

Human Physiology
Dr. Sudip Mukherjee
School of Biomedical Engineering
IIT(BHU), Varanasi
Week - 03
Lecture - 03

Welcome, everyone, to another new class of Human Physiology. In this class, we will discuss the anatomy of the heart, and we will also see different diseases related to the heart and how the electrical activities of the heart occur. So, let us start with that. So, what different contents will be covered in this class? So, we will first see what the size, shape, and location of the heart are, then we will discuss the physiology of the cardiac muscle. We will discuss the anatomy and division of the heart, the pathway of blood flow, and then we will see the arrangement of the cardiomyocyte cells. We will also discuss different heart-related diseases, and finally, we will discuss the electrical activities of the heart.

So, to start with, as you see, the heart is like a muscle, right? It has a conical and pointed shape. Basically, the size of the heart is about the size of your closed fist. So, it is not bigger than your closed fist, and it is located exactly between our chest and heart, which is nicely protected by the rib cage. As I said, the heart is a muscle; it moves about 2,000 gallons of blood per day.

So, as you can imagine, 2000 gallons per day is not a very small amount, right? So, the heart needs to continuously pump blood to the lungs and to other tissues to supply oxygen to them. So, it continuously pumps for performing this action. And as you can see, the heart beats about 60 to 100 times per minute, and the weight of the heart is about 9 to 12 ounces. So, if you look a little bit deeper into the heart anatomy, the first part of the heart will appear to have a membrane layer. So, let us see what the different types of membrane layers are that cover our heart.

Basically, it will be around 3 different membrane layers. The first would be the endocardium, which is the deepest layer of the heart. So, as you can see in the images, the endocardium is the deepest layer of the heart, and then there is the myocardium layer, which is mostly like the middle layer of the heart. The outermost layer of the heart, which is the pericardium, is a type of membrane or sac that surrounds our heart; basically, the role of all these membranes is to protect our heart from any external substances, viruses, or bacteria, and it also provides structural support so that the heart works properly. So, let us see the anatomy and division of the heart.

So, the heart basically has four different compartments: two on the right side and two on the left. So, on the right side, we have the right atrium on the top part and the right ventricle on the bottom part. In the same way, on the left side, we have the left atrium in the upper part, and in the bottom part, we have the left ventricle; and as you can see, in between the right atrium and the right ventricle, we have this valve, which is called a tricuspid valve. I will discuss the function of the valve, but just remember that there is a valve which separates the right atrium and the right ventricle, and it is called the tricuspid valve because you can see there are three kinds of sharp edges, so it is called the tricuspid valve. What it does, basically, is control the flow of deoxygenated blood from the right atrium to the right ventricle.

In the same way on the left side, you can see that in the upper part of the left atrium and the bottom part of the left atrium, there is a separation of valves in between, which is the bicuspid valve. This also functions the same way. This controls the blood flow only from the left atrium to the left ventricle and prevents any upward backflow. So, as I said, there are two different valves: one is the bicuspid valve and the other is the tricuspid valve. So, the bicuspid valve is also called the mitral valve.

So, you can see there are two cusps: one is the upper part and one is the lower part. This is also called the mitral valve, and it is located between the left atrium and the left ventricle of the heart. And what is its function? It allows blood flow from the left atrium to the left ventricle in a controlled manner; it also prevents the backflow of blood from the ventricle to the atrial area. In between the right atrium and right ventricle, there is this tricuspid valve; you see, it has a three-cusp structure: one, two, and three. So this is called the tricuspid valve, and the function is the same; it prevents any blood flow from the right ventricle to the right atrial area and only allows blood flow from the atrium to the ventricle.

Then, as we said, the heart is a muscle, and the unit cells of the heart are called cardiomyocytes. So, the unit cell of the heart is called a cardiomyocyte. These are muscle cells which are present in our heart. Cardiac muscle cells are mostly elongated in nature and somewhat tubular like those of muscle. It is a basic unit of a cardiomyocyte called a sarcomere.

So, the basic unit of a cardiomyocyte is called a sarcomere, and it contains a lot of contractile proteins, such as actin and myosin. Apart from that, it also contains a lot of mitochondria, and these mitochondria help to produce ATP or energy because the heart continuously pumps, and that is why it requires a lot of energy; hence, the heart cells, or cardiomyocytes, have a lot of mitochondria, and this helps in terms of developing or making ATP or energy. There is also a network of tubules that is called the sarcoplasmic reticulum. The sarcoplasmic reticulum has calcium stored in it, and this is very helpful for proper muscle contraction function. So, in detail, we will discuss the muscle and its function, where we will discuss bones, joints, and muscle classes, plus just some brief information about cardiomyocytes and cardiomyocyte-related muscle cells present in the heart.

And you see some brief discussion we can also have about the arrangement of the cardiomyocyte, which is mostly like the sarcomere. So, the proteins in the cardiomyocytes are arranged in parallel bundles that include both thick filaments and thin filaments, and they are arranged in a parallel manner. And the sarcomere is defined as the segment between two Z lines. So, see, this is like a Z line; this is like a Z line, and this side is also another Z line. So, between the two Z lines, this is called the sarcomere.

And what is the Z-line? If you see an electron microscope, the z-line appears between two I-bands. So, basically in between the I-band, if you look in between the I-band, exactly in between the I-band, there is this Z-line that appears, right? And it looks like a dark line that anchors the actin myofilaments. Finally, the area that extends in both directions from any z line is called the I band. The I band is mostly the zone of the thin filament, so you can see that the I band has thin filaments and there is no presence of any thick filaments. Finally, there is an overlap area.

So, you see this A band area; there is an overlap area of the thick filament and the thin filament. So, this is called A band, and it looks mostly like a darker shade in complexity. So, in between two Z lines, the area is called a sarcomere, and then exactly in the middle of the I band, you

can observe the Z line. Just beside the Z line with the thin filament, we called it the I band, where the I band contains the thin filament and the thick filament, which is mostly present in between the sarcomeres, where they have an overlapping zone; that place is mostly called the A band. So, this is like a very general structure of cardiomyocyte cells.

Now, let us discuss some heart-related diseases. So, the first one is coronary artery disease. So, heart disease is very significant and challenging, and if someone is suffering from any of these related heart diseases, it can be life-threatening. So, the first one is coronary artery disease, which is a type of blood vessel disease. So, you see, if there is a healthy artery, there is enough space, and the blood is flowing in a proper manner, you see down here.

Due to lipid fat deposition or possibly thrombus formation, the blood artery can become narrower. So, in this case, you can see that there is maybe fat deposition, cholesterol deposition, and due to all these elemental depositions, the blood artery gets narrower. So, the blood artery gets narrower, and whenever there is a narrowing of a coronary artery, there is a high risk of pressure building inside the arteries, which can lead to a blood pressure buildup that can damage your blood vessels and arteries, potentially causing a stroke. So, this is a very serious type of disease called coronary artery disease. The next one is a congenital heart defect.

These are basically birth defect. So, the normal heart looks like this: a normal heart has the proper shape, thickness, and all. But if there is a birth defect, for example, it can be even a hole in the heart. There might be a gap, for example, like an arterial septal defect, where there is a gap between the arteries; there can also be a ventricular septal defect or ventricular gap, where there is an opening or gap between the ventricles. So, these are not normal situations, right? Even narrowing of the aorta can happen.

Like, maybe if you compare this regular aorta to a narrowed condition of the aorta, which can also be a congenital blood defect, this can significantly cause challenges in terms of proper blood flow. So, all these congenital birth defects can cause significant issues for the baby, and even when they grow into adults, they can be life-threatening and cause a lack of proper oxygen distribution to the body. The next disease is called cardiomyopathy; it is a disease of the heart muscle cells. So, cardiomyopathy, which is a heart muscle disease, is a condition in which the heart muscle either gets weakened, can also be stretched, or becomes stiff. So, in normal cases, the heart muscle should perform in a manner of contraction followed by relaxation.

But in case the heart muscle becomes too stiff or also weakened, the situation will be called cardiomyopathy, and in that case, proper contraction or proper relaxation of the heart muscle will not occur, which will significantly affect proper oxygen distribution and proper blood flow. Then there can be diseases related to blood vessels. So, you can see that a normal valve should have a proper opening, but in cases of a disease called stenosis, the narrowing of this blood valve occurs. So, a heart valve should have a proper opening in case of an open kind of condition, but even in an open condition, which is called stenosis, there would be narrowing of this heart valve. And if there is a narrowing of this heart valve, there would be a lot of issues related to proper blood flow, and there can be other diseases; for example, irregular heartbeat.

It can happen when either the heart beats too fast or too slow. Basically, the heart also needs to beat in a regular manner with a rhythmic and systematic kind of beat. In cases of being too fast or too slow, it may cause a lot of issues and significant challenges to our body. Now let us discuss the electrical potentials of the cardiac muscle because, as you know, the heart continuously pumps in a rhythmic manner, and the main function of the heart is to pump blood

to all the tissues and organs and also to accept deoxygenated blood from the lungs to return to the heart. So, the heart needs this electrical potential or electrical activity to perform its rhythmic beat and rhythmic function.

So, mostly it goes via the action potential, and as you can see, the duration of this action potential in cardiac muscle is about 250 to 350 milliseconds. So, it is very small, around 0.25 to 0.35 seconds for each beat or each electrical action of the heart muscles, and this action potential has four different phases. For example, the first step happens with an initial depolarization.

Followed by repolarization, there is a stage where a plateau or final depolarization occurs, and eventually, there is a fourth step, which is called final repolarization. So, we will see each of these stages one by one, and we will also discuss why these stages occur and what role some ion transporters play in causing these phases. So, the first step we mentioned is the initial depolarization. So, the initial depolarization is a very rapid step. It lasts only about 1 to 2 milliseconds, and the amplitude of the depolarization is also around plus 20 millivolts.

So, you can see in this plot that this is the initial depolarization phase, which lasts only about 2 milliseconds, but the amplitude becomes about plus 20 millivolts. Followed by this initial depolarization, there is an initial depolarization state where, immediately after the depolarization, a rapid depolarization occurs. The time for this depolarization is also very small; it is about 2 milliseconds, and then there is a notch, a representable notch, that kind of signals the end of the rapid depolarization. So, you can see from this that there is a notch-like formation, which signals that there is an end to the depolarization step. And after this initial depolarization, there is a plateau of final depolarization.

So, you can see there is a long plateau of final depolarization. And in this case, muscle fibers remain in a depolarized state for some time. And this is a very long step; it takes about 200 milliseconds in the arterial muscle fibers and about 200 to 300 milliseconds in the ventricular muscle fiber. So, it takes about 200 to 300 milliseconds to continue this plateau of the final depolarization stage, and once this happens, we will observe a final repolarization state, which takes about 50 to 80 milliseconds. So, the first step is the initial depolarization, followed by the initial repolarization, and then there would be a long plateau, which is a final depolarization state, and finally, we will see a final repolarization state.

So, together all these are called electrical potentials, which are nothing but the action potential of the heart. And let us see what the different ions are that are responsible. So, we will start with the first stage, which is the initial depolarization, right? So, we will start with the first step, which is the initial depolarization, and what happens here is that rapid sodium channel ions open. So, what will happen if the rapid sodium ion channel is open is that a lot of sodium ions will move inside, which will cause an increase in the potential. So, that is why you see that there is this plus 20 millivolt that the potential attains.

So, this stage is called initial depolarization, and it takes about 2 milliseconds to occur. After this initial depolarization, the next stage, which is called initial repolarization, involves the fast sodium channels closing. So what happened was the fast sodium channel got closed, but there are some slow sodium channels; maybe only one sodium ion will come per millisecond. In this case, maybe there were a few additional sodium ions coming per millisecond. So, these are rapid sodium ion channels and these are slow sodium ion channels.

So, in cases of the second stage, these rapid sodium channels will be closed, and slow sodium channels will open up. Along with that, there will be some efflux of the potassium ion channel. So, what will happen apart from the changes in the sodium channel is that there will be some efflux of the potassium ion channel. So, together what is happening is that only a few sodium ions are coming inside, and some more potassium ions are also going out. So, in that case, you will see that there will be a little bit of decrease in the potential, and this is called the repolarization step, where the potential, from about plus 20 millivolts, will go down to close to 0 millivolts.

So, this is the repolarization step, and in the third step, where there is a long plateau, you can see that there is a long plateau. In this case, a lot of calcium ion channels or the calcium ions get inside the cell. So, in the first stage, there was activity of the sodium channel in the second initial repolarization stage; maybe here you will see a lot of potassium influx happening, and then in the third stage, there are calcium ions that can come inside. So, after this initial repolarization, there is a plateau or final depolarization where the slow opening of calcium channels causes the movement of large calcium ions to influx inside. And in the final stages of the repolarization, there would be a lot of flux of potassium ions, and you can see that the voltage goes from about minus 30 to 40 millivolts down to minus 100 millivolts.

So, these are like steps by step. The action potential of the heart cell occurs in four different stages: initial depolarization, initial repolarization, the plateau of final depolarization, and final repolarization. So, this action potential, which actually happens, causes the electrical activity of the heart that creates this systemic rhythm of the heart's pumping or the heartbeat. Then let us discuss what a pacemaker is. A pacemaker is the structure of the heart from which the impulses for the heartbeat are produced. So, basically, the area of the heart from where the impulses of the heartbeats are generated is found by the pacemaker cells, which are also called P cells.

So, where these heartbeats are generated is also called pacemaker cells or P cells. This is mostly made up of one node, which is the sinoatrial node or SA node. So, basically, the pacemaker is made of the SA node, and what is the SA node you can see here. So, the sinoatrial node, or the SA node, is a small strip of modified cardiac muscle that is situated in the superior part of the lateral wall of the right atrium. So, this is like a small strip of cardiac muscle called the SA node, from which the electrical impulses are generally generated.

And why the SA node is called a pacemaker is because the rapid rate of impulse production is very high in cases of the SA node compared to other parts. It can produce almost 70 to 80 pulses per minute. You can see that the SA node can produce about 70 to 80 pulses per minute. Then, exactly below the SA node, you can see there is another node, which is called the AV node. So, you can see that behind the SA node, there is another node called the atrioventricular node, or AV node.

This is also called a gatekeeper between the atria and the ventricles, and it is located at the AV junction on the right side of the heart. The primary role of this node is to conduct the action potential from the atria to the ventricle. So, basically, the role of this AV node is to conduct the action potential from the atria to the ventricle. And as you can see how these pulses are generated, initially, as we said, the electrical pulses are generated in the SA node, which is also called the pacemaker, right? And then from this SA node, the pulses are moved to the AV node, okay. So, initially, the electrical pulse is generated in the SA node, and then from this SA node, the pulses are moved to the AV node.

Once these pulses are moved to the AV node, what the AV node does is move these pulses from the AV node to the bundle of His. So, where they move, they move the pulses from the AV node to the bundle of His area. And finally, from the bundle of his area, you can see there are a lot of small fibers which are called Purkinje fibers. So, eventually from the bundle of His, this impulse gets transmitted to different ventricular areas by the Purkinje fibers. So, this is mostly the way that the initial electrical pulse generated inside the SA node eventually moves to the AV node, then to the bundle of His, followed by the Purkinje fibers, and eventually spreads across the ventricular myocardium.

Hopefully, it is clear how the electrical activities occur in our heart. So, think about how heart valves ensure unidirectional blood flow, and how the heart adapts structurally and functionally to increase workload. Also, can you tell me what the primary causes of coronary artery disease are? Okay, so you can think about these questions, and if you have any further questions, please drop us an email with those questions. Also, you can discuss things during the live sessions. So, hopefully you enjoyed this class where we discussed the anatomy of the heart.

We also discussed different heart diseases, and with that, we briefly discussed the electrical activities of the heart. Hopefully, you enjoyed the class, and let us meet for another class of human physiology very soon. Thank you.