Neural Science for Engineers
Prof. Vikas V
Department of Electronics and Communication Engineering
National Institute of Mental Health and Neurosciences (NIMHANS)
Indian Institute of Science, Bengaluru

Lecture - 40
Human auditory system - I

So, after we have completed vision, we proceed on to hearing which is another important sensory modality. A lot of data which we take from the environment is either through sound or through vision which we have covered earlier. So, the analysis of sound forms the basis of this class. Lot of it is based upon wave theory.

We will look into it in a lot more detail and some very interesting concepts I would like to put forth in this class. Teaching in this course has been a great opportunity for me not just to convey thoughts on medical topics to this very nice audience which I hope will respond positively.

But it has also been a platform in which I put forth ideas which have always been there in the biological textbooks but have never been conveyed to the engineering audience. Now, a recurrent theme which I have used in this course is the idea of conveying the information in the biological realm to something which becomes a little more palatable for engineering students, faculty, teachers, and whoever is viewing this.

So, as I told you the treatment that way differs. So, when I talked about action potentials in my introductory classes, I use the concepts of how very important engineering concepts may have a biological equivalent. One of the important concepts which I dealt there was the idea of how biological systems do equivalence of binary processing?

How biological systems have analog processing? How biological systems work between and with analog systems and binary systems side by side? How mechanisms are there for translation of analog to binary to analog back again? And how they are all seamlessly connected and integrated within the system?

So, there are similar concepts when it comes to hearing. Hearing is again a very complex entity. So, hearing again is based on analysis of waves, a lot of my wave theory I owe it

to my teacher from 30 years back, Gururaj sir to who taught me the fundamentals of wave analysis and what actually is meant by waves.

So, sound is a form of wave transmitted in air and through material media and biological systems are liquid systems, you know you have got ions, you have got water, you have got electricity which is ionic. So, for some media which is you know basically air based, you know to be transmitted, processed in a liquid-based medium is something which I would like to share with you in this topic on hearing.

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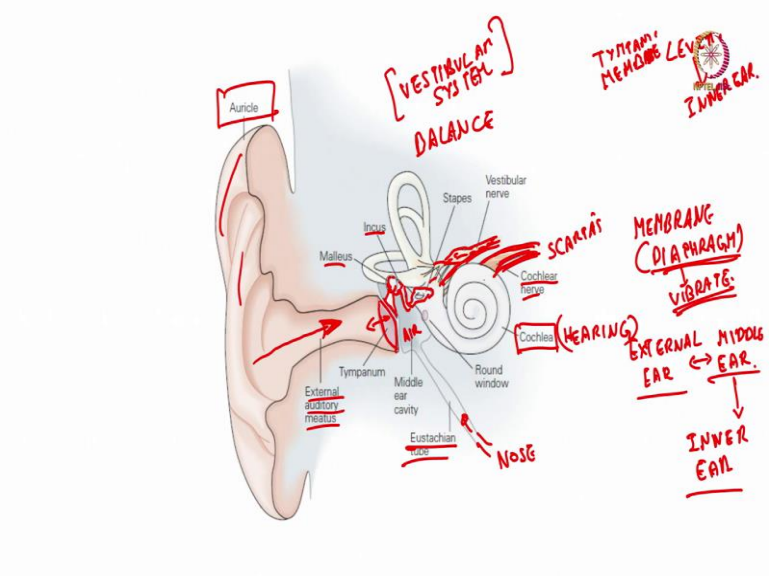

So, we will start with some basics as usual. So, how sound is captured and how it is processed and then we will go a little more into how sound is processed and interpreted in the human ear, head and in the brain. So, some essentials are necessary for which reason I have included. So, auricle is the technical term of your ear.

So, the ear basically is like a trumpet, it captures a sound, the exact design of this, you know big helix, the minor helices and why it is there is not very obvious, with some optimized mechanism over several millions of years which is designed to ensure that the sound is channeled effectively into something called as the external ear canal.

So, external ear canal also indicates that there is an internal ear canal which we will come to sometime later. Now, the first point of contact of sound is the tympanic membrane which is membrane as in diaphragm so which can vibrate. So, the tympanic

membrane sort of closes, it connects between the external ear and the middle ear. So, you have an external ear and then you have a middle ear, the middle ear goes into the inner ear.

So, three parts, external, the middle and the inner ear. External ear is the air facing side of the story, where it is in contact with air. Middle ear cavity incidentally is also air based. So, that is the middle ear, and it is connected part of the nose through the eustachian tube.

And you might have heard diseases which you know you got blocked ears, when you ascend up in a flight or climb a mountain you have the sensation of block. That is because the vibration is decreased because the diaphragm gets the; so the pressure is altered between the middle ear and the external ear.

When you swallow you restore pressure through the eustachian tube and that is how you get back your hearing when you ascended a particular height. So, that is the mechanism. So, I needed to relate pressure dynamics with air with hearing and how it is important that the diaphragm vibrates free of any impedance within due to the changes in air.

You have diseases which replace the air and that causes hearing loss, but we are not here to discuss hearing loss. Now, the tympanic membrane is in turn connected to a set of bony it is a bony system. So, the first set of the bone is called as the malleus, then that goes into something called as the incus which is over here. So, that is the incus and then you have something which is called as the stapes, this is a part of the middle ear.

So, these bones exist within the middle ear, they are basically levers. So, levers which connect the tympanic membrane to the inner ear. So, the inner ear is all this beautiful structure over here, it is one of the most beautiful anatomical structures present within the human body.

Inner ear consists of a spiral structure called as the cochlea which is for hearing, and it is very clearly very closely connected with this structure over here. These round structures which are over here and this structure over here and that is related to balance.

And that is called as the vestibular system, to jog your memory a bit, we use the vestibular system in our discussion on control of eye moments, because the vestibular

ocular reflects is based upon stimulus which comes from the vestibular apparatus and then goes into the eye to control the eye movement, when the head is moving.

So, for the current time, for the time being we will be discussing the ear which basically starts from somewhere over here and the cochlea which is over here. So, the cochlea in turn the center of the spiral gives rise to the cochlear nerve, which is over here which comes from this the center of the, it is a conch shape.

So, the center of this conch has this space from which the nerve comes out and then you have this nucleus called Scarpa's ganglion which is in the center over here, it is on the other side. So, that is why I am not drawing on the surface of this thing.

And the vestibular nuclear, vestibular nerve in turn comes out from the other side. So, that is the arrangement of stuff within the ear. It is one of the most compact structures which are present as I told you with a beautiful anatomy. The picture; however, well drawn does not do any kind of justice to the beauty and complexity.

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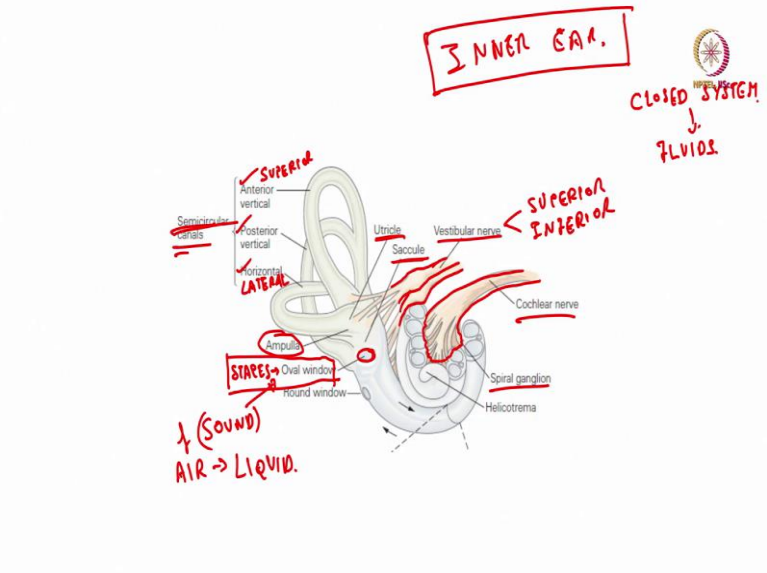

So, this is a cut section, and the cut section is important to have a better idea. We start the discussion here of the inner ear. So, we started with the outer ear, middle ear and the inner ear. So, we start with something which is known, so, this is something called as the oval window.

So, the oval window is where the footplate of the stapes, stapes is the bone which is connected over here. So, tympanic membrane goes on to these bones and then it goes on to the oval window and this is a closed system.

So, the whole inner ear is a closed system. So, closed system containing various fluids. So, the fluids will come to it in a greater detail. Now, I would like you to check note that this is the cut section of the spiral; sorry, what is it? Cochlea. So, this is the cut section of the cochlea; cochlea shown as a spiral over here, we have cut the cochlea and you can see the spirals over here, this is the topmost spiral, in the central space is this scarpa's spiral ganglion over here.

So, this is the area of the spiral ganglion and that gives rise to the cochlear nerve. So, utricle and saccule are parts of the vestibular apparatus and with the semicircular canal. So, these are parts of the vestibular apparatus. Semicircular canals, utricle and the saccule. So, all of these communicate in something called as the ampulla which is sort of a meeting place between these various structures, the semicircular canals, there is one anterior, posterior, horizontal or lateral.

So, superior, posterior and lateral. Anterior is also called called superior, that is highest, horizontal is also called lateral if you remember my discussion on medical terminal, lateral is away from the center. So, that is the idea. So, these are the parts of the inner ear. Nerves so, you have a cochlear nerve, a vestibular nerve which in turn has superior and inferior.

So, these are the vestibular nerves. So, two vestibular nerves which convey information regarding something else, it conveys information regarding position. So, we will be discussing that later. So, this is in brief, relevant parts of the structure, which is necessary for further discussion.

So, the communication, where air to liquid you know the transition between air to liquid for sound. So, the this is done at this place. So, you need to transfer the sound from an air medium into a liquid medium and that is what is happening over here.

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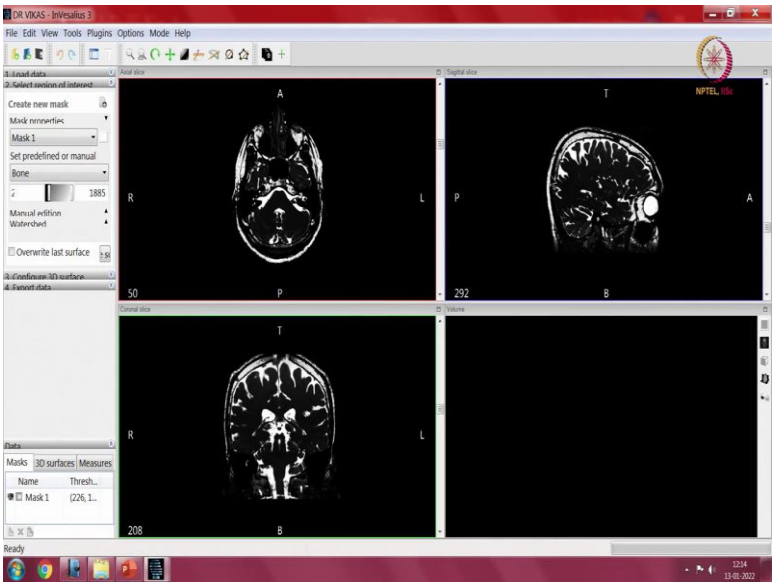

So, it is important to understand things in context and that is the reason I thought it is necessary to see these things how they look.

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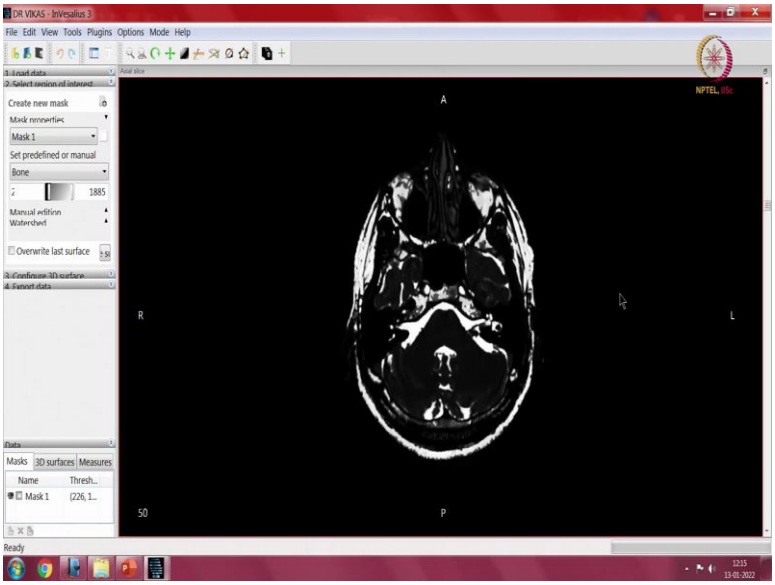

We have already discussed how to interpret MR images.

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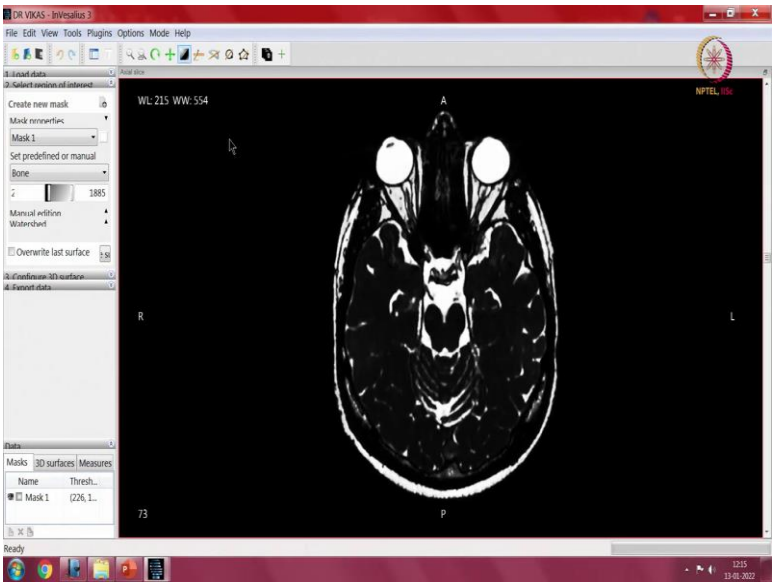

So, this is a CISS image and yeah.

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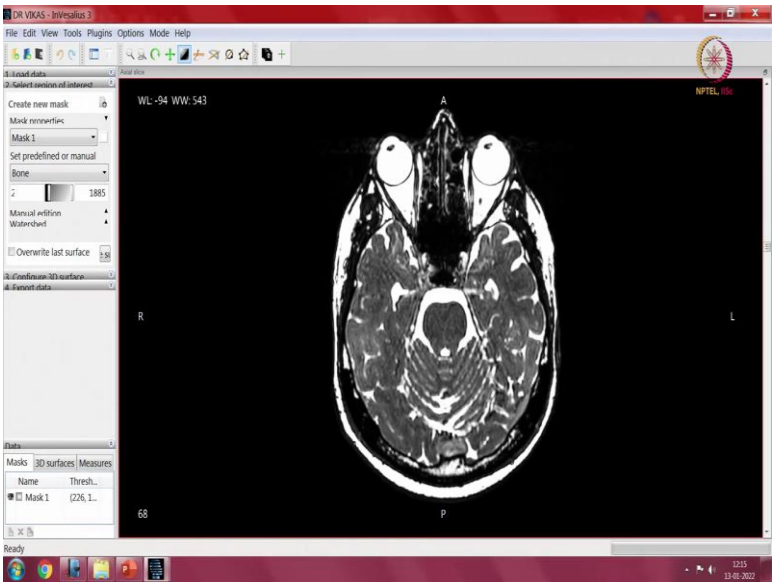

So, I have used this imaging because some of you may be interested in knowing how these things look actually within the body or more than how they look within the body I would want you to appreciate how what is the size you know and size is important in this thing.

So, here we start with something known. So, eyeball and this is an axial section of the brain and the skull. I use this particular thing because it is easier to make out some features within the bone.

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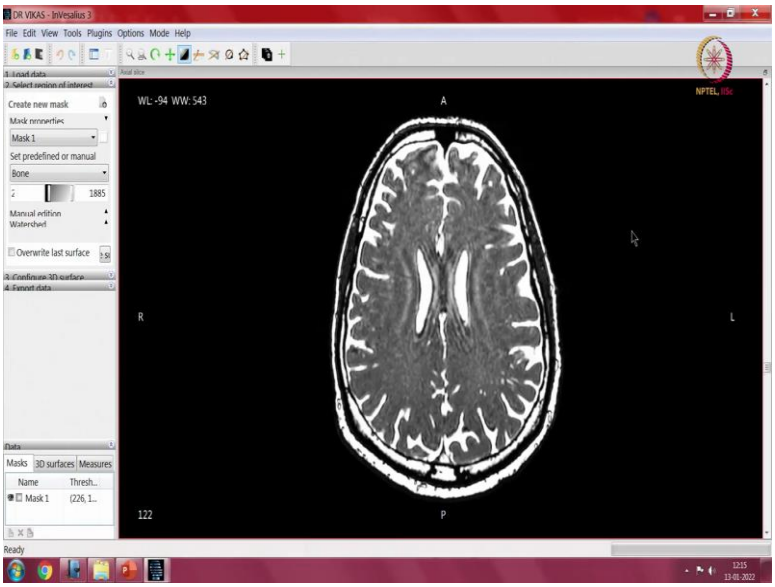

The entire ear apparatus is situated within the temporal bone. Temporal bone is the place where your ear is connected to the body.

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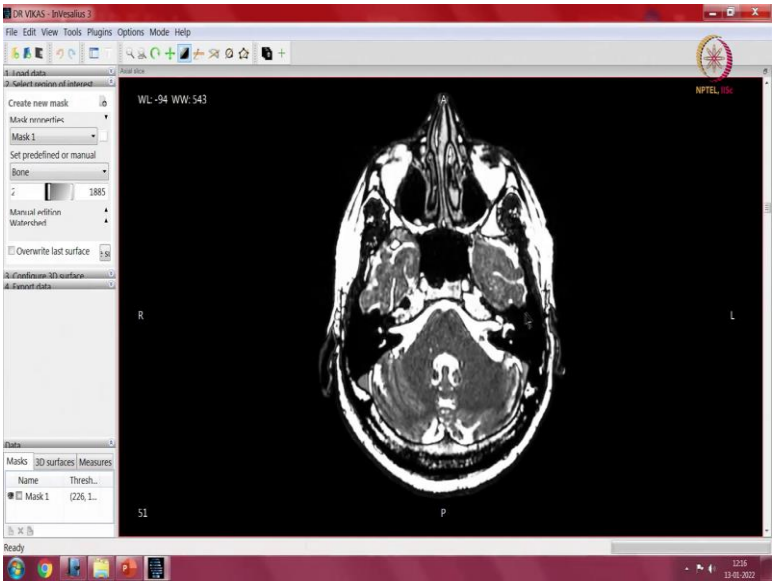

So, this whole stuff is the temporal bone. If you notice here this is the ear canal, ear which is here and somewhere here is.

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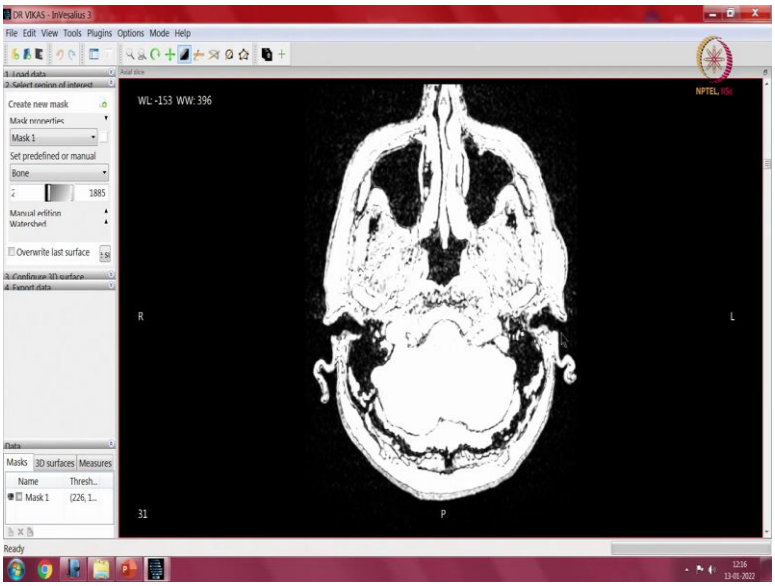

So, this is the ear canal. So, ear canal I did want you to have a sense of one position, another is relative sizes.

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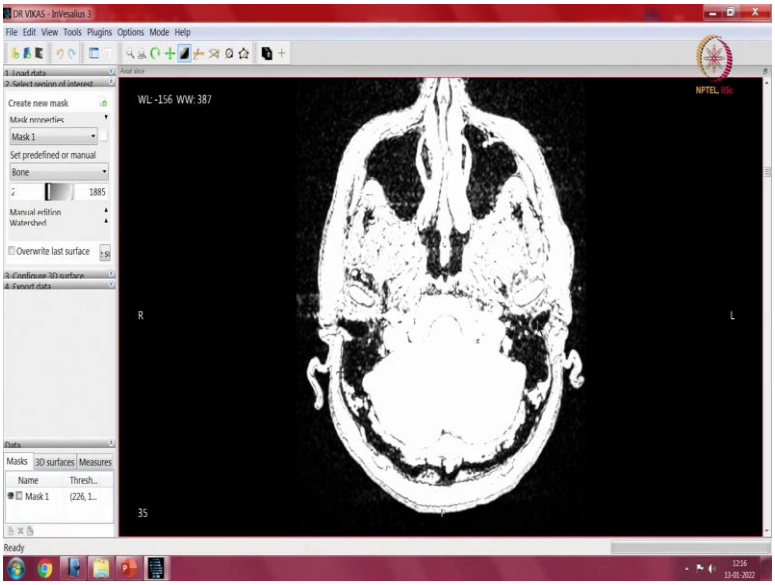

So, this is the place where this is a tympanic membrane over here. One tympanic membrane, the other tympanic membrane is a bit more difficult yeah.

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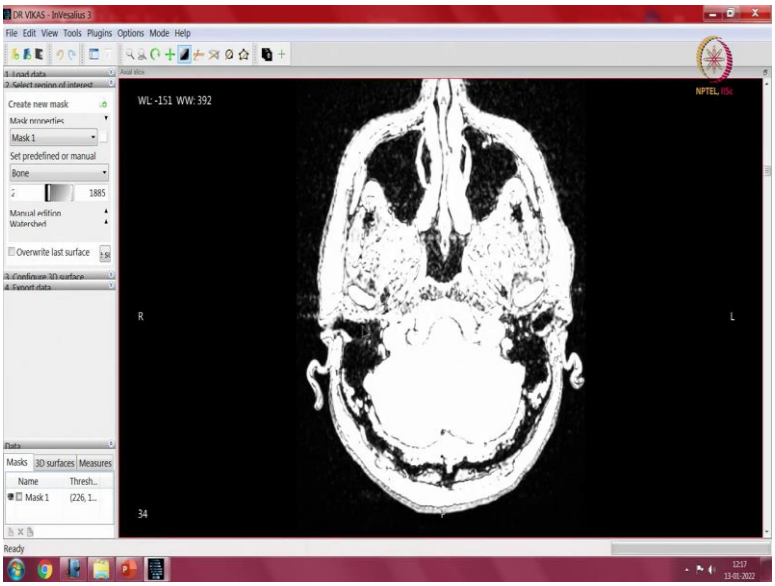

So, here it is here it is. So, tympanic membrane, remember this is not in the same axial section for which reason I cannot show all the things in one single section.

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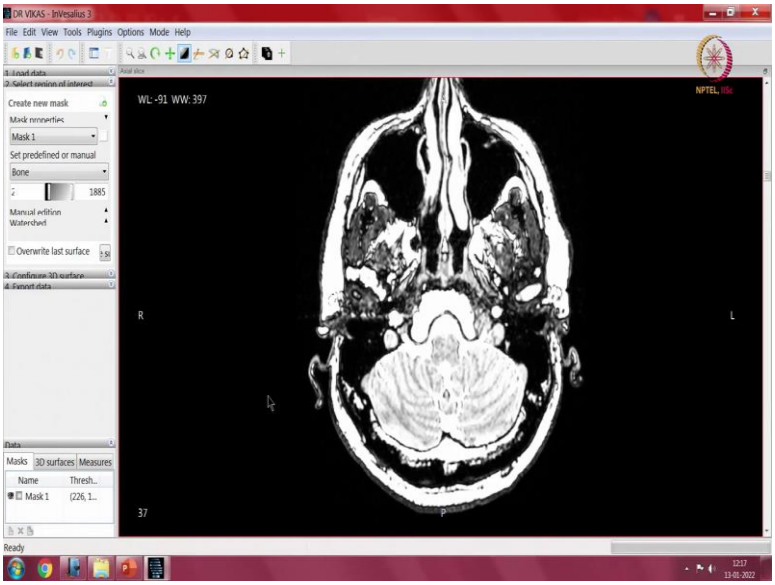

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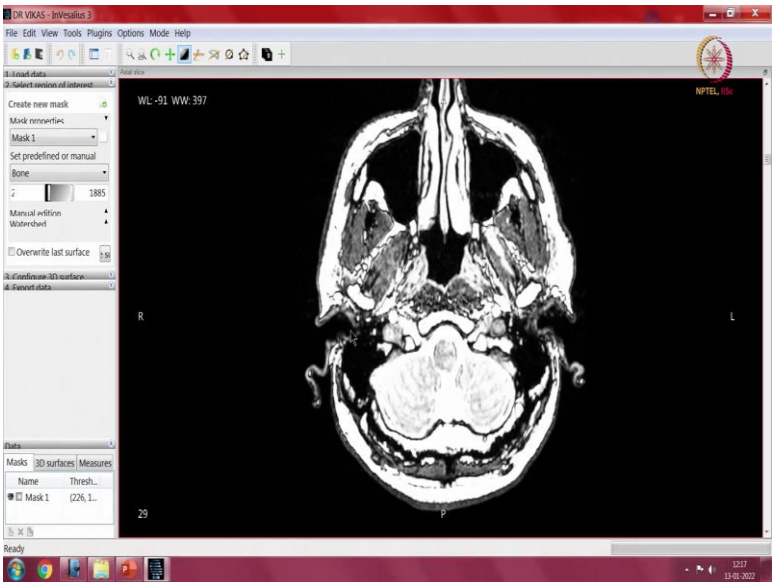

And so, we show the external ear canal over here.

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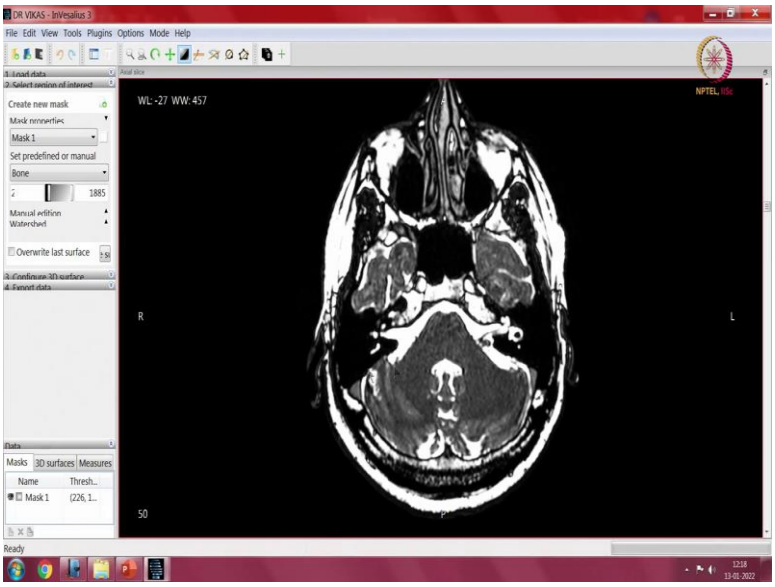

Now, what happens inside is this is the other internal acoustic meatus. So, that is the technical way of telling internal ear tube.

So, this is the external, is the outside. This is the internal and you can see a thread like thing over here, which is the combination of the 8th nerve; 8th nerve which in turn consists of the cochlear nerve and the vestibular nerves. So, two vestibular nerves and one cochlear nerve seen over here.

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And also, if you remember my discussion on cranial nerves the 7th nerve which is the nerve which is controlling facial musculature goes through this exact place.

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Now, once that we have done that part of it, we will expand the view a bit. We are somewhere in the region of the pons. So, this is the pons, and this is the 7th 8th complex, 7th 8th nerve complex at the end of it, you know this structure is the cochlear.

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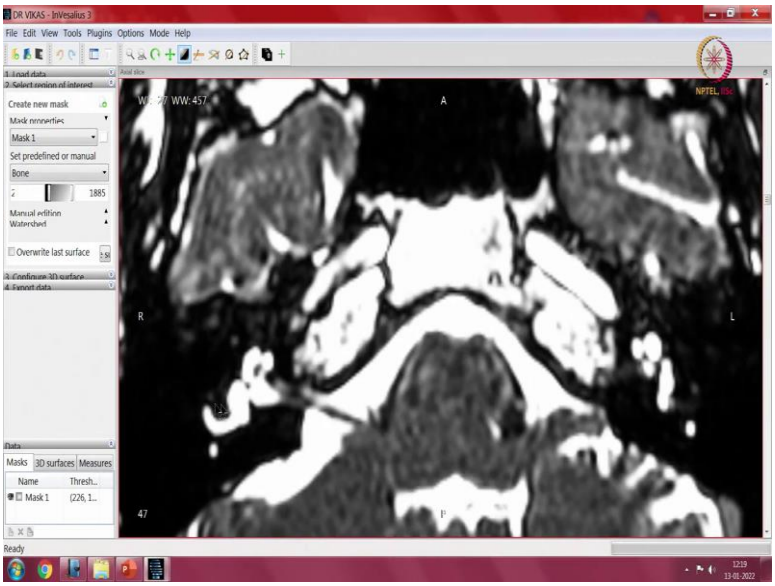

So, this is how the cochlear looks like. So, this is how the cochlear actually looks like, it is an MR imaging. So, and if you remember resolutions are not as good as they need to be.

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So, cochlear on one side, cochlear on the other side.

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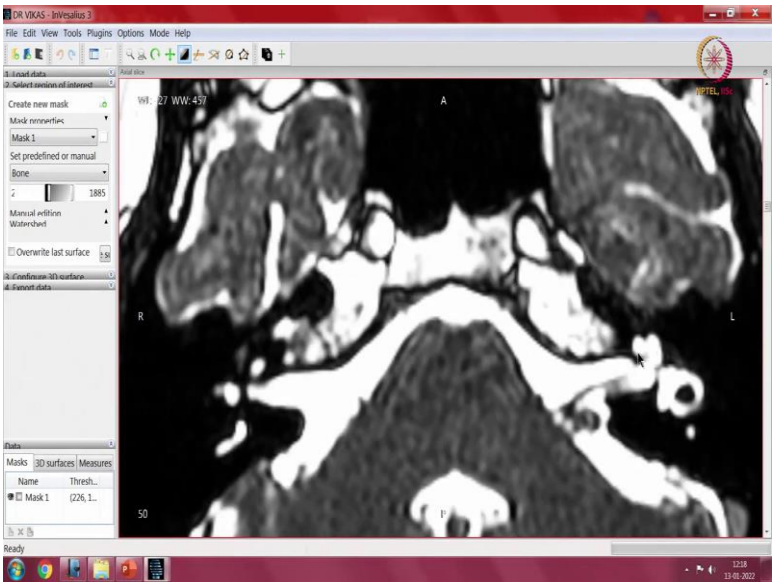

This is the cochlear on the other side, this is the cochlear on the other side.

So, lateral; lateral is away from the center, you can see this whole thing. So, this is the lateral semicircular canal lateral semicircular canal, lateral semicircular canal. So, this is the lateral semicircular canal.

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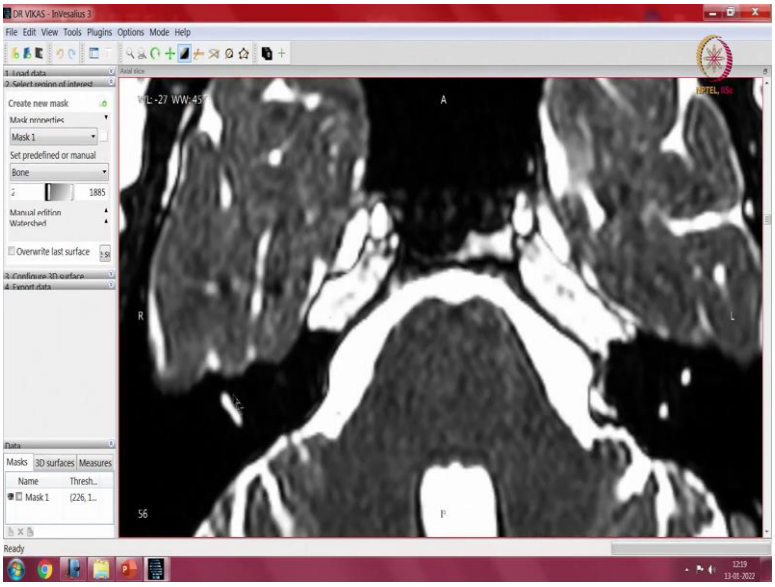

Now, you notice this structure over here.

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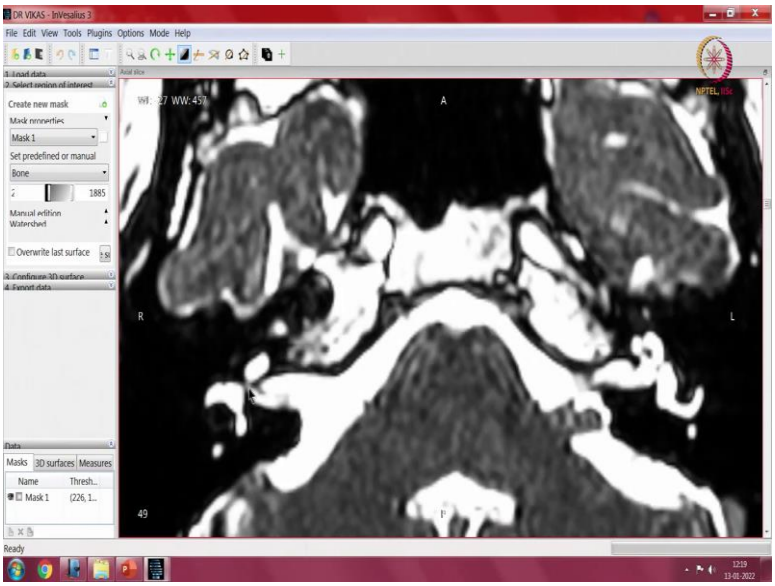

It is going splitting into two joining with this apparatus over here.

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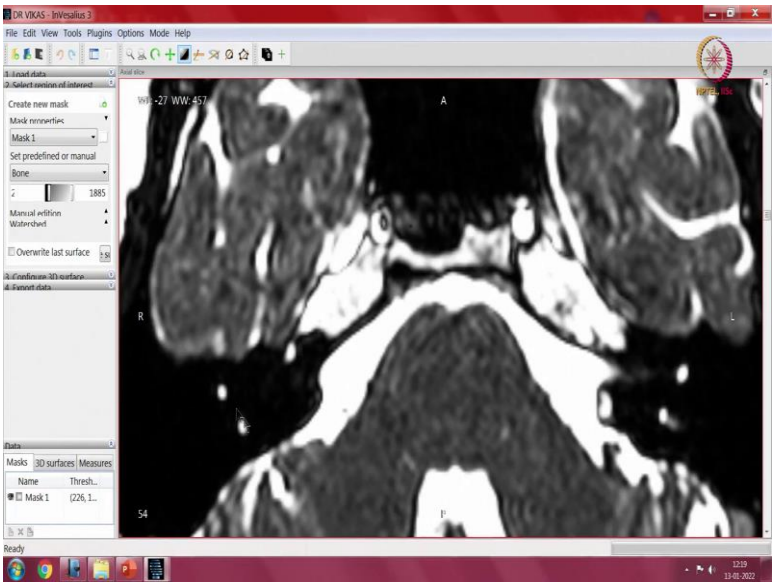

So, that is this superior semicircular canal. So, superior semicircular canal starts from here.

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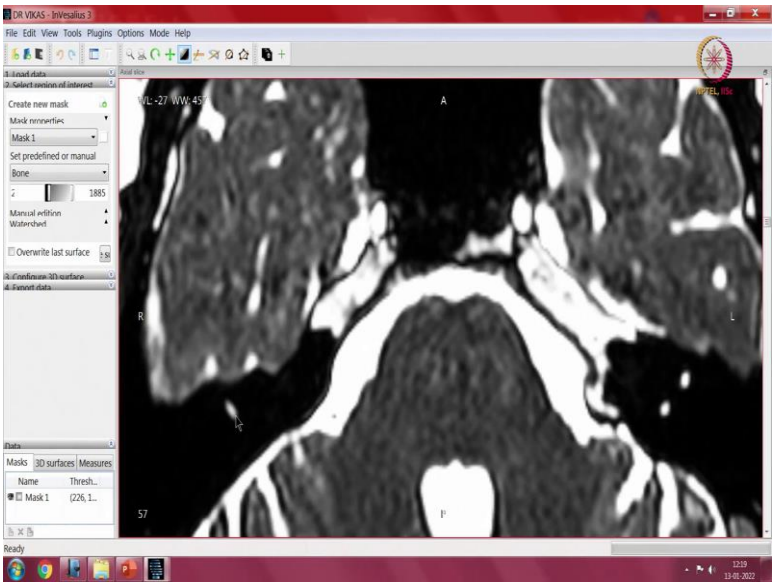

So, you can make out the upper part of the ring, it splits into two, the ring splits into two and joins back over here.

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This is the lateral semicircular canal and coming up is the superior semicircular canal. Next one is the posterior semicircular canal. So, where do we find the posterior is here. So, the posterior semicircular canal is here, joining back here to the superior canal.

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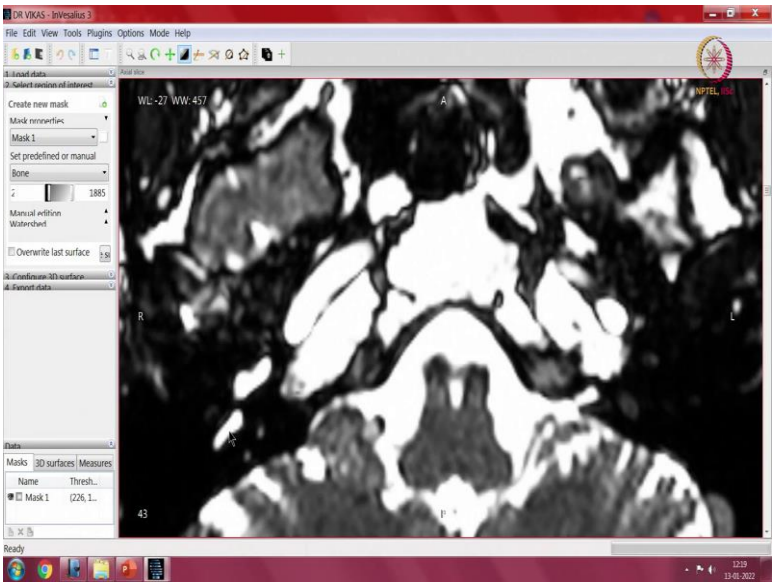

So, the three semicircular canals the cochlea over here and the vestibular cochlear nerves coming over here. So, that is how these things look like in real terms.

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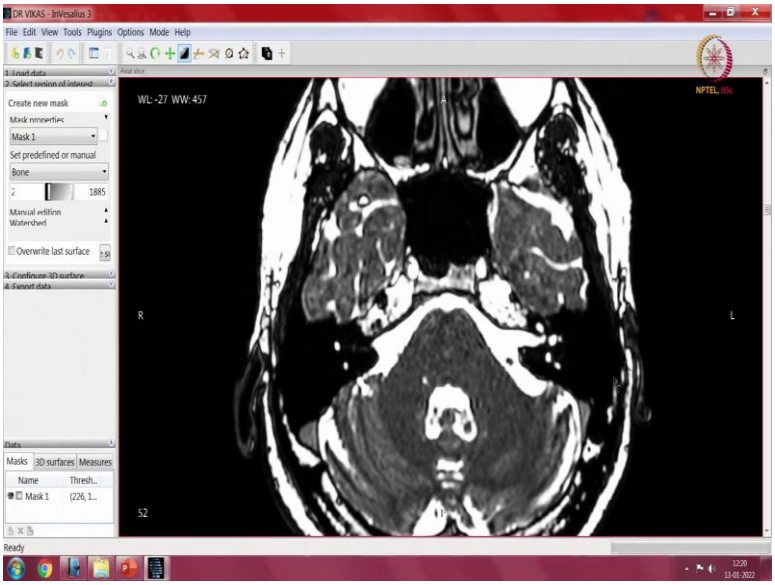

And this is whole complex is situated within the petrous bone, what was shown in the diagram is the 3D.

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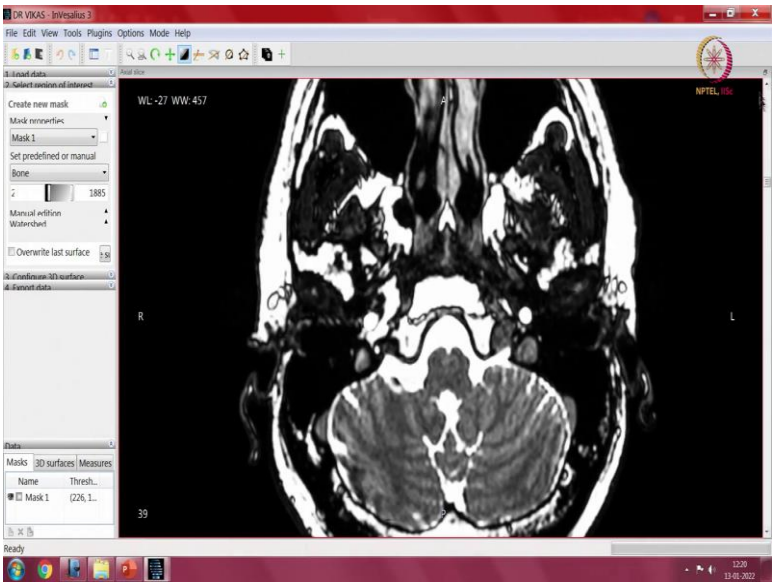

This is in this is in actual brain imaging, that I am showing this stuff.

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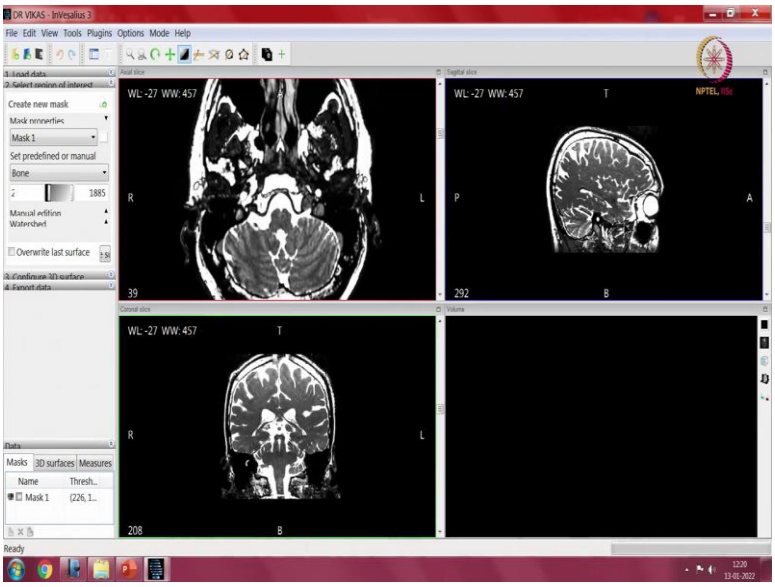

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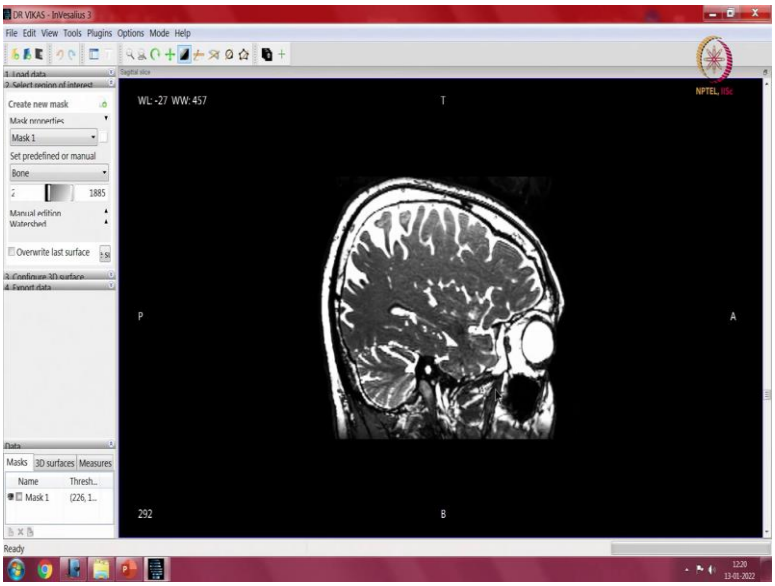

So, let us look at a different viewpoint. So, that what was the axial images, remember that axial images. Coronal and sagittal images are the ways in which you get imaging for viewing and this is a this is sagittal image.

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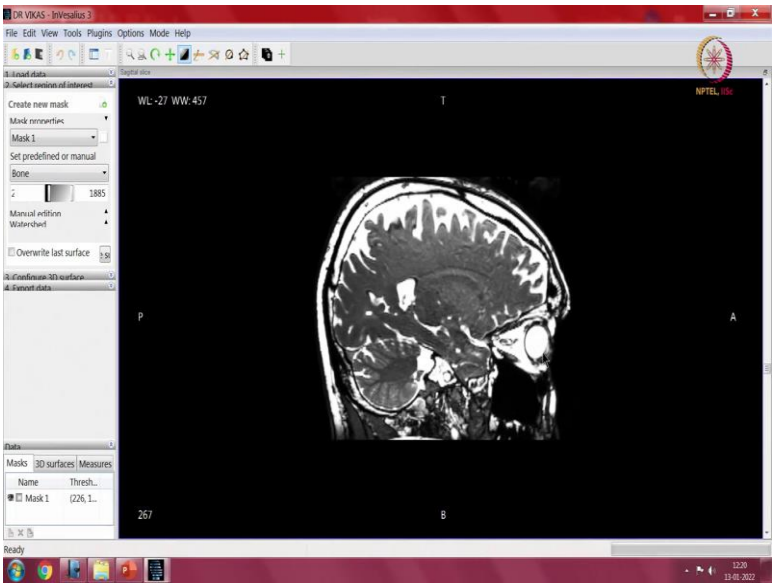

So, sagittal image eyeball of one side, optic nerve over here and let us see if we can make some sense of this parts yeah.

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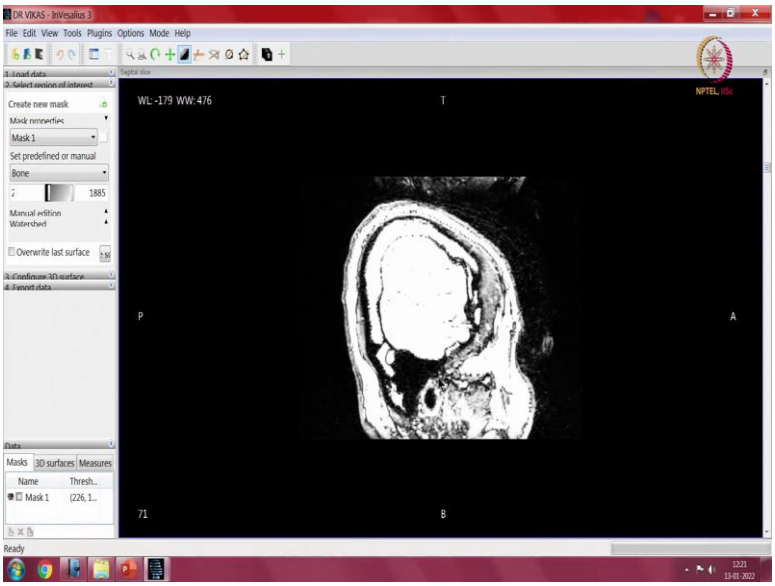

So, yeah so this should be the external auditory canal yes.

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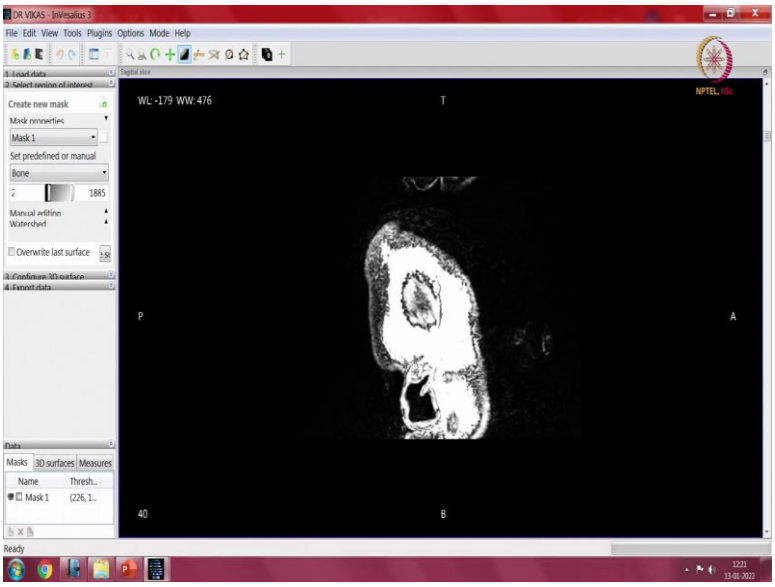

So, that is the ear, which is coming over here, it is a section remember. So, you cannot make out the ear as a distinct entity.

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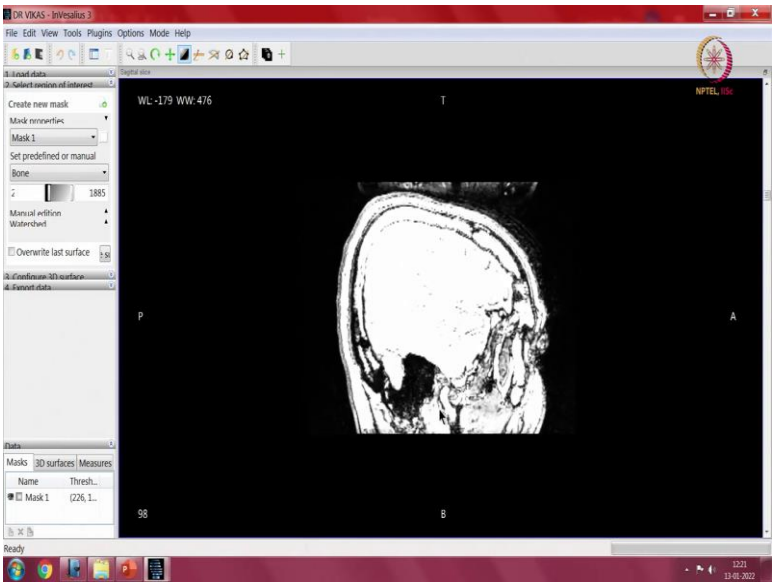

So, this is the external ear canal and goes on to form all these other structures.

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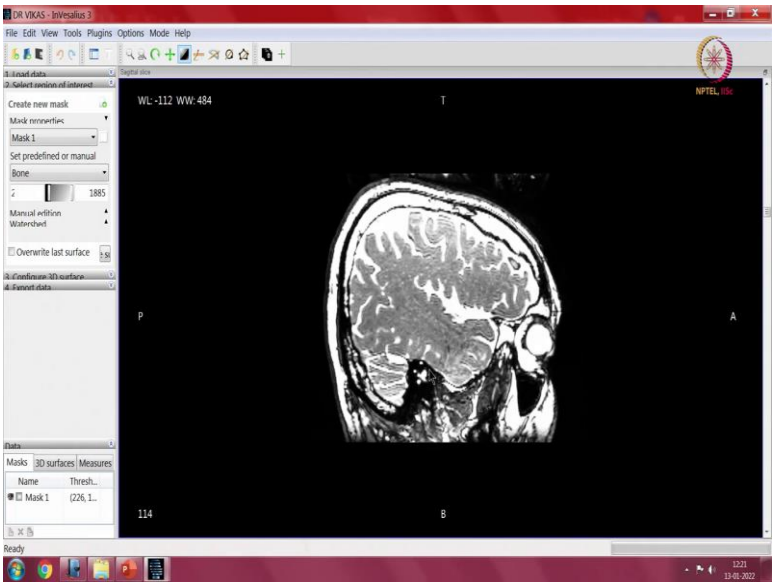

So, what actually I wanted to showcase is the superior, is the semicircular canal. So, this is the superior semicircular canal going up, up, up, up, and joining over here.

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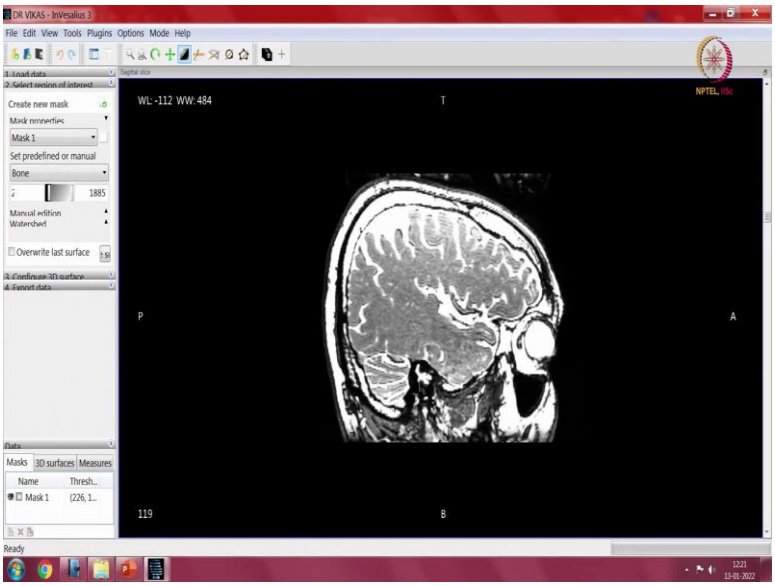

Lateral you cannot make out distinctly in this section.

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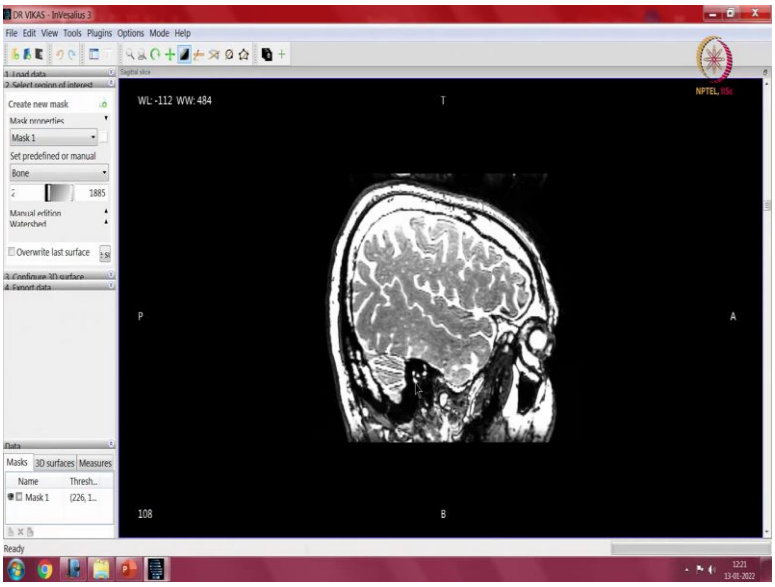

This would be the posterior semicircular canal here yeah, that is the posterior semicircular canal.

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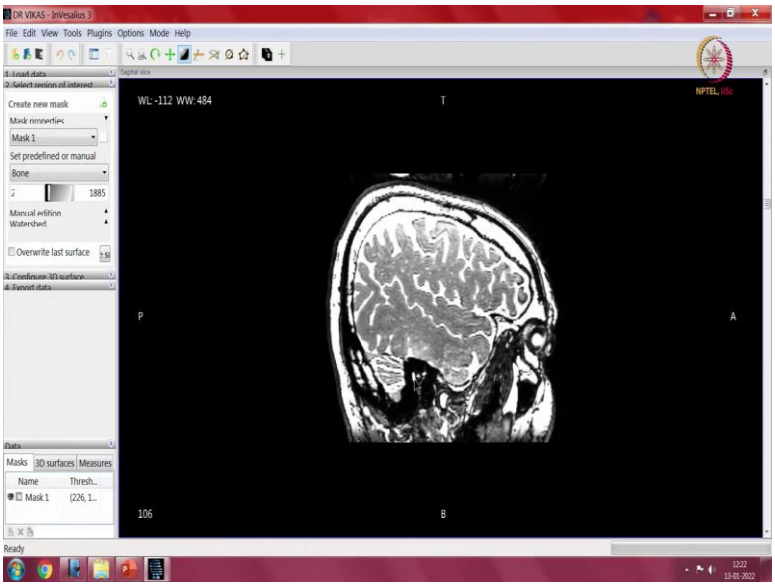

Posterior was not seen properly in the prior discussion.

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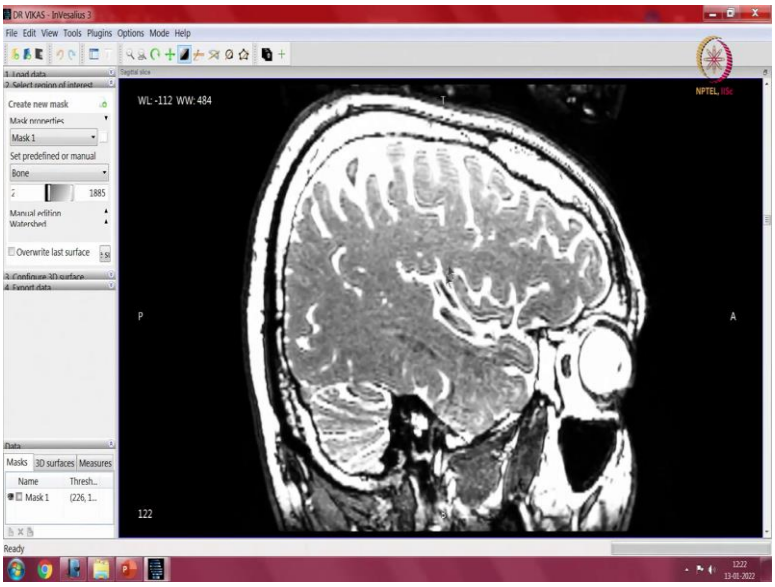

So, two semicircular canals we are able to see, and this is the cochlea. So, that is how the cochlea looks like. It does not look very elegant on imaging, because the imaging resolution is really bad.

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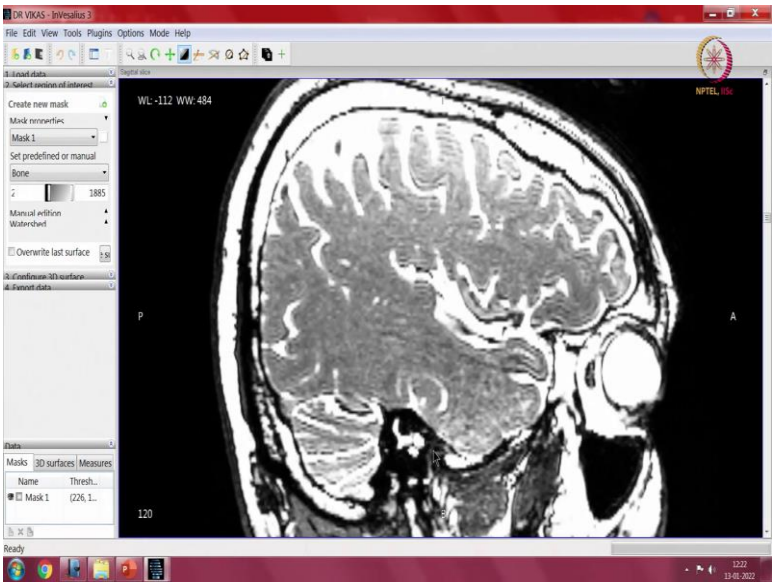

And you are just able to make out blobs, you can make out the helical design which is there in that beautiful 3D picture.

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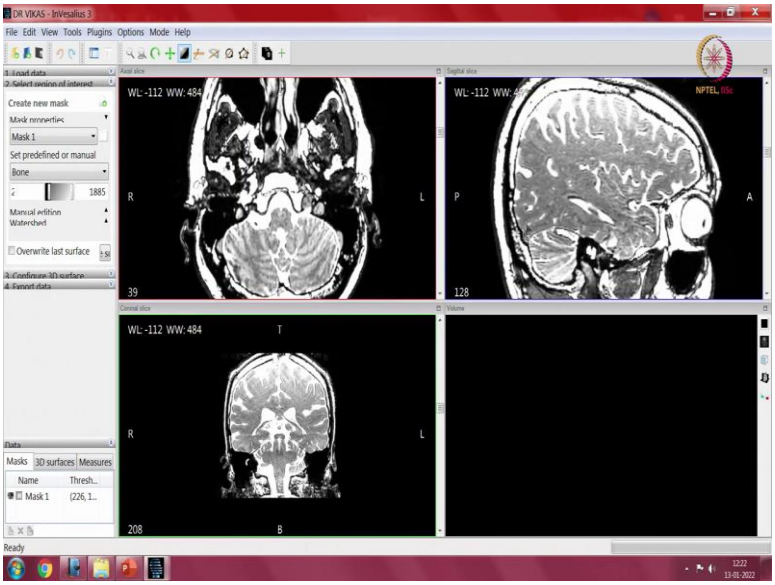

So, that is in two dimensions.

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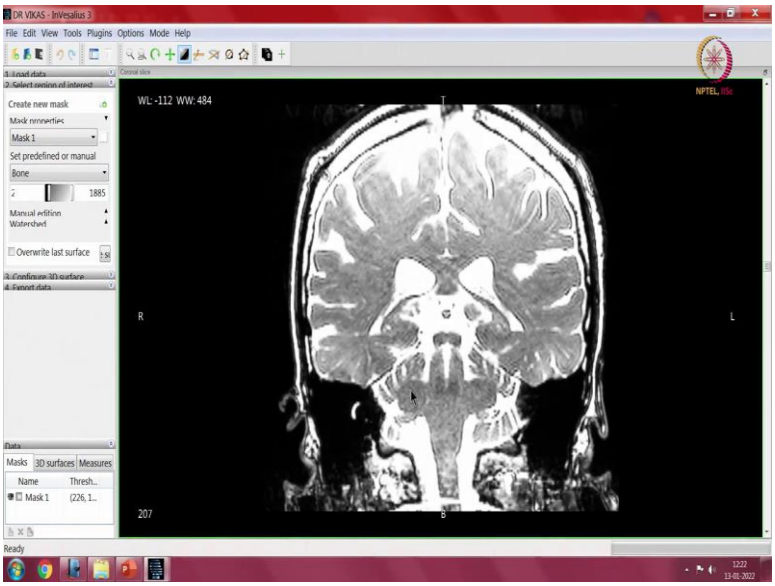

Let us look at coronal imaging and see if we can make out better.

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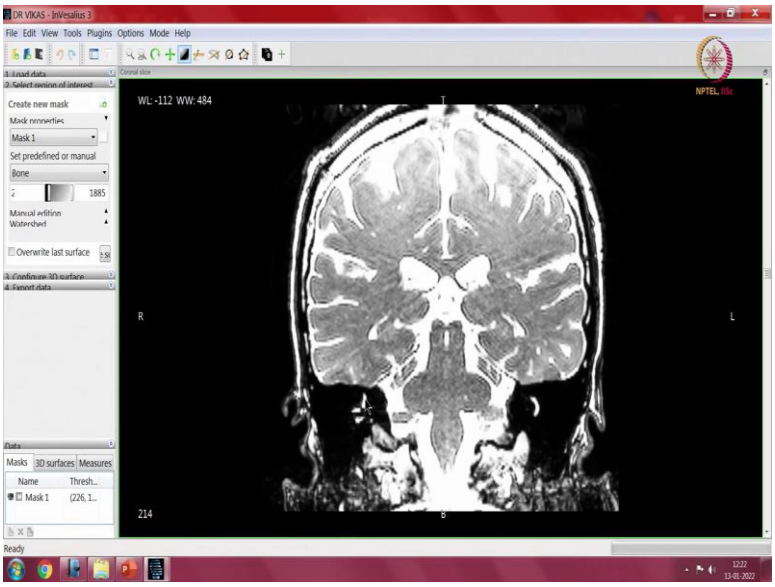

And so, this is superior semicircular canal, superior is above, superior is above.

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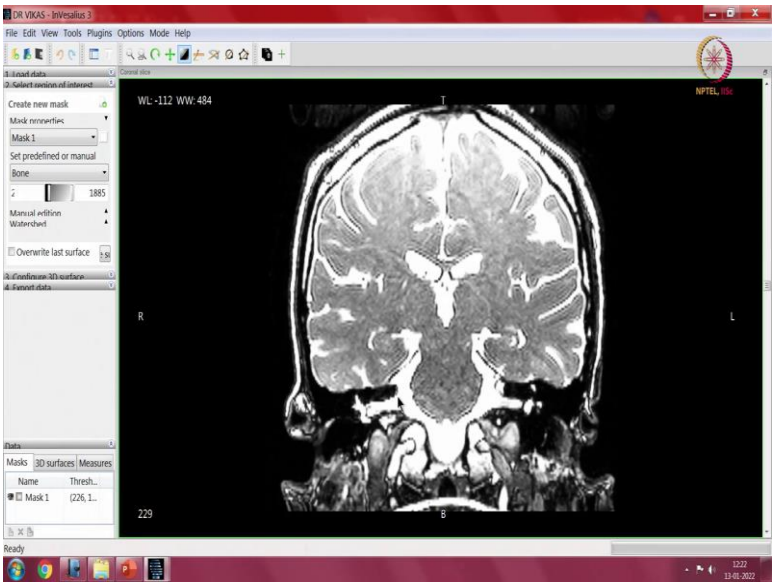

So, you can trace this back coming over here. So, this is the internal acoustic meatus. So, this whole stuff white over here is the internal acoustic meatus, it is closely connected to the base of the cochlea.

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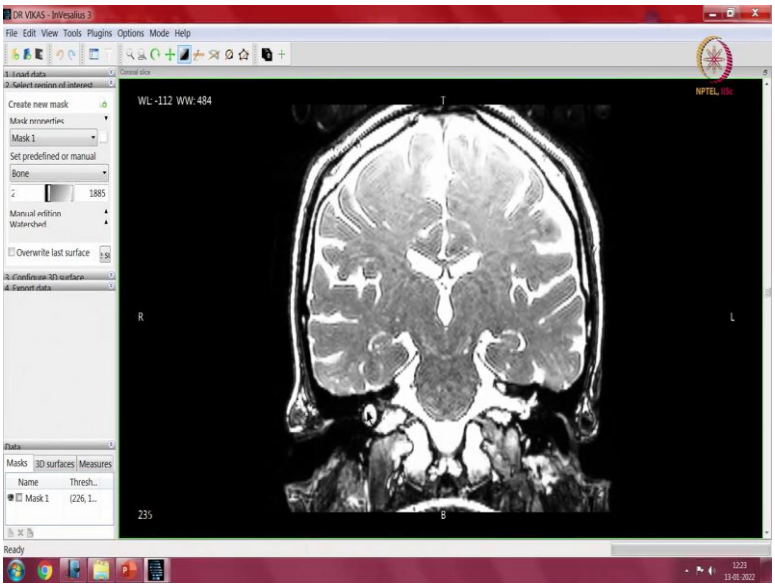

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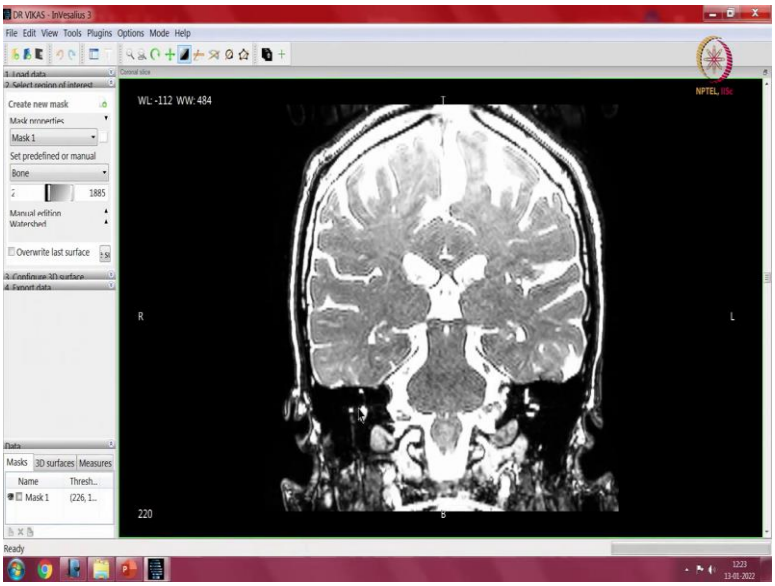

And the various semicircular canals are arranged around this yeah.

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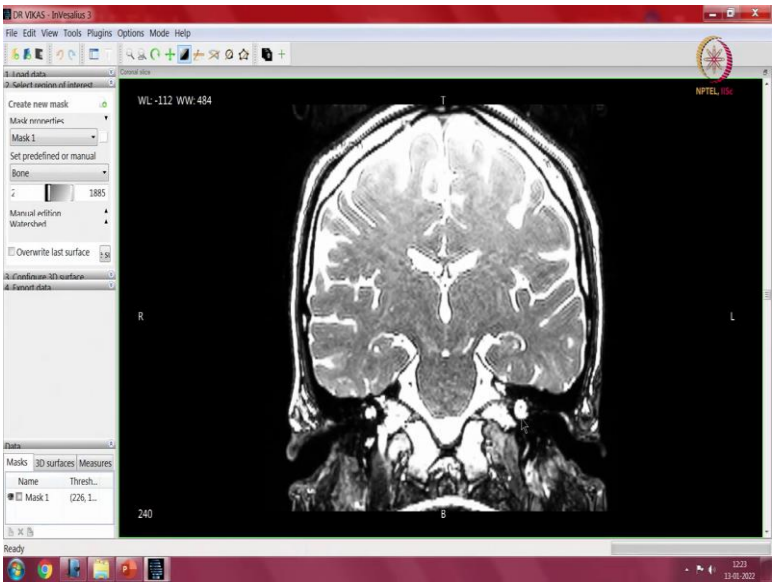

So, here you can make out, you know there is a spiral over here, hope you can appreciate the spiral over here. This is the apex of the spiral and so that is the cochlea.

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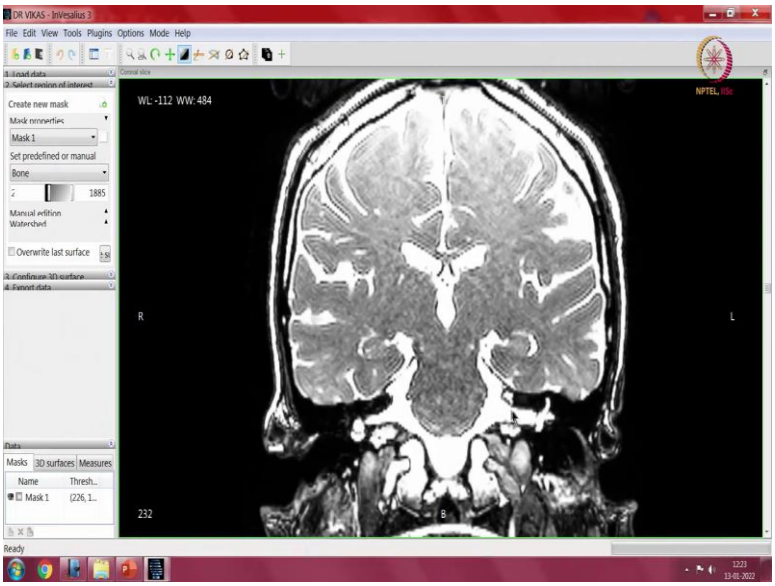

So, cochlea and then there is this internal acoustic meatus the various semicircular superior, lateral and posterior semicircular canal. So, that is how you identify structures within the images and to understand a little bit of the form and function of the ear and its various components the apparatus.

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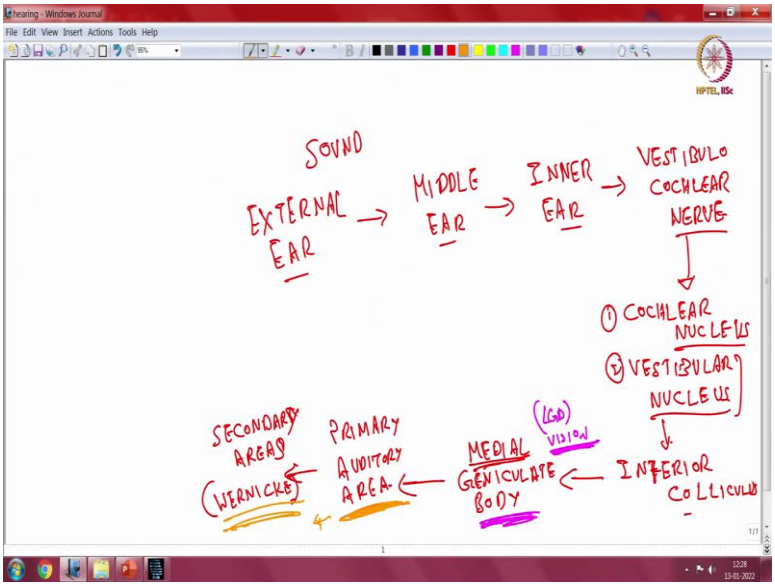

So, sound goes through external ear to the middle ear, to the inner ear, to the vestibulocochlear nerve and that in turn splits into cochlear nucleus 1, the vestibular nucleus. So, once that happens it would go into something called as the inferior

colliculus. From the inferior colliculus it would go to the medial geniculate body from which it goes to the primary auditory area.

Secondary areas would be Wernicke. So, this is sort of the pathway. So, sound which is generated from a source gets impinged down to internal ear, then middle ear, inner ear the nerve, two nuclei, the vestibular is for balance that is a separate pathway. So, it goes to the inferior colliculus medial geniculate body. Medial if you remember, the lateral is for vision.

So, all of these are close by, there is a lot of interconnections between them, but they are compartmentalized. So, most nervous system are like that. You do not have rigid compartmentalization in which you know they structurally have boundaries between each other, and they are not like they are connected by a bus. So, you have these components which are very closely placed with each other.

They have sort of a functional independence, they can be made out structurally as you know recognizable entities, but when you look at connections, they are very close to each other, and they have seamless connections from one entity to another entity.

So, that is a common theme which is there within most structures within the nervous system and relevant things are very often kept close to each other. So, vision and hearing are kept close to each other because they form the primary modes of communication which data acquisition, which from the environment and that is why they are placed close to each other.

Primary auditory area is the area where most of the advanced sound processing happens. And a more advanced step happens in the secondary areas where you know actual language is perceived, interpreted and understood.

So, that is the role of these secondary areas. The highest of the secondary area is the Wernicke's area which is for speech. So, you have different areas which sort of are useful for say music and not distinct areas you know they are not named as such. But there are play parts within the cortexes which are specific for each of these different kinds of data.

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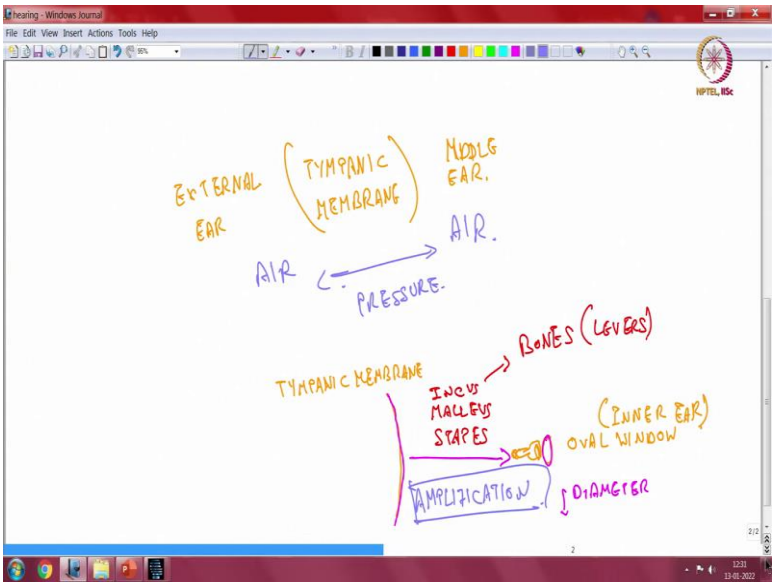

So, that is how it is. Now, a little bit detail of tympanic membrane. So, it is between external ear and middle ear. Now, both of them have air and it is sort of equilibrated. So, pressure is in normal terms is equilibrated between across the tympanic membrane and that, so the tympanic membrane captures the sound.

So, the surface area of the tympanic membrane is pretty large, I think it is 20 to 1 or something and the stapes which is there it goes and on the oval window and it is much smaller.

Now, this is in the inner ear. So, tympanic membrane and oval membrane have a reduction in diameter. So, this is one of the mechanisms. So, how that is transmitted is through in order, incus, malleus and stapes. So, these are bones which are basically levers and the sound is transmitted across it. So, what happens with that is there is amplification of sound. So, sound gets amplified by this mechanism and it is that is the chief purpose of transferring sound waves from across the tympanic membrane.

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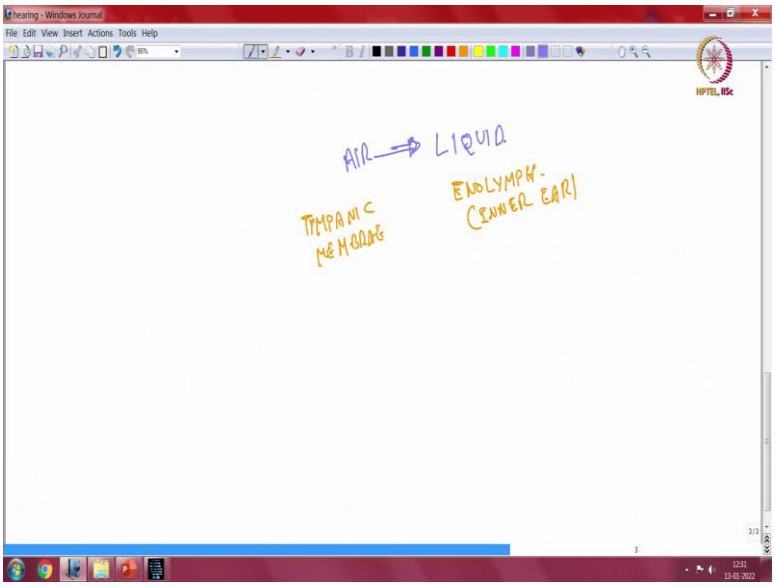

The other thing is air to liquid. So, tympanic membrane to endolymph which is in the inner ear. So, transfer of sound happens between the air to a liquid medium and that is done through this. So, that is how sound transfers. Now, we look into the next session, where we look into signal transaction, which happens when and how signal processing happens for sound waves.