Bioelectricity
Prof. Mainak Das
Department of Biological Sciences and Bioengineering
Indian Institute of Technology, Kanpur

Lecture – 20

Welcome back to the lecture series in Bioelectricity. In the previous class, we talked about vision, and we talked about the retinal processing, the dark current rather the cones and I highlighted about the work of Marko Mayon where he has developed or by passed the whole retina or the eye and developed cameras interfacing with the brains. So, this whole area of neural prosthesis, where different kind of electronic intervention or where electronic tools have been used to interface with the brains; it all started with the hearing in the ears, it was not in the visual system. So, initial attempts were made where they were eight electrodes, where they are people who had the complete hearing loss and instead of their ears, it was all replaced by with the mike. You know the mike which is interfaced with the eight-probe electrode and which would convey the sound information to the brain.

So, today what we will do in this class, we will be talking about the basic architecture of the ear and the cells, which are responsible for translating the sound waves into electrical signals. So, in the previous class, we talked about the cells which are responsible for translating the light signals into electrical signals. So, it is basically the rods in the cones and we talked about the different cones with which are sensitivity towards different wavelength of light. So, here we will be talking about a series of cells within the cochlear or the inner ear which are sensitized different frequencies of sound. So, essentially what happens when the sound waves gets into the cochlear, based on the component what frequency, what amplitude, the sound waves kind of you know get divided or sensitized by different cell types. So, we will be talking about that whole architecture, cellular geometry, and in the case of prosthesis how it is being bypassed.

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So, let us start the lecture twenty with hearing and the anatomy of the ear. So, we are into lecture-twenty which is essentially hearing. So, for hearing, we have the ears, the anatomy of the ear that is what we are going to study and the function. It is very interesting, it has two functions one is of course, the hearing then it is another function function of equilibrium. In the sense, say for example, you are moving along the mountain you are moving up some people feels, the feeling of you know throwing away or throwing out or in a vomiting feeling, because when you move up like this or you kind of keep on looking like this or keep looking like this you feel uneasy. Because your face has to be parallel with the ground, when you look up like this after a point, you feel uneasy, because there is disequilibrium in your body.

And this disequilibrium is being sensed by a specific part of cochlear will be talking about that in very briefly though. And then we will be talking about within this functional systems will be about a specific cell types which in anatomy will be coming through function by something called hair cells.

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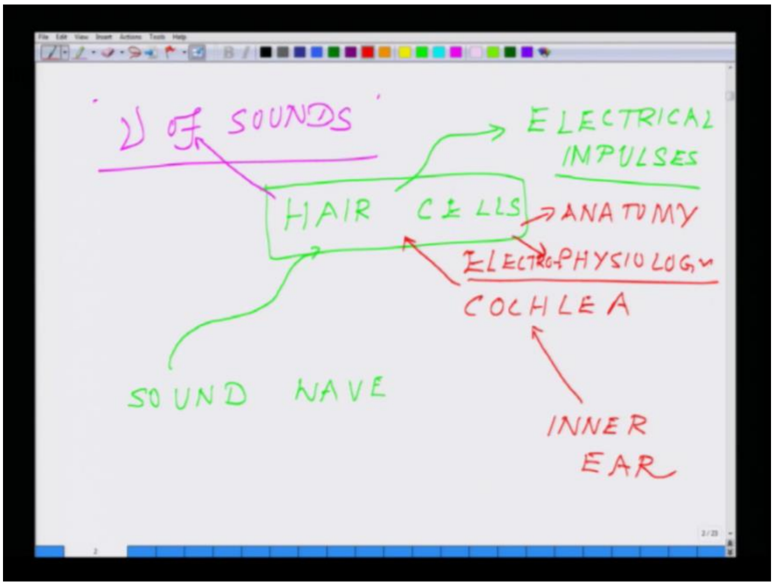

These are the cells, which cotes for let us go to the next slide. So, these are the hair cells which cotes for your sound wave to electrical signals or electrical impulses. And these hair cells are the once which constitute or they set inside their location is cochlea which is essentially the inner ear. So, the hair cells got sense different frequencies of sounds. So, this is the feature of the hair cells. So, we will be talking about hair cells anatomy and physiology or essentially electro physiology of these cells.

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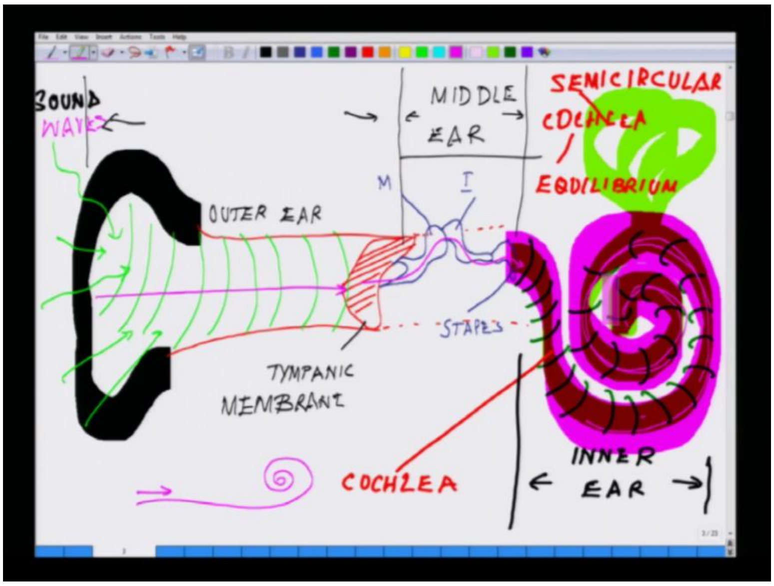

So, to start with let us explore the structure of the ear itself. The ear is something like this. Now the structure of the ear is something like this. So, this is the outer ear which consists of something called tympanic membrane like this, the membrane of a structure like this. So, the sound waves are coming like about right. So, here the sound waves are travelling. So, first they hit upon the tympanic membrane; after hitting upon the tympanic membrane, they had to interface, so this the outer ear. Now the sound waves move to the middle ear which consists of three different bones, the bones are kind of you know ranged like this mealiest, incrust and stapes. So, this is what is essentially this is bone one mealiest, incrust and this is stapes this constitute your middle ear.

So, after this you have the outer ear, now this is constitute the middle ear. After the middle ear, now from here starts the inner ear which is essentially, so from here it is a very interesting spiral structure like this which has a extension out here like this, network of channels like this. This is your inner ear and this is cochlear. And on top of cochlear, you have something called semi circular cannels; the upper part of the cochlear and the semi circular cannels are the once which are involved in the equilibrium and cochlea is the one which is involved all the sound deciphering the sound. So, basically the sound waves travels along this; and at different zones, it is being you know perceives at different level. So, this is essentially the overall architecture of the ear how it looks like.

Let us summarize. Here you have the sound waves travelling out here, hit upon the tympanic membrane, transmitted through this the vibration within this mealiest incrust stapes. Within the middle ear, those three middle ear bones, it reaches to the cochlear and this vibration now travels all along this spiral flute like structure. You must have seen those the kids have those you know they blow from here a structure like this you know the kids blows from here and it it flattens out. It is almost like a very similar structure like that. We do like this and that whole thing flattens out, and it again comes back to its original position. So, imagine cochlear is very similar structure like that looks like this.

Now from here what we will be doing we will moving on to now coming back to the next slide. Now what we will be doing is we will be talking about the structure of the cells, which are lining this out here, what is the structure of those. These cells are essentially called the hair cells like your corollary should be that when we talked about retina, we talked about the rods in the cones which are translating the light impulse into electrical impulse. Here we will be talking about the hair cells, which will be translating the sound signals into electrical signals, and all those hair cells are located all along this track out here. This is the track where the hair cells are sitting.

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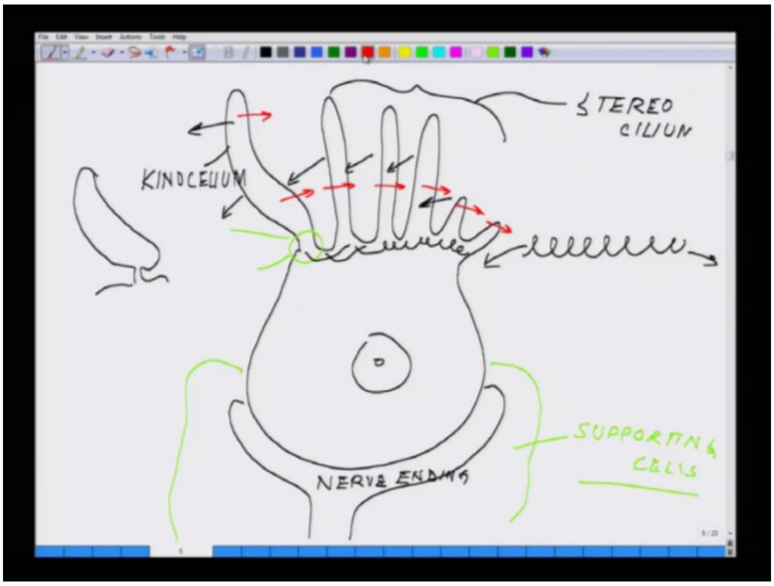

So, let us talk about the structure of the hair cells now. So, these are the stereo cilium and so these are the kino celium, and these are the stereo cilium, these are the nerve endings and just like the retinol pigment cell in the retina, these are sitting on a there is a lot of supporting cells which are there I am showing in green. So, these are the supporting cells. So, this is the overall structure. So, now most interesting feature out here are those interesting hair like structures, and that is why they got their name hair cells, and do not mistake them with your hair, they are totally different. So, those stereo cilia and kino cilia has a very interesting feature.

If you see the tip, if you if you kind of highlighted at this part of the structure, this is not that simple this is structure actually is something like this. It is a narrow something like this and depending on which direction the kino cilia is moving all the stereo cilium will move on the same directions. So, for example, if imagine, these are the hair or like I assumed that this is the kino cilia and these are the stereo cilia; if kino cilia moves bends like this, all of them will bend in this direction. And if the kino cilia bends in this direction, all of them will bend in other direction. It is just like they are all attached as if underneath, they are all kind of you know just like a spring they are all attached with each other like this or it is like kind of spring like a structure.

So, if you give a pull in this side, they all will move like this; and if you give a pull on that side they all will move in a reverse direction. Or in other word, actually what happens actually the pull has to be given only on the kino cilia. If you move the kino cilia like this or you can move the kino cilia in this direction, depending on which direction you are moving, the whole thing will move on to that specific direction. Based on the direction, it decides whether this is going to conduct electricity or conduct current or not. So, it is purely purely mechanical. If all of them will move in one direction, they will be on; and if they move other direction, they will be off; it is almost like this.

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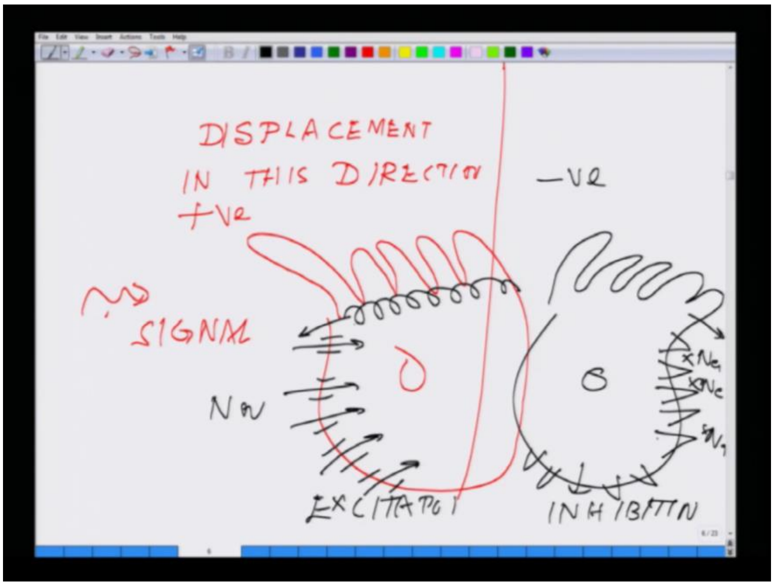

So, what we can essentially put on here this. So, what is essentially happening is that if you have to put in step then it will be displacement in this direction. Say for example, if all of them are moving like this, is positive or generates signal, and if the displacements are on other direction, say for example, something like this, this is negative signal or this is in inhibition and this is excitation. So, what is essentially is happening, now think of it, when they are bending in one direction like this, they are sending excitatory signals. It means when they bend in one direction as if, they are coupled with series of sodium channels then all the sodium channels open; and bend in other directions, all the sodium channels closes.

So, you can add one more component to this; if there is a molecular this is something like this, it is a spring which is pulling in this direction, this spring motion is ensuring the sodium channels to open. And the reverse direction, when they are moving in this direction, these ensures sodium channels are all closed, these are the closed state the triangle I am drawing the half triangle I am drawing. These are the no more sodium is unable to enter sodium is unable to enter. So, depending on the full of the string, they ensure that the sodium is entering or the sodium is exiting. So, this is a very very classic feature of these hair cells. These hair cells if you go back to this picture, all these hair cells are sitting out here likewise.

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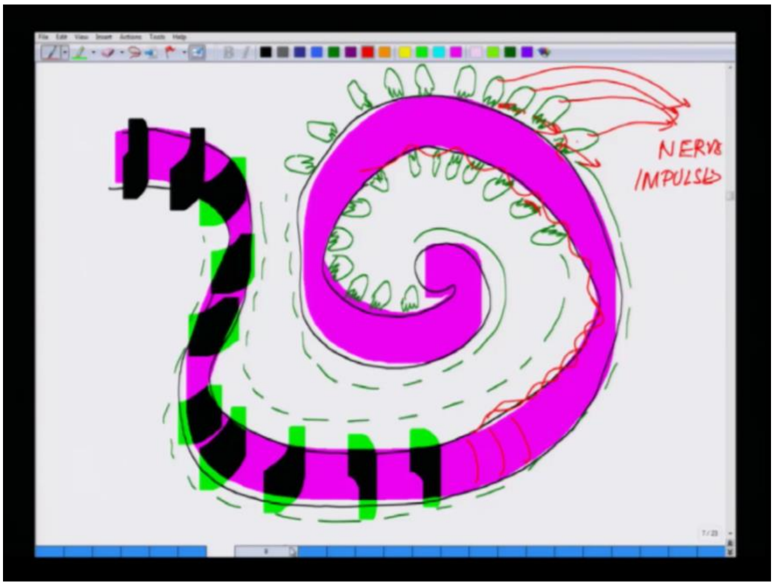

So, the weight the structure is, now I will come to the further micro structure of it. If this is now I will be only drawing the cochlear structure. So, if this is the cochlear structure think of it, I kept it simple. So, then the hair cells, so this is the membrane, the one side of membrane of the tube, and this is the other side of the tube. So, the hair cells are sitting something like this. So, these are the locations of the hair cells; these are the hair cells, where they are locating. First, I will draw it, and then explain exactly what it happens. So, likewise this is continuing all the way to this, and similarly all the way to this and of course, continuing all the way like this.

So, now when the sound wave enters, lets the sound wave is here, now the sound wave is entering like this. So, the sound wave is creating pressure on these walls, the sound wave is creating bulge on these walls something like this. And these bulge which is creating is deforming these cells, either in this direction or this direction or that direction whichever;

and this bulge which is creating deformation in this cells are sent as nerve impulses. So, sound wave is moving here; and along this tube, it is creating inflation like this. As it is creating inflation underneath you have the sensor cells or the hair cells, which are all sitting underneath it. As it is moving like this, it is creating those bulges and those bulges are deforming these hair cells, which are just sitting underneath that membrane.

So, essentially these hair cells are outside the cochlear, it is kind of they are lining the whole cochlear, but there is a thin membrane which is ensuring, there are not directly getting head. So, it is basically the bulging of the membrane like this, sound is moving and the bulging of membrane which is like this. Sound is moving, and it is bulging the membrane, and you have the hair cells like this, and based on that that movement the hair cells changes their shape. So, there on top the stereo cells move this direction or moves in the other direction.

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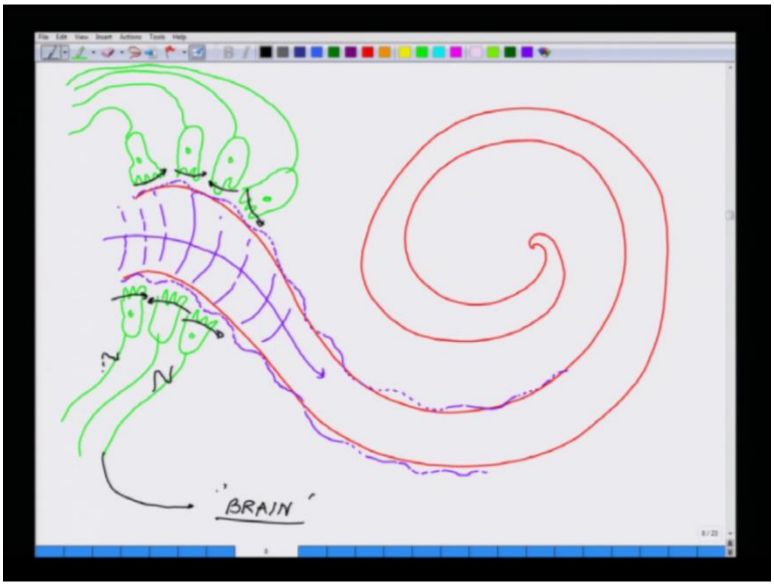

And that generates on, so I have to just slightly more cleaner picture out here. So, something like this, here is the tube, and here you have the deformities taking place within the tube. As the sound wave is moving through and on both the walls what I was trying to animate and show you this membrane is kind of you know changing its micro features with respective time and as sound wave is traveling. So, this is the sound wave which I am drawing now, and and here is a direction where it is moving and underneath you have under this membrane you have these cells which are sitting which are connected to the nerve on both sides. You have to realize that this is three-dimensional structure, and I am just drawing two dimension, and these are all collected with nerve endings like this, like this.

So, whatsoever bulging taking place, this is resulting in a motion of these either in this direction or this direction depending on which direction they all will be moving. And this movement is essentially generating a signal or not generating a signal depending on, and these impulses are all eventually reaching to the brain. This is the overall functioning just the way when we talked about rods in the cones, here the sodium channels are regulated by the mechanical motion of the stereos cilia and the stereos cidia in whatsoever direction they move depending on the direction, all of them will move, and that will either will open up all the sodium channels or will close them and will and not send any further signal.

So, this is how this whole architecture work, but there are few other features what which I wanted to add now on that on top of this. Some of the features what has to be added now is something to do with one more thing I have to tell you which is just slightly all the track coming back to this structure when I talked to you that it involves in equilibrium out here. It is one more feature let me added that and let me come back to the sound processing. What is happening in those cells.

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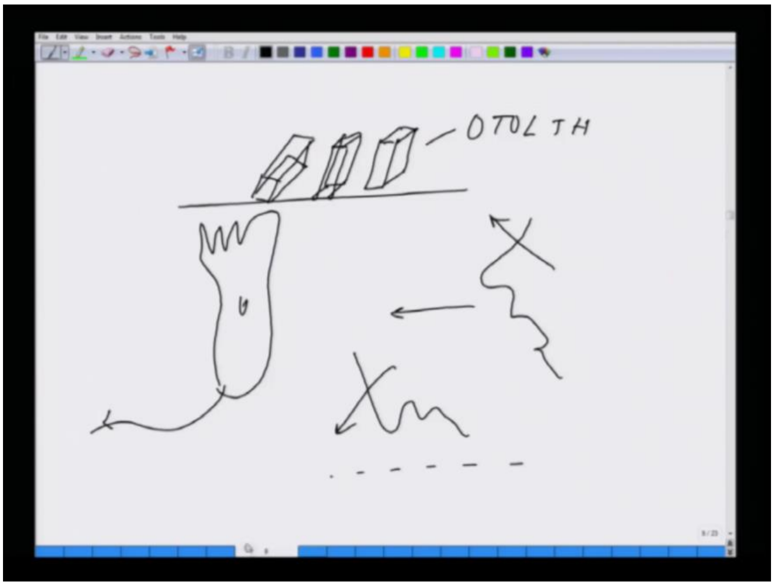

In those cells again they have their hair cells sitting like this, and there is a membrane on top of it; but out here, there are some wonderful three-dimensional cube like structure which are sitting there. This is all to do with equilibrium, and those are essentially called otolith, these otolith are gelatinous material depending on whether a person is looking up like this or a person is looking down like this or a person is an equilibrium like this depending with respective as a mouth or respect to the plane. These otolith all these small gelatinous matrix on top of these hair cells either become like this or become like this and these are of course, all connected to the brain and this is what regulates your equilibrium. So, whenever there is a ear damage or something, there are people who had problem in understanding in equilibration with respect to the body and the as a mouth and the plane were they are looking at.

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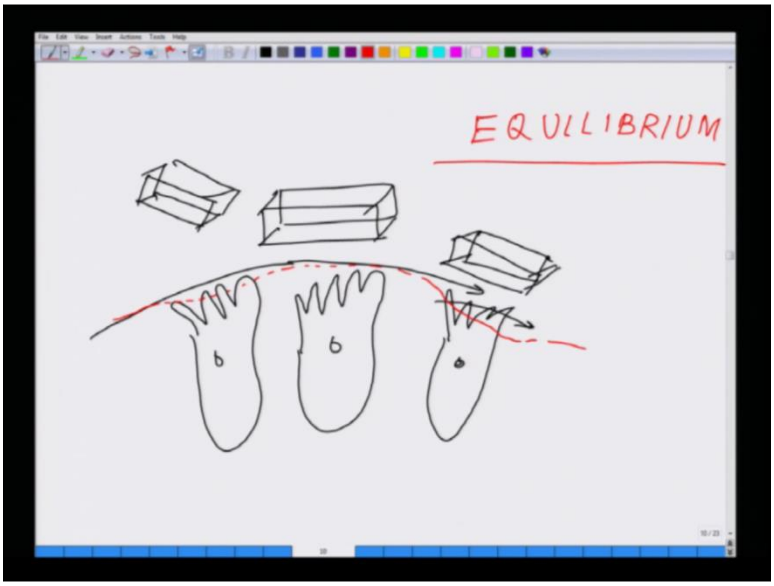

So, coming back, so this was ah little detour because for the sound thing because this is what I want to tell you this otolith is basically a gelelitineous matrix which is present on top of instead of the sound waves they are basically what you are having is complete matrix. And this matrix and these cubes actually the way this cubes moves say for example, if this a rectangular tube sitting here. So, if the person is looking down like this, they will create, they will attain a shape like this or and they may attain a shape like this and underneath this is the normal situation.

Now here you can understand these cells will be attending to move like this or these cells will be attending to move like this depending on the position of those small small nano cubes, which are present there. These all the general matrix will move like or move like this and that will create a different varying pressure on this membrane. And this pressure on this membrane is going to decide in which direction the kaino cilia or stereo cilia is going to move and that will ensures the corresponding electrical impulse which will be send to the brain which will ask the body to compensate according to the plane where we are standing. So, this is one small detour to tell you that ear also has the role in the equilibration with respect to the ground.

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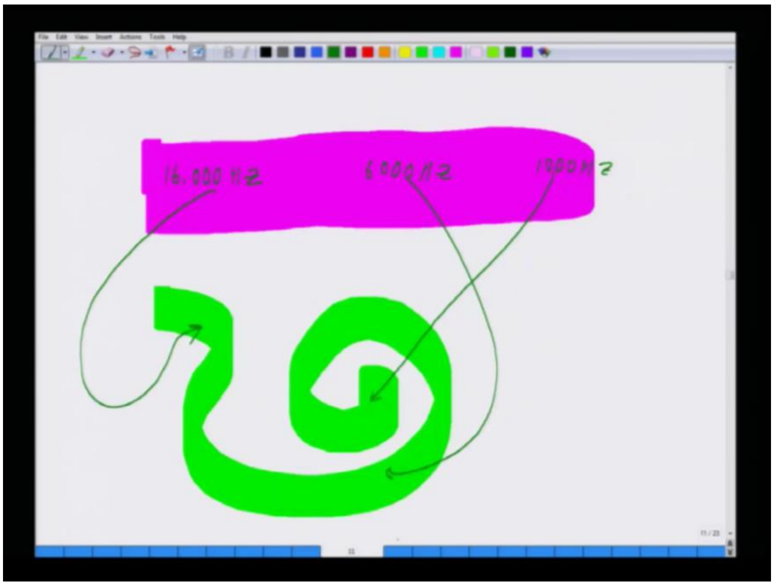

Now coming back to the next slide; in the next slide will be talking about some of the features, which are needed to be added out there about the cochlear. So, within the cochlear if you look at it. So, if this is the cochlear structure, this defies straightened it up instead you know instead of having spiral structure, if just demonstrate it a with respect like you know if I straightened up the whole semicircular structure. So, you will see in the beginning of it, it could sense all those a hair cells could sense signal of around very high sixteen thousand hertz; and in the center it could send signal around six thousand hertz and as you go up deep inside, it sends signal of thousand hertz. So, essentially what is happening here is something like this.

If you look at this structure, so out here you have the thousand hertz; out here, you have six thousand hertz; and out here, in the beginning, you have thousand hertz. So, as I was telling you it has a different kind of the different hair cells. Now if you go back into the ear cells structure where I was trying to draw the ear cells, so these ear cells which as just very similar to the to the cells of cones in the retina which could sense different wave length of light. It could be blue cone, it could be green cone, it could be red cone, the hair cells could sense the different hertz; it could sense sixteen thousand hertz, it could sense six thousand hertz, it could sense thousand hertz. So, they based on that their iron channels are coded.

So, there will be cells if there you see ten thousand hertz they are going to respond that many those iron channels are regulated to check kind of you know coded with which are mechanically regulated iron channels, so sodium channels will open. So you realize that how much improvisation biology has done in a simple process like hearing were this has a whole tube which has a very different kind of. So, if you look at it.

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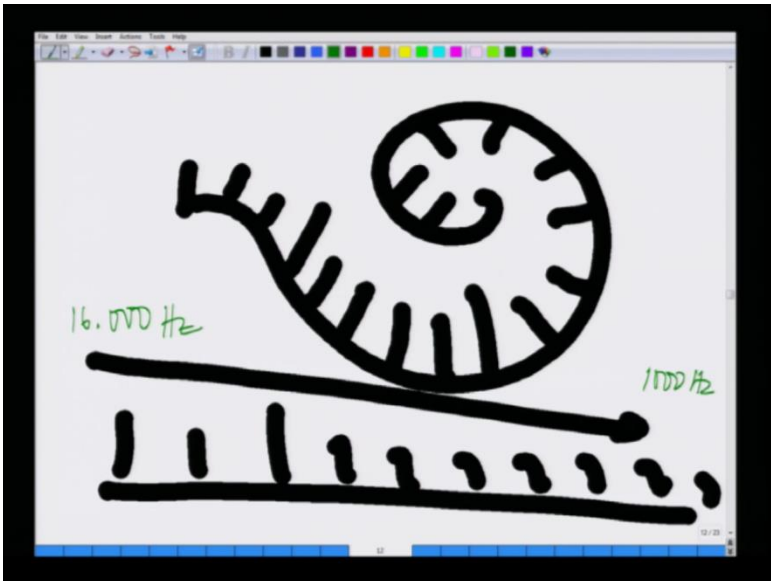

So, now in terms of the functionality if you have to look at the tube. So, this tube something like this. So, out here all those. So, you get really divided in terms of different parts. It is almost like you are seen those harmonica or harmonium something like that it is almost like the harmonium beats you can you can pretty much play it like you know different beats are going to come like this and it can go all the way say from sixteen thousand hertz still we know thousand hertz.

And an you can pretty much play it just like a harmonium board where you really can you know explore all these thing, and the nerve endings.

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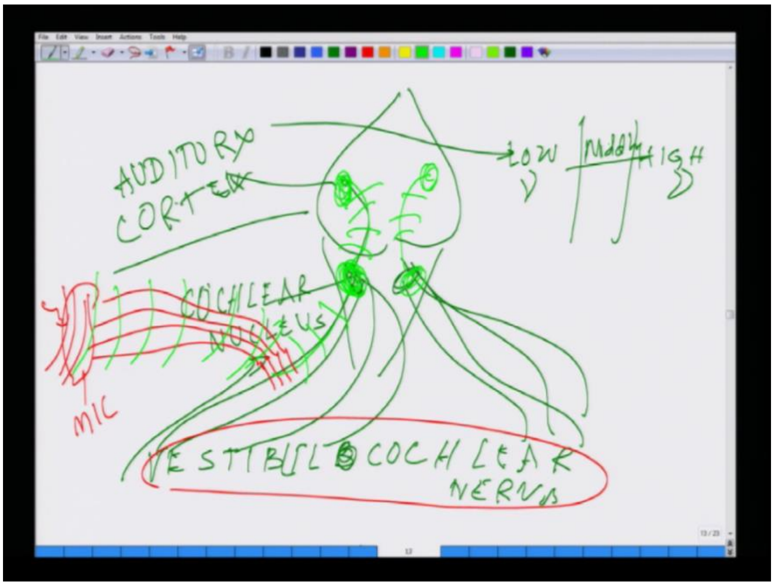

Which are kind of taking to the there is something within the brain called cochlear nucleus which is pretty much present in the somewhere half of the brain cochlear nucleus. In the cochlear nucleus, the signal is sent from the cochlear by a series of nerves called Vestibulo cochlear vestibulo cochlear nerves. So, depending on whether it is coming from the high frequency sound or the low frequency sound this vestibulo. So, there is specific high frequency and low frequency coding nerves which are coming from both the ears and being sent to the auditory cortex from here, it reaches the auditory cortex out in the brain where the further processing takes place. And within the auditory cortex also there are zones which are for the high frequency and the low frequency

There are the different areas within the brains within the auditory cortex. Where you have especially it is in the temper of low actually where you have the low frequency sounds are coded different at the different part of the brain within the auditory cortex of course, in the medium frequency hours process another part of the brain. And the high frequency are coded another part of that and they are very close to each other, but ant they are in that automatically distance zones within the auditory cortex

So, now, think of a situation which we were we actually. So, let us coming back to the overall structures. So, if somebody this structure is has gone wrong this person is not receiving any further signal from the sound waves are not reaching the brain.

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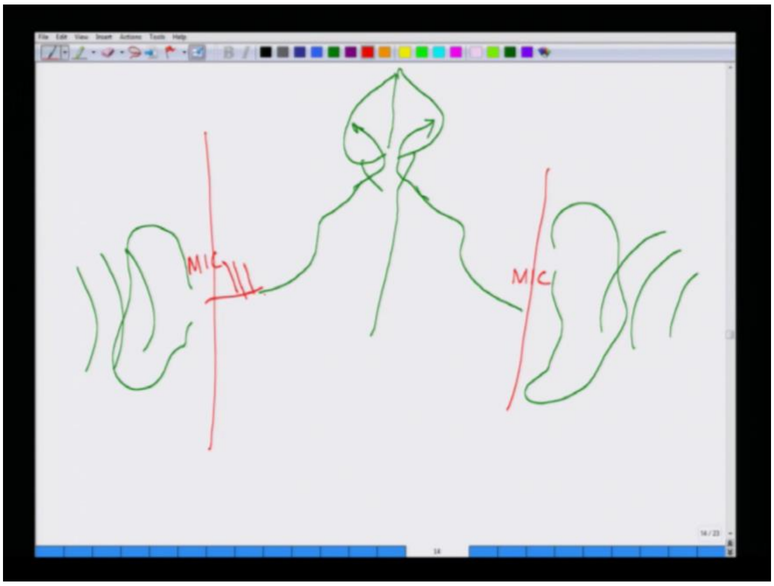

So, here you have the ear and sounds waves are coming, but but some were other signal is not reaching the brain x y z region technically it is suppose to reach like this which is not happening. So, one of the option is that

You replace the ear with a say a mic and you interface these electrodes to the vestibulo cochlear nerves which I have just talked in the previous slide you see this vestibulo cochlear nerves. So, you implant the electrodes like this and this is connected to a ear mic. So, what is. So, ever sound information are coming like this are travelling all along and from here there will be reaching the cochlear nucleus from the cochlear nucleus they will be reaching the auditory cortex.

Of course, assuming that you know the auditory cortex and the vestibule cochlear nerves and the cochlear nucleus is all functioning right. So, the whole area of neural engineering or neural prosthesis actually has its origin in the cochlear implants were basically once second were essentially the cochlear was damaged and that to replace it with some hearing device with during interfacing with eight electrode pro to the vestibulo cochlear nerves. And the message was been sent to the cochlear nucleus from the cochlear nucleus depending on the coding with this high frequency are sound or low frequency are sound or medium frequencies are sound this coded by the different regions by the brain. So, this is where it originated and now it has moved all the way into the visual cortex were basically rectal processes taking place

So, this gives you an overall idea about the different celtiles in the ear in the eyes which are which helps in processing next. In the next class, what we will be doing will be talking about the celtiles present in the all faction in the nose which is well very developed insects which I will give you certain examples in the case of insects. And will be talking about the tongue you know what we taste the gustated euroceptors. So, and the electrical signals which are travelling through this. So, I will closing here. So, in the next class will be talking about these two senses and that will pretty much covered most of our special senses which helps us in all our survival modes.

Thank you.