node has this whole circuit. Area of the AV node and from the AV node the circuit moves like this, likewise, so this is the SA node, this is the AV node, this is the bundles, this part is the bundle what you see out here and these are the Purkinje fibers.

And we have already discussed that the stimulation out here, a kind of the wave fronts which are generated all along are spread out like this. And now we will be systematically talking about how these wave fronts are exactly moving across the heart from this end to this end. So, I have put the arrow, the arrow is like this the wave front is moving like this, following this green arrow. So, this wave front movement is a time dependent phenomena and now what we will do is that, we will be talking about that time dependent phenomena in it.

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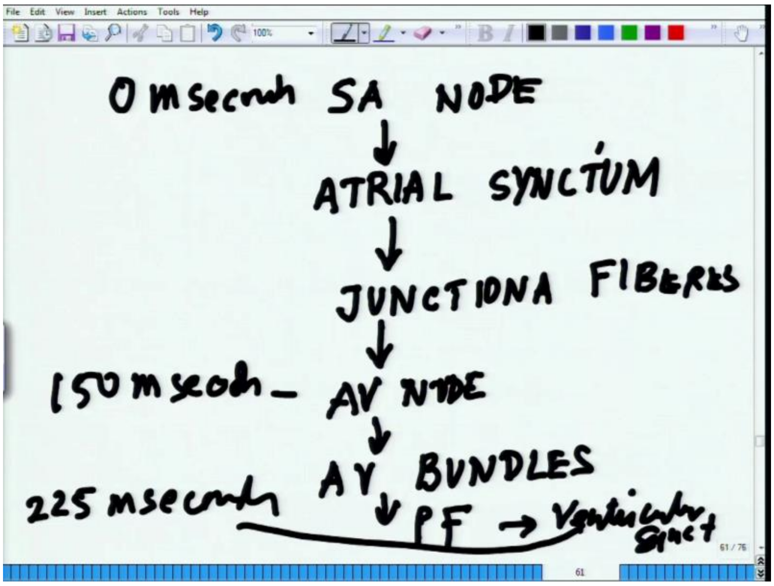

So, it starts from the SA node, so first step is that the SA node, from the SA node it move to the atrial synctum, so in other word atrial synctum, so basically all the atriums or the two upper chambers are kind of definition are stimulated. From there it moves on to the junctional fibers, which is basically just before the AV nodes from there it moves on to the AV node, from the AV node it moves to the bundles AV bundles, anti ventricle bundles.

And from the AV bundles it moves to the P of the Purkinje fibers and from there it moves on to the ventricular syncytium, all the ventricles kind of the complete ventricular chamber kind of gets excited. So, if this is started below 0 milliseconds by the time it reaches the AV node it is 100 milliseconds, there is almost a 100 milliseconds, so 100 milliseconds is the lack phase. And by the time the ventricles kind of gets completely stimulated it is around 225 milliseconds. Now what we will do I showed you like this, now what I will try to do I will draw the whole thing, so that it makes more sense.

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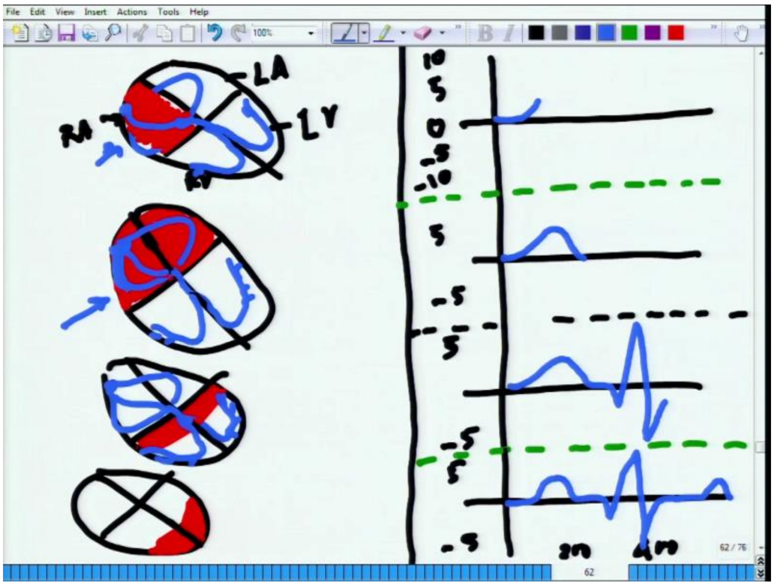

And what I will do simultaneously I will draw the, so let us start with this let me draw 4 chambers that will be easy 1, 2, 3 let me redraw it, because I cannot accommodate here. So, let me see 1, 2, 3 and 4 fine and on the other side what we will do, we will have the suppose you have electrodes, surface electrode on top of the heart, how you could measure it 2, 3, 4.

The y axis is talking in terms of the volt, 5 volt, 10 volt, minus 5 volt, minus 10 volt similarly this one ends here, the next one again same way 5, minus 5, now just putting in minus 5 because of the space constraint you can and these are all in mille volts. And you have same way 5, minus 5 and the x axis is showing you the time 5, minus 5, so these are the 4 graphs which you could see.

Now, what we will do I will try to plot it how this looks like, so this is the time when the stimulation is involved here, this red shading what I am doing. So, your Right Atrium if I put this as RA this one and RV and this is LV, left ventricle and this is Left Atrium, so this is the first step and what you see on the trace is like rise like this. So, this is happening, so let me put the time on the y axis, so around 200 milliseconds 200 to 400 milliseconds something like this.

So, the next step comes when both this Left Atrium and Right Atrium both are completely excited, because of the propagation of impulse from the conduction systems. So, what exactly does is that whenever the conductile system sends the stimulus to the contracting system. So, all the cardiac myocytes which are across this all the shaded red region they start contracting and will come to that and how that is being governed. So, by the time it finishes this the curve shows you something like this.

Next what you observe is out here when the ventricle starts getting the contraction because of the impulse from the conduction system and this is the stage when you see this is already done, when you see like this big rise and something like this, this is the third phase now from here we move on to the fourth one, sorry actually I drew it wrong. I should have drawn it on lower line sorry let me redraw it. So, it is like this yes now this is right.

Now comes the fourth phase where your lower half of the ventricle kind of getting the stimulation. So, it is reaching through and now if I had to redraw the circuit, the circuit is like this, I am redrawing it for all of them, so that you know, so this is how it is happening. So, initially the stimulation was out here if you go through it, it was here, at this zone then the stimulation completely spreads on the other side and then the stimulation out here, and then now the stimulation is at this fag ends. So, this fag ends when the stimulation is there what is happening the graph is getting completed this moves up and then with a gap you see. So, this trace what you see is a characteristic ECG trace and now will give the nomenclature for it, I will redraw this particular graph in a bigger platform.

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So, that will give you an idea all that it looks like. Likewise and comes back and this is how a single ECG or EKG, Electrocardiogram or Electro EKG or ECG whichever you call that exactly meant and if I go back to the previous diagram give the time constrained out here.

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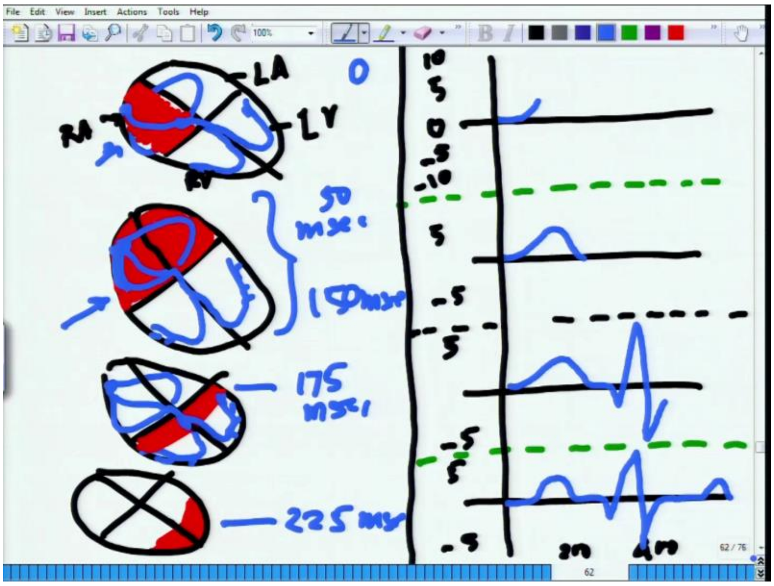

So, this event what is happening this is happening 0 to 50 milliseconds and this events kind of get over by 150 milliseconds and from here the first phase goes through 175 millisecond and by the time it ends here, it is around 225 milliseconds which tallies up with the previous one, If you look at while I was putting these values out here, this is what was happening. Now I showed you in the diagrammatic manner how the electrical impulses are getting transmitted.

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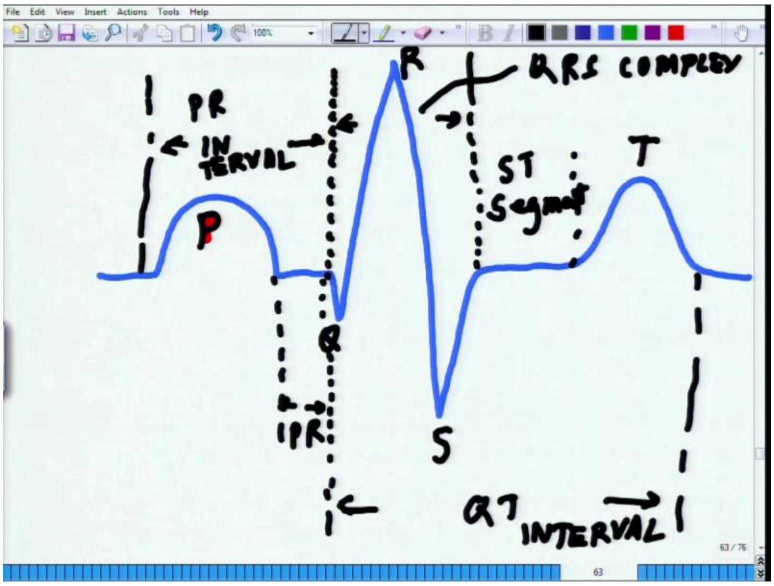

Now, coming back to giving the nomenclature what is essential this one is called P, I will use another color for better understanding this one is called P. This one is called let me put it like this one is P this is called the QRS complex. So, here you have the Q, here you have the R, here the S. QRS complex and this is called T. This is a characteristic EKG trace looks like, PQRS complex and within that you have the different terms, which are used if this is P then from here to here, this one is called PR. PR in PR segment and this one is called PR interval.

Then you have this QRS complex, which is this from here to here, this one is called QRS complex, and from here to this part it is called ST segment. And from this part from this Q where the Q starts to the end of the T this is called QT interval. So, this what is exactly is the QT interval is, the QT interval is the time required for the ventricles to undergo a single cycle of Depolarization and Repolarization, this is what the QT interval is all about.

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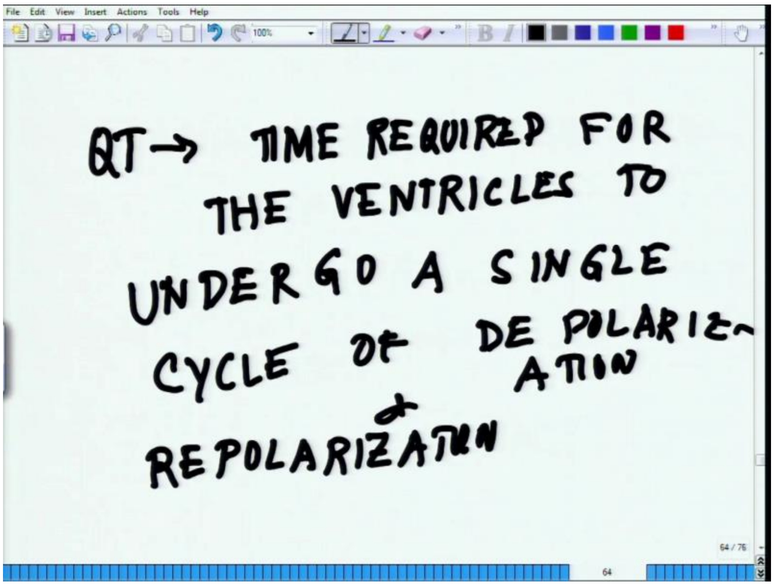

So, this what is exactly is the QT interval is, the QT interval is the time required for the ventricles to undergo a single cycle of Depolarization and Repolarization. This is what the QT interval is all about.

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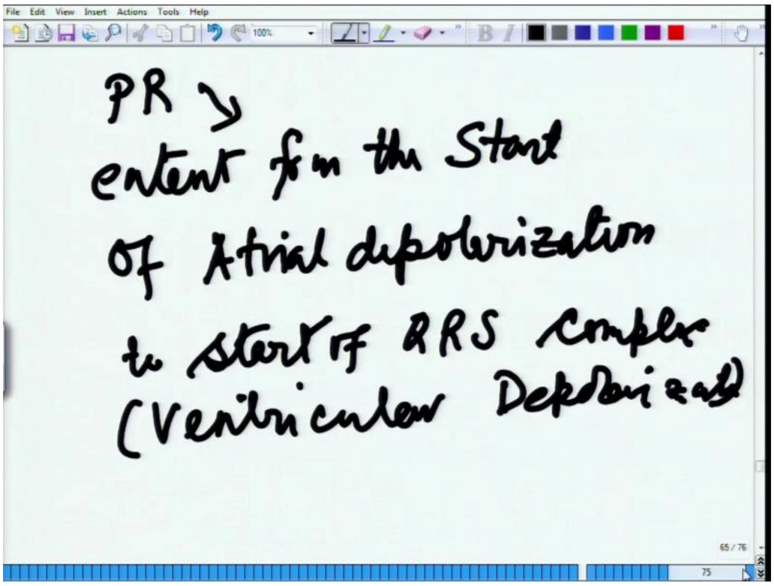

And what is the PR interval, will come back. So, the PR interval is basically extent from the start of atrial depolarization to start of QRS complex or which could also be called ventricular depolarization, so these are some of the things and based on this.

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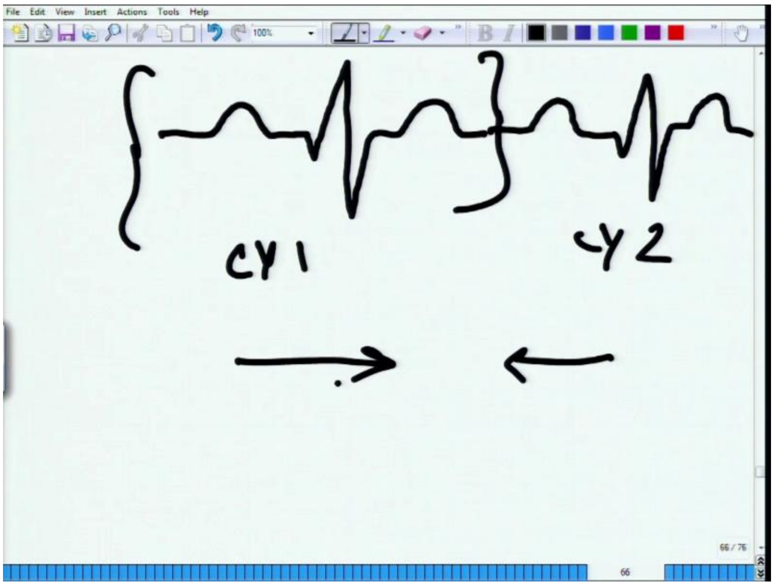

So, if you look at the EKG trace so, this is P this is the QRS complex and this is the T. Based on that if so, this is one cycle. So, followed by the next cycle again a P ((Refer Time: 15:52)), so cycle 1, cycle 2, so if they are much more closer like this, so there is a lesser time gap between the two cycles, so that is when the heart is beating very fast, that is a fast heart beat. And if they are far apart then, there is a slow heart beat and if it is irregular, if the time gap between these two is irregular that is a irregular situation which we falls under cardiac arrhythmias.

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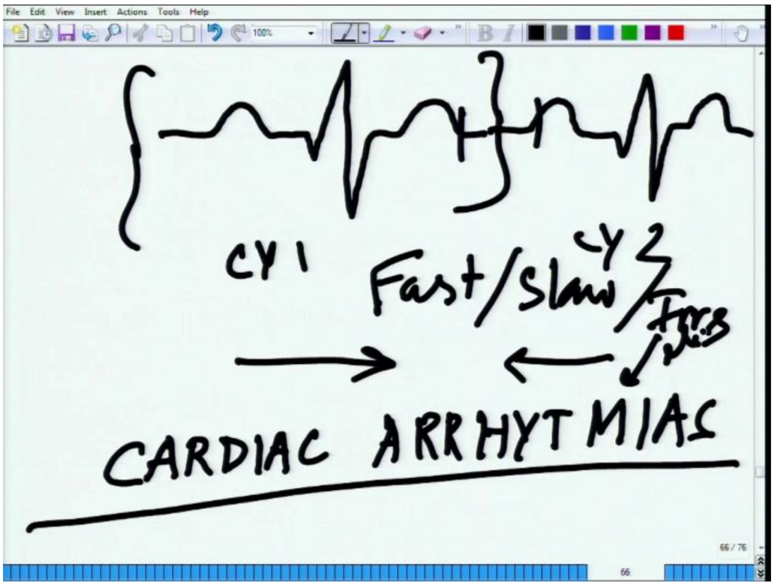

This is the basic understanding of this is fall under let me put it Cardiac Arrhythmias where there you have irregular heart beat. So, you could have the fast heart beat, you could have a slow heart beat, you could have a irregular heart beat and that falls under all kind of arrhythmic condition. So, what really arrhythmia really means, so this is very, very interesting to understand.

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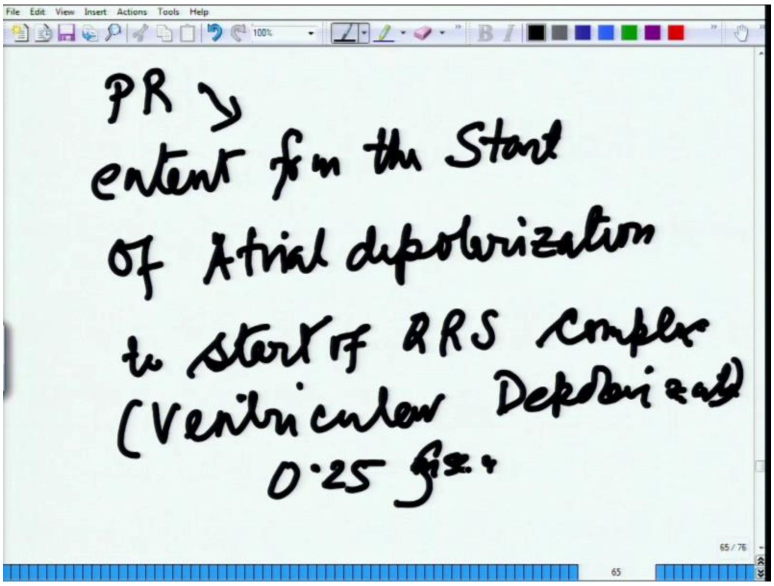

So, one more thing before I talking about the PR interval when you talk about the, so PR. So, generally whenever PR is more than 0.25 seconds there is some kind of problems why is it?

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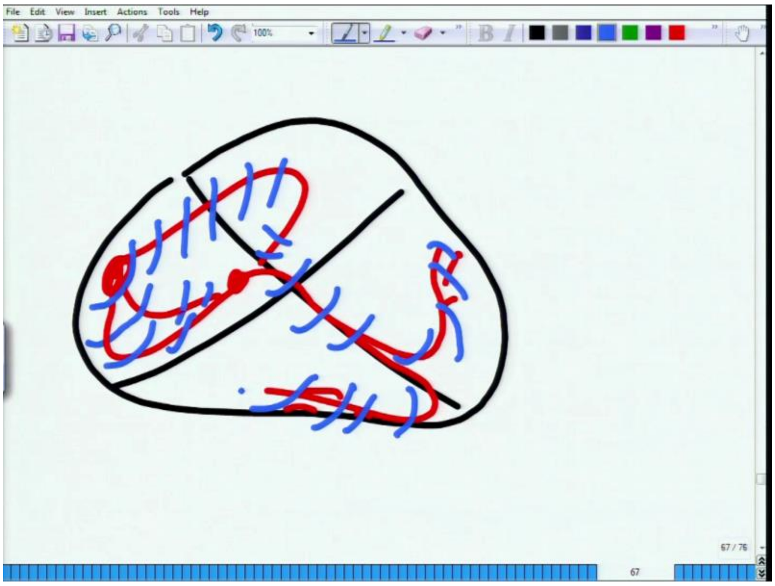

So, Let us physically understand the process so, what exactly is happening. If this is the heart we have then, this is the circuit what we are talking about with AV node, SA node and Purkinje fiber and everything. So, the signal is following a certain speed with which it is spreading out here spreading here, spreading here, spreading here and these signal spread decides in what sequence the atrium will empty its blood to the ventricle, from the right side to the right ventricle, from the left side to the left ventricle. And at what rate the left ventricle and the right ventricle will pump the blood to their respective target from the left of its will go towards rest of the body and from right it will go to the lungs.

This whole sequence of event is very, very tightly regulated in terms of time, the volume. And this is continuously being regulated by this conduction system of the heart. The conduction system is that very important here, because it sets the tone by which the heart is going to continuously beat for rest of your life.

And it will adjust whenever there is you know, your heart is beating fast because of some you know physical exercise or you know some x y z situation or you are sleeping when the heart may be slower likewise. So, that tone is very, very important for us to understand and based on simple EKG trace you really can figure out that, what is the status of the heart and there are certain things were EKG can tell and yet there are certain things which EKG cannot tell.

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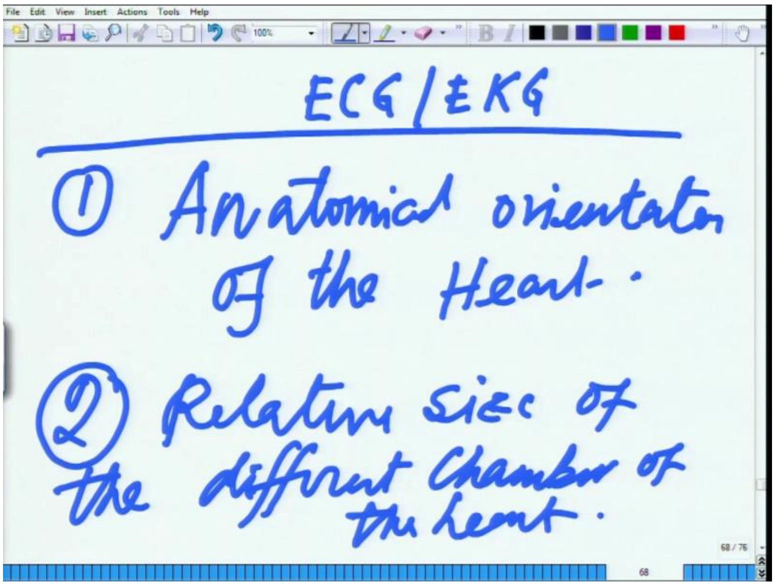

And we will talk about what EKG can tell you and what EKG cannot tell you. What ECG, EKG or ECG can tell you so, these are the things what EKG can tell you. First it can tell you the and please be very careful on this one, anatomical orientation of the heart, this is EKG can tell you straight away of the anatomical orientation of the heart, this EKG can tell you first thing. Second thing EKG can tell you a relative size of the different chambers of the heart, this EKG can for sure tell you.

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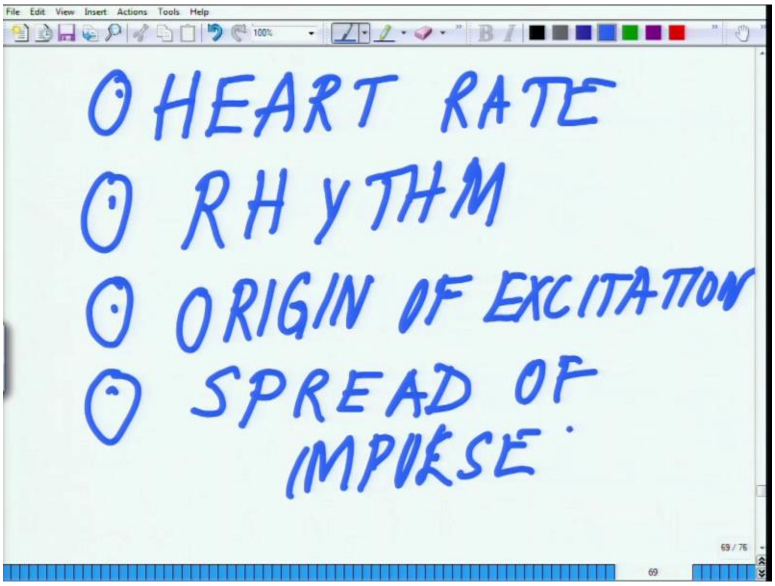

What else EKG can tell you, it can tell you the heart rate, this EKG definitely can tell you. Fourth what can tell you, the rhythm of the heart. Fifth it can tell you, origin of excitation from where the excitation is getting originated. Fourth it can tell you, about spread of impulse, how the impulse is getting spread is there a blockage in the path way or anything spread of impulse it could be worked out from the EKG traces, spread of impulse.

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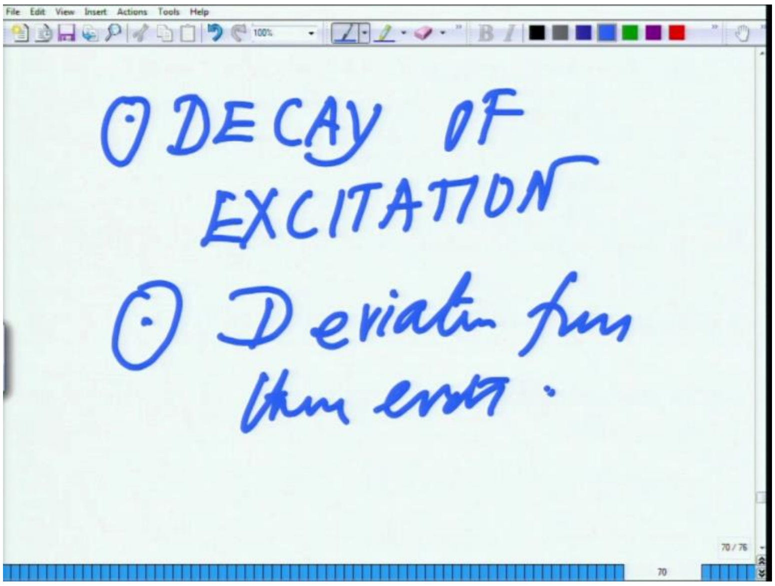

Apart from it what it can tell you, the decay of excitation because it is an electrical impulse so you can measure it, decay of excitation what else it can tell you, it can tell you about the deviation from these different events.

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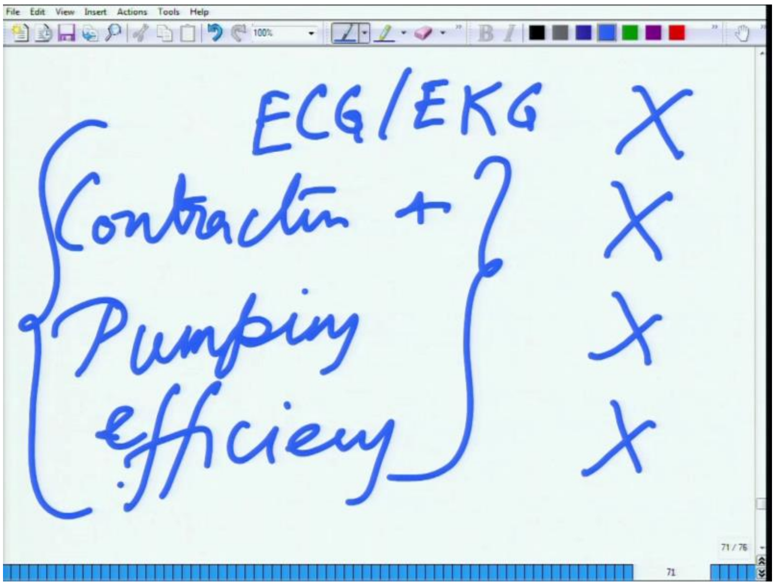

What EKG cannot tell you, this is very important What ECG or EKG cannot tell this information cannot come from an EKG. This is what it cannot tell you contraction and pumping efficiency. And that make perfect sense, because the contraction is a function of the contractile system of the heart and the pumping efficiency is based on the contraction process. So, those things can never be predicted by the conduction system, conduction system can say how the impulse will move in what direction it will move, what will be the time gap from one point to the another point. Like from SA node to AV node there could be a situation when you may see two P waves followed by the QRS complex, you can immediately tell that if there are two P waves it means the atria has to put more pressure.

So, it mean, so in other word it means there is a blockage or there is a damage in the path way you see, from SA node to AV node you will see those three path ways you know there may be some kind of a blockage by which you need two P waves you need more energy more impulse to you know make the atria pump it bald to the ventricles. Those things can tell, but what it cannot tell you always remember this, the contraction and the pumping efficiency can never ever we predicted by seeing a ECG trace this thing is exceptionally important for you guys to understand, because it has something to do with the heart attack and I will come to that what really heart attack means. And what ECG can never tell you.

So, from here, let us move on to the next slide which is very important in terms of how the different volumes are changing, this is very important.

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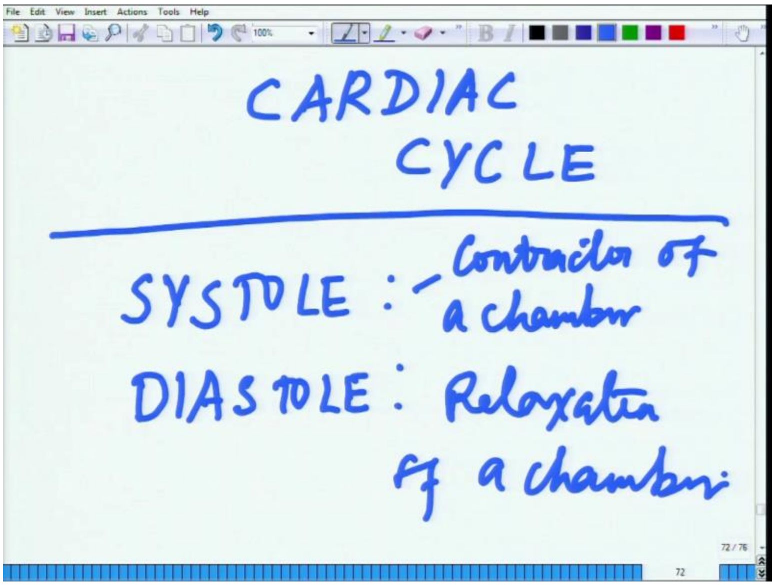

There are two terms. So, one of the terms I am going to so, will be the call cardiac cycle before you understand cardiac cycle there are two terms which you need to understand one is called Systole or somebody some of them you call it Systole or Diastole or Diastole. This is very important what is Systole and what is Diastole. Systole is contraction of a chamber in the situation it could be a atrium or a ventricle left or right. Diastole means relaxation of a chamber, this is what is meant by systole and diastole.

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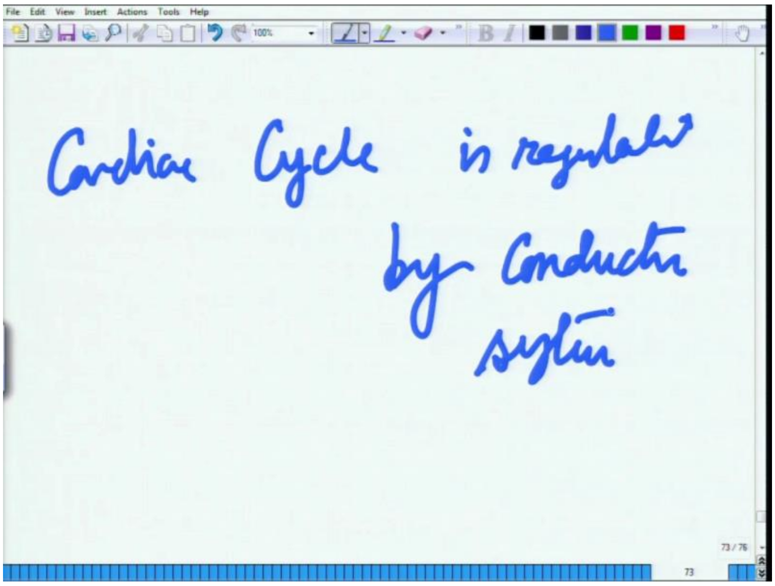

So, this Systole and Diastole the cardiac cycle is regulated by the conduction system. So, how it all starts is this cardiac cycle is regulated by the conduction system. So, how it is being done let us systematically go through step by step.

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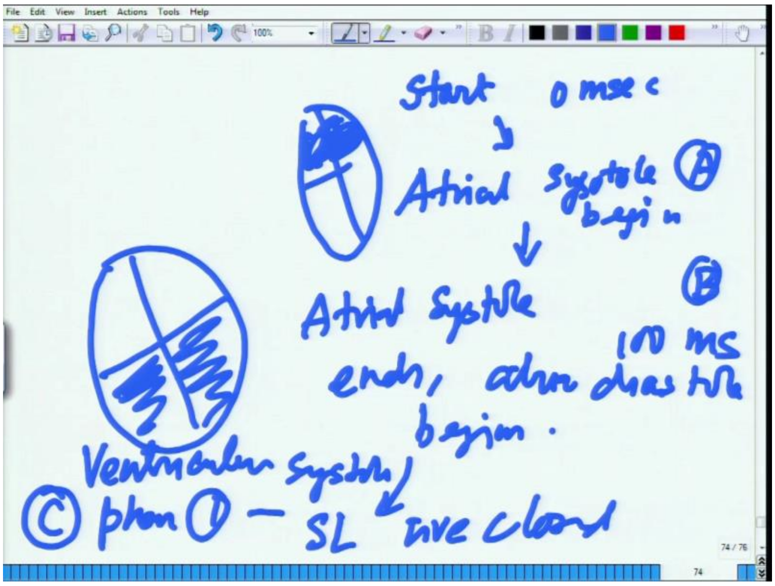

So, it starts let us put a start point somewhere let us put as start point here. So, the first thing which happens and this is at 0 millisecond. The first thing which happens is atrial systole begins, this is a step when these are atrials so, which are all felt they start to contract then phase this is A. Then stage B when around 100 milliseconds, what is happening is that atrial systole continues atrial systole actually ends and atrial diastole begins, this is phase two now the phase three is C, I am putting it as C. So, we that is the ventricular systole begins that is the phase one, this is the time when the blood has moved out from atrium and this is all over this place what I am shaded just now.

So, this is the time when the semi lunar valves along the ventricles the pulmonary semi lunar valve and the aortic semi lunar valves are closed. So, I am putting it SL are closed. So, in other word what is happening inside the ventricle there is huge amount of blood at that stage. So, it is all contracted.

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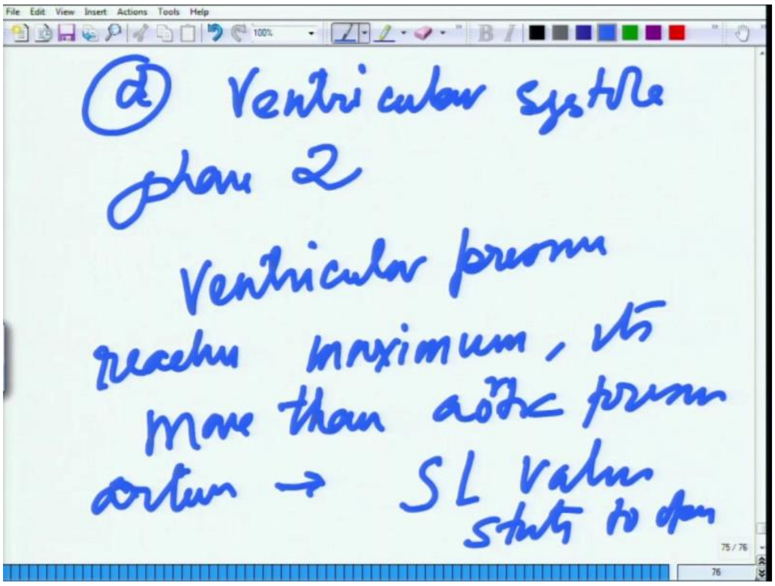

So, that is the first phase of the ventricular systole I will move on to the next slide where the phase D, I will coming back that is the ventricular systole phase 2. So, this is the time when the pressure of **v**entricular pressure increases, pressure reaches maximum and it is more than aortic pressure and or the pressure of the arteries. So, this is the time when semi lunar valves starts to open.

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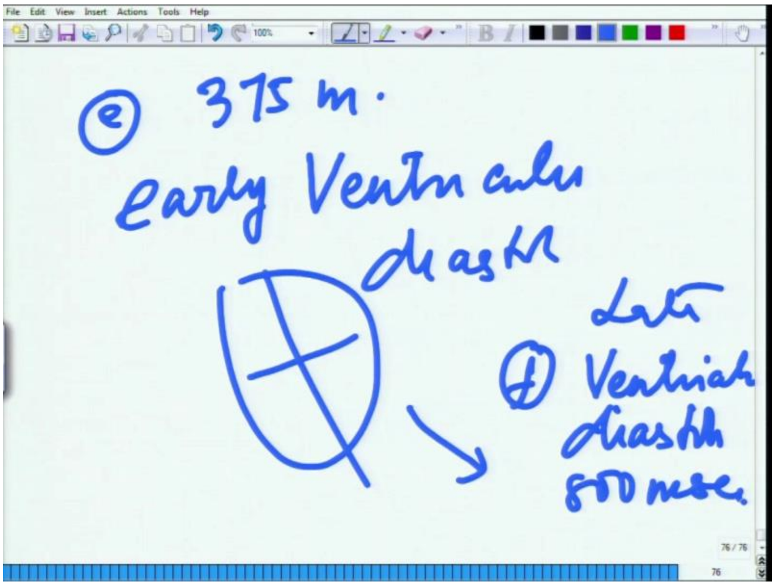

Then comes the phase E, which is around 375 milliseconds that is the early ventricular diastole and followed by the F phase which is which is late ventricular diastole when their relax phase around 800 milliseconds. So, this whole cardiac cycle this continues in a fashion and I will give you another diagrammatic representation of it which will help you to understand, how it looks like so.

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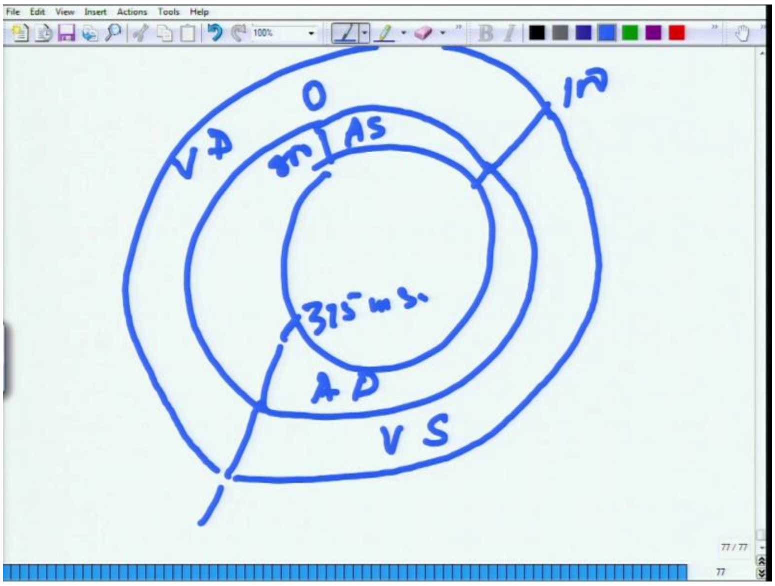

Lets draw a circle like this and start with phase one the Atrial Systole. I am putting at AS followed by Atrial Diastole AD and then there is a phase, so neither the diastolic or systolic it is a its kind of stand out there. So, it starts at 0 and this is around 375 milliseconds.

Or on the other hand in terms of the Ventricular Diastole, it continues from here the Ventricular Systole sorry around this is the Ventricular Systole phase around 375 and from here it moves on and this is the Ventricular Diastole phase which is around 100 milliseconds and this is 375 and this one ends there at 800 milliseconds. So, this is how it goes. So, physically you have to understand, what is happening?

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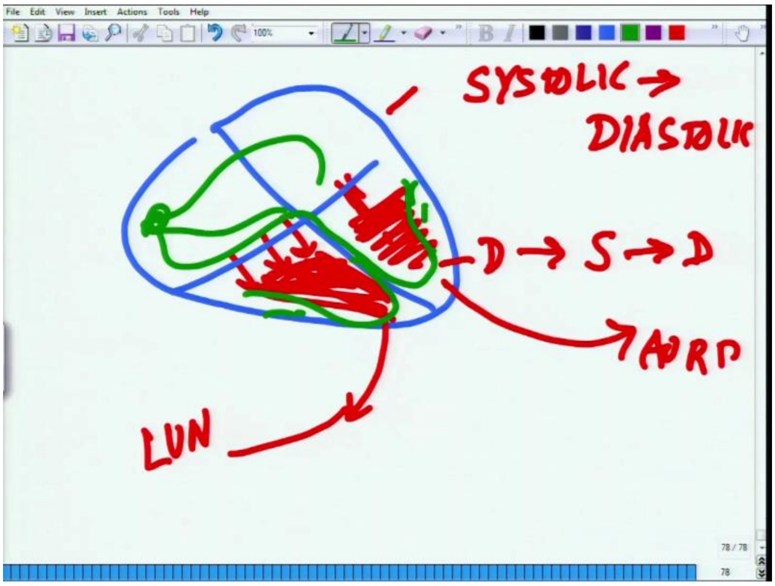

This is the heart the first thing what happens the blood starts coming here, that is filled with blood both of these, there is huge amount of pressure while it is processing. So, initially the blood is low and then the blood grows up, the concentration of blood increases.

So, then it reaches a peak pressure then what happens from here the blood starts moving to this chamber moving here. So, when moves here. So, the blood is slowly getting depleted here, blood is slowly getting depleted into this zone and the blood is filled in this zone. So, initially this was in a pressure it was in systolic phase then it moves to the relax phase, which is diastolic phase whereas, this one which was initially diastolic phase moves to the systolic phase and then when it throws the blood out, this goes to the lungs assuming that, this one is right side and this one goes to the aorta, then this enters again a diastolic phase.

And this whole sequence of event systolic, diastolic, systolic, diastolic for the atrium and the ventricle the sequence of the event is being regulated by that wonderful contractile circuits, which I am repeatedly trying to draw to kind a make you understand why this is. So, very important that this has to be regulated in a sub sequential manner.

Otherwise things will go out of context and will suffer from cardiac acedmy and similar other problems. So, now, what I will do, I will superimpose.

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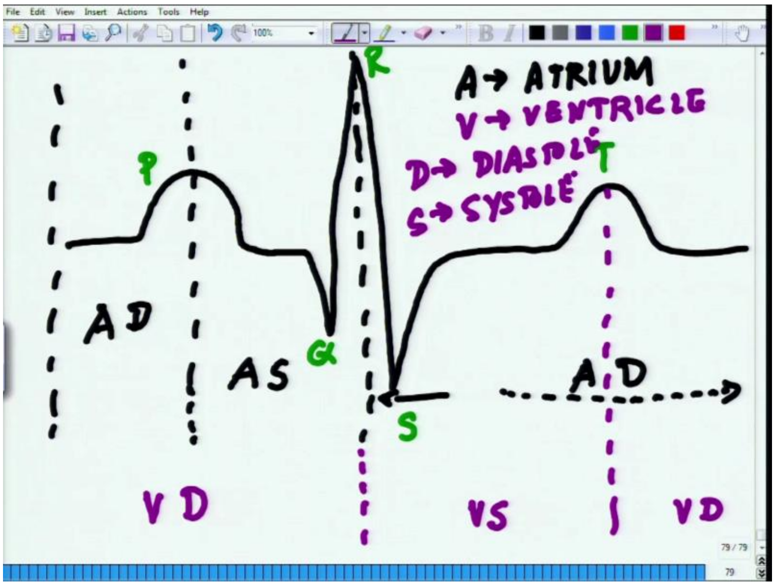

I will superimpose the PQRS graph with the systolic and diastolic, here we have. So, this is the phase of Atrial Diastole.

I am not writing this is not space to write the full forms you can just hear with me and understand this follow the lectures, you will be able to understand and this is the phase of Atrial Systole, that again from here starts your Atrial Diastole till the next P starts. So, this is P let me mark it this is P this is QRS complex and this is T. Till the next P starts again we are into the Atrium Diastolic phase, where you on the other hand if I see what is happening in terms of the Ventricular Diastole. So, this is Ventricular Diastole phase and this one continues as ventricular. So, this is the Ventricular Systole phase and again the Ventricular Diastole phase.

So, if you co-relate both of them where A stand for Atrium and V stands for Ventricle and D stands for Diastole and S stands for Systole. So, this is how you can put the filling of the atrium, sending the blood or the moment of the blood from the atrium to the ventricle and vice versa. The filling of the ventricle and the emptying of the ventricle in terms of Atrium Diastole, Atrium Systole, Ventricular Diastole, Ventricular Systole. And this is how you plot it with respect to the electrocardiogram traces and this is how it looks like and this is a exceptionally important for you people to understand that, it is a very well coordinated system and any kind of problem in this, leads to a series of complications.

Then from here we will move on to the next phase of it, which is our cardio dynamics, but before move on to the cardio dynamics I wanted to touch couple of more stuff here.

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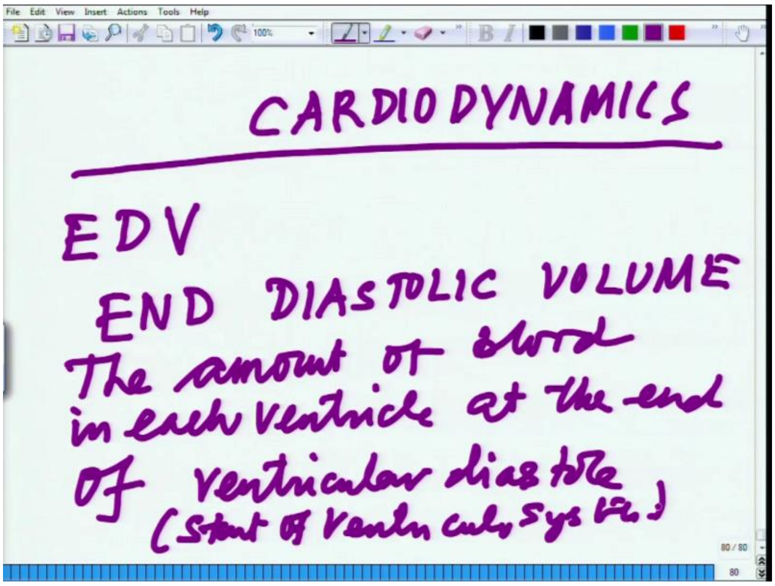

Let us move onto the cardio dynamics and I will come back to that what is cardio dynamics. So, before I move on to the cardio dynamics we, have to realize the bigger vessels within the heart among the chambers of the heart are the ventricles. How much blood a ventricle will accommodate is exceptionally important. So, here I will give you some terminology.

And, I will explain and how those terminologies can be used to understand the efficiency of the cardiac output the first terminology, I will give you is End Diastolic Volume will write it down End Diastolic Volume. What End Diastolic Volume means, it is the amount of blood in each ventricle at the end of Ventricular Diastole or this is basically start of Ventricular Systole.

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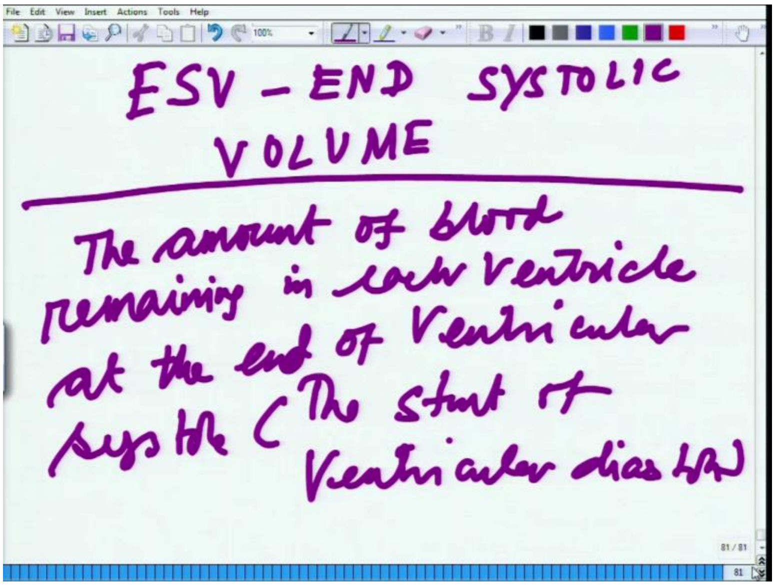

The next term is important is ESV, End Systolic Volume what this means, this means the amount of blood remaining in each ventricle at the end of Ventricular Systole or the start of Ventricular Diastole. These two definitions are exceptionally important for you people to understand may be something called SV or Stroke Volume.

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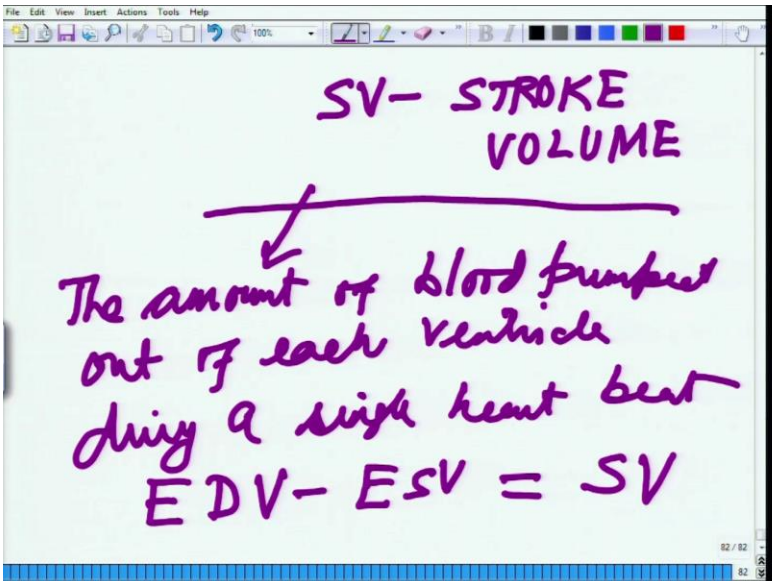

Stroke Volume is the amount of blood pumped out of each ventricle during a single heart beat and expressed as EDV, what we have just now explained minus ESV, End Diastolic Volume minus End Systolic Volume that gives you the Stroke Volume.

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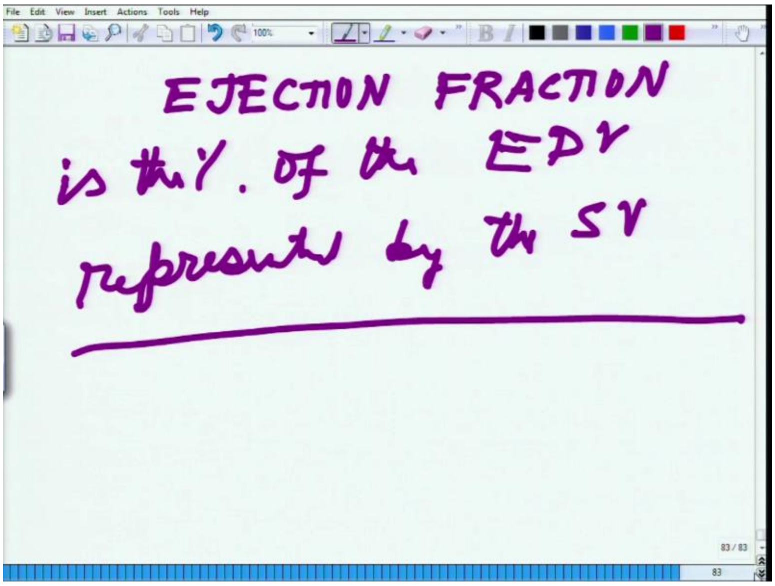

And then, the Ejection Fraction is the percentage of the EDV, End Diastolic Volume represented by the SV or Stroke Volume.

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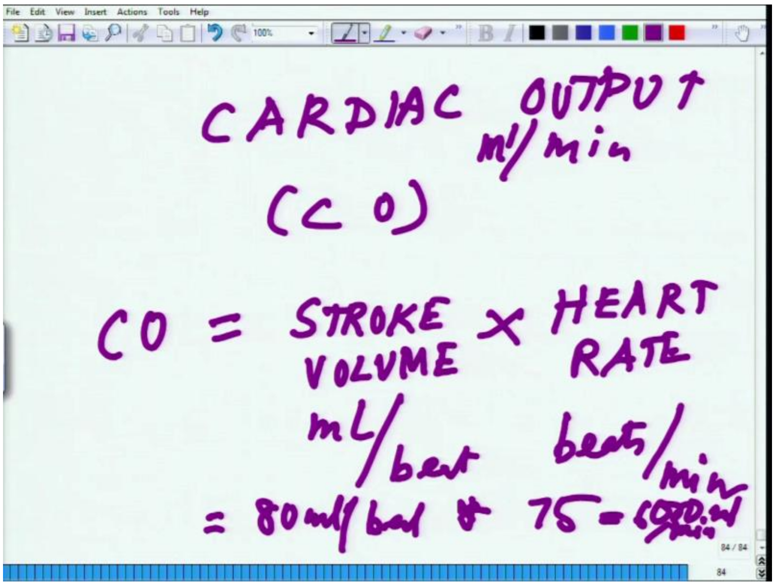

From here what we will do, we will measure the Cardiac Output this parameters are very important for Cardiac Output. So, Cardiac Output is expressed as milliliters of blood per minute. So, CO if I represent it as CO or Cardiac Output is equal to the Stroke Volume multiplied by the Heart Rate. So, Heart Rate is explained by beats per minute and ml per beat Stroke Volume.

So, say for example, if I got two values say for example, you have a Stroke Volume of say 80mL per beat and you have a heart rate of 75. So, that sums up to approximately 6000mL per minute which is around 61 per minute. if I just change the unit.

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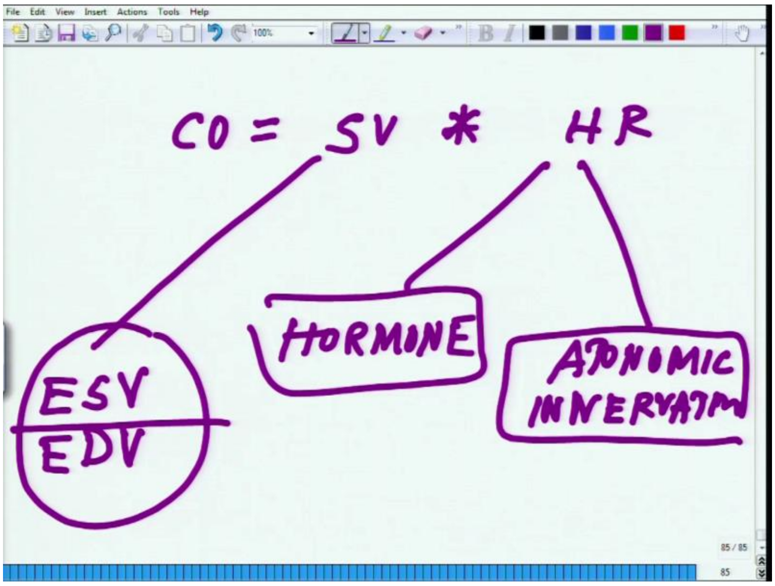

So, Cardiac Output is equal to Stroke Volume multiplied by Heart Rate. So, what are the factors which are governing heart rate. So, as we will be touching in the endocrine system there are hormone, which regulate heart rate and there is an autonomic nervous system. So, at this point we are not discussing in depth, because I have not touched nervous system. So, once I will come to nervous system I will come back to this.

Autonomic innervations this is very important for you people to understand and what dictates Stroke Volume, Stroke Volume is dictated by End Systolic Volume and End Diastolic Volume.

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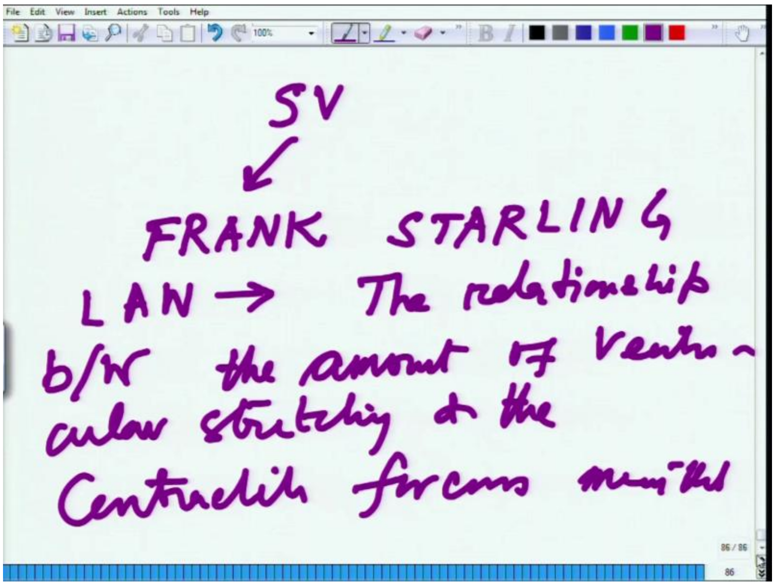

These two are the factors, which governs the Stroke Volume. And there is another factor which decides what will be the Stroke Volume that falls under and there is long back this is interesting something called a Frank Starling Law. So, it is worth discussing here Frank Starling Law. So, what this law says is this the relationship between the amount of ventricular stretching and the contractile forces and the contractile forces means that within physiological limits increasing EDV will result in corresponding increase in Stroke Volume.

So, in other words sometimes it is called more in equals to more out, and this was first developed by ((Refer Time : 42:42)) Arms ages starling, based on some of the findings of Otto Franks and now it is being said that this falls under something called a Frank Starling Law or Frank Starling rule which, basically says that within the physiological limit, the ventricles can expand as more and more contractile forces or more and more, I should say stretching is allowed. So, they have significant amount of room to do so.

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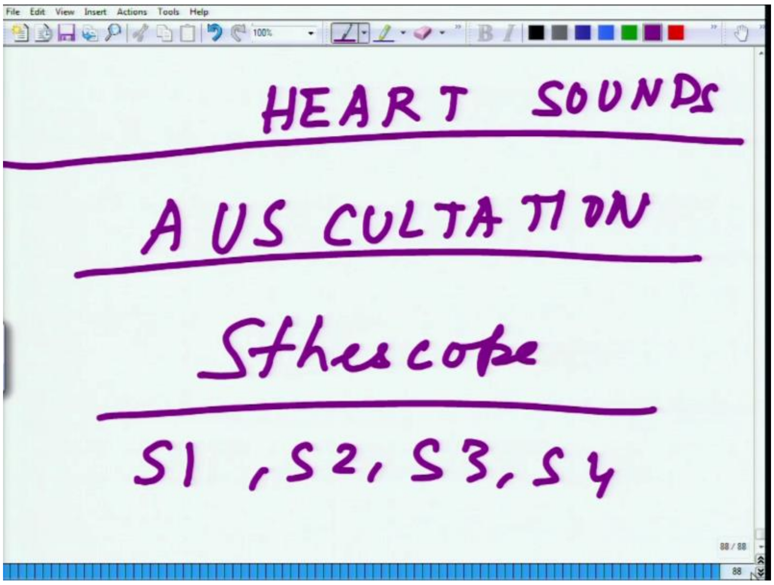

From here on, let us move on to the next phase of it, which is basically another very interesting thing so, that is Heart Sounds. So, whenever we sees the doctor says about the Heart Sounds what really is the Heart Sounds. Heart generate four kinds of sounds and there is a term for this when you see the doctor is using Stethoscope. So, figure out the Heart Sound generates four kinds of sounds sound 1, sound 2, sound 3 and sound 4.

But generally most of the time we could hear to only one sound only two kinds of sounds which could hear is basically something like this here.

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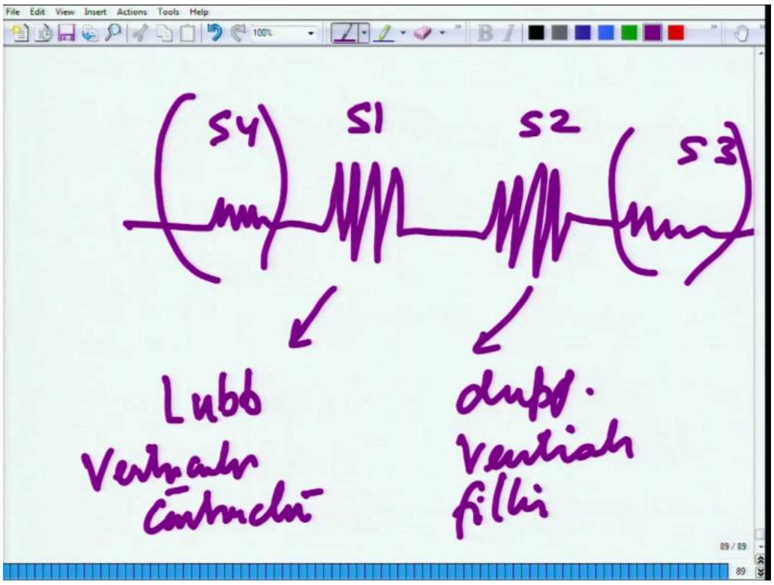

If these are the sound waves which are getting generated because of placing of then the sound waves are generated because of the opening and closing of the walls. So, S1 this one is S2, this one is S3, and this one is S4. So, these two sounds are fairly fink you really cannot hear this sound so easily. This one is basically lub you hear and your another sound which is called dup. The lub and the dup are basically mark this one mark the ventricular contraction and on the other hand, the dup talked about the ventricular filling and the closing of the semi lunar walls.

So, based on this you can even figure out the volume change in the volumes so, that the maximum volume which is being accommodate in the ventricles. So, the volume changes is maximum volume becomes in the ventricle. So, if you look at now summarize what we have touched as of now is that we talked about the contraction system, we talked about the conduction system, we talked about the irregularity in the conduction system leading to some form of arrhythmia or the regularity which can be cured. So, how you get around all this things say for example,

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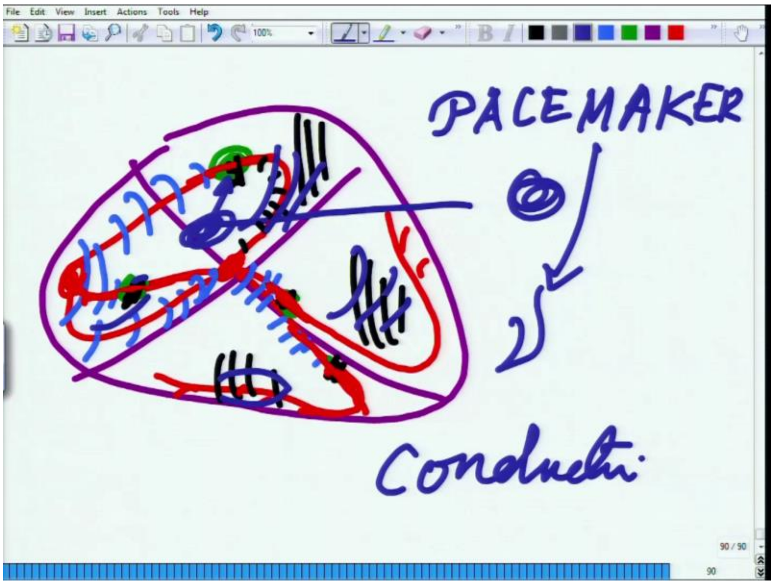

So, if again back you hear that people are having pacemakers. So, what exactly pacemaker is all about. So, if this is the circuit where you have the AV node and this is moving and is Purkinje and all other things.

So, say for example, there is some form of blockage out here say for example, there is some blockage or some blockage here or something here. So, what will happen the signal will move, signal in this case it will move up to this, in this case up to this, this case it will move faintly up to this and then it will move along with this and it will stop here and this will stop here.

Signal would not be able to propagate along these lines. So, these are the places which are dawn in the black they are all divide off signals there is no signal reaching. So, basically the contraction of this is not going to take place or the contraction of this is not going to take place, contraction of this is not going to take place how to get around it.

What is the way what are the different ways. So, one way is that either you repair this some way or other you repair this, it is just you know there is a gap in the bridge there is a breakage and you will again regulate the circuit you get the circuit back in the place like this, this is one way of doing it, but that is not a easy was that is not. So, that is not something. pacemaker out here wherever it they know exactly.

So, what a peacemaker does this is what a pacemaker does, it generates certain frequencies certain specific frequencies it generate. And those frequencies stimulate these different muscle cells wherever there are cardiac myocytes to pump the blood. So, in other word what you are doing is that you replacing the electrical blockage in the electrical conduction by introducing a artificial electrical conducting system in the form of a pacemaker.

This is exactly what you do, you introduce another artificial small chip which is being implanted out here and that chip generates the certain kind of frequencies and that frequency is good enough it has been worked out good enough to you know to ensure that all your four chambers keeps on beating in a ((Refer Time: 48:11)) in a sequence same sequence as it is being regulated by the conduction system.

So, this is the problem of the pacemaker, which is taking care of your conduction system. Pacemaker has nothing to do with your contraction system. What about the heart attacks? heart attacks are situations, When there is something called Myocardial Infarction.

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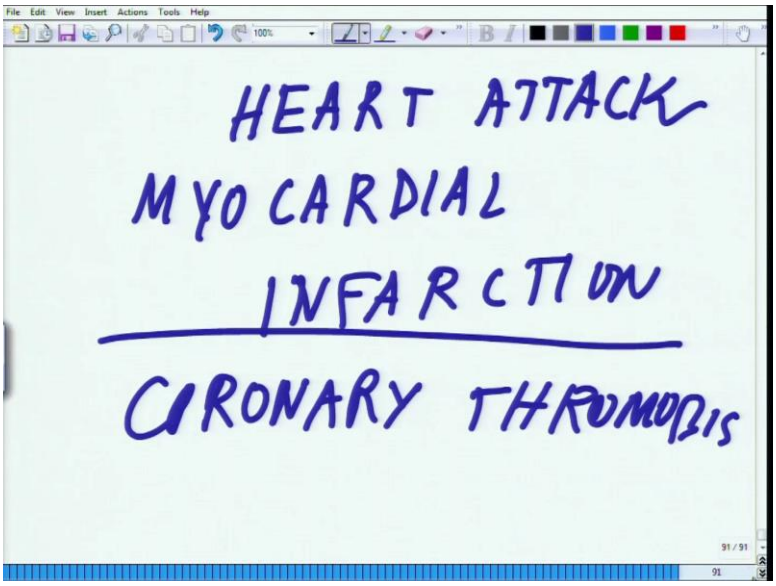

What does that mean? Myocardial Infarction or Coronary Thrombosis these are different pathological condition.

What is exactly happening? So, what is happening in the situation is whenever there is a cardiac arrest or (()).

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We talked about the conduction system, but in the case of heart attacks these contractile elements which I am putting in magenta now gets damaged, damage in contractile elements. So, in other words your elements which are suppose to contract are unable to contract properly and that is a case of heart attack and this could be diagnosed using bunch of cellular acids like ill age, lactic dehydrogenous.

Because, these cells secrete certain specific enzymes into the blood then you have serum glutomic oxolo acidic trans ammines it is in short it is called SGOT aces, then you are create nine phosphor kenine, CPK aces. So, there are whole range of aces which helps you to you know understand that there is a damage in the contractile element.

So, if I had to summarize what we have discussed in this whole section is, we talked about let me go back so, we talked about the structure of the heart, we talked about let me wait I will write it down.

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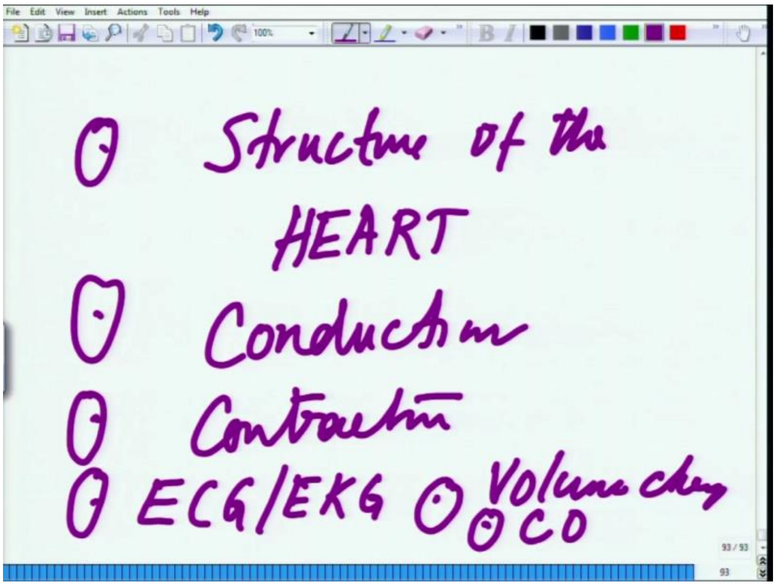

So, we talked about the structure of the heart, we talked about the conduction system, we talked about contraction system. We talked about ECG or EKG, we talked about volume change and we talked about cardiac output and few other things there and finally, we talked about what is heart attack. So, I believe that this much is sufficient for you people to understand that how the heart is exactly functioning and this will help you to you know get a feel about how the system is getting integrated.

And as we will move further into the nervous system and a hormonal mille, you will come back to the system to talk about how the nervous system is controlling the heart or the hormonal system is controlling the heart and will be coming back to the excitation contraction coupling amparatus within the cardiac myo cycle will be talking on that also. Because while will be talking about the muscle with this I am finishing the section three which constitute our heart and from here we will move on to the section four. So, thanks for now.