Advanced Neural Science for Engineers
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Lecture – 54
Neuroanatomy for Neural Engineering

Hello. Hello, everyone. I am Dr. Shabri Girishan, Consultant Neurosurgeon at Ramaiah Memorial Hospital and I am an Associate Professor in the department of neurosurgery at Ramaiah Medical College. So, here I am to take a course on neuroanatomy for neural engineering. A little bit of my background would help as to why I have taken interest in this particular session.

I am an epilepsy and functional neurosurgeon and I deal with a lot of epilepsy patients and patients with parkinsonism, where we offer them the surgical treatment to treat the difficult to treat epilepsy, difficult to treat movement disorders like parkinsonism we give them the optional curative options using surgical resections as well as deep brain stimulation for parkinsonism.

So, I am pretty close to the field of neural engineering. In fact I have taken a keen interest to even do a PhD course with the bio-system engineering under Dr. Hardik Pandya at BSSE lab at IISC Bangalore. And the reason being that there are, there is a big demand for this neural engineering in the field of epilepsy and functional research and for that matter any cutting edge neural rehabilitation, neuro-prosthetics lab does have a lot of application in the field of computational neuroscience and neural engineering.

So, today's session I am going to dedicate a lot of time as to how this knowledge of the anatomy and as to how we collect the data and from where do we collect the data and how do we deal with the neural data with a brief introduction to the computational neuroscience as well. So, without much due, I would like to start the slides. So, I will take you through the anatomy and briefly about the computational neuroscience as well.

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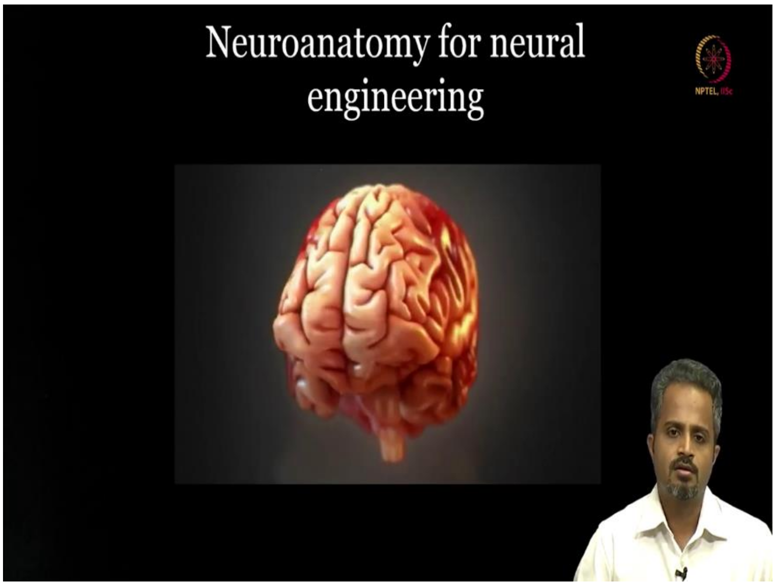

So, let us begin. So, as you all can see I have chosen this video which displays the three-dimensional anatomy of the brain. So, this is definitely a challenge where the entire brain has the very three-dimensional perspective as compared to the other organs of the body. So, and that is what makes difficult for to comprehend the entire gross anatomy of the brain and also that there are no strict borders visible as such to understand as to which part of the brain does what. It is not very obvious.

So, if at all anybody is interested in neural engineering the first question they would want to address would be, as to what function are we trying to address. So, to understand a particular function one would want to know which part of the brain is actually being studied. So, that is where I thought let us begin with gross anatomy.

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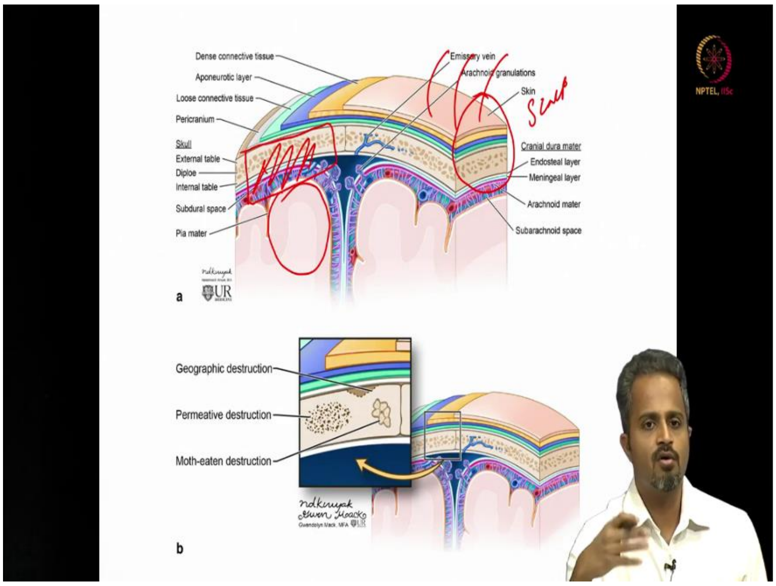

So, before I go to the brain anatomy, a little bit of the layers starting from the scalp. So, one would always wonder how many layers are there above the brain or for that matter, outside in how many layers are need to be open to approach the brain. So, as you can see here, that part would be the scalp area of the… your scalp as we see there are hairs there.

So, after that would be your skin and in the skin itself… the skin and the scalp there are two different things in cranium, this scalp has multiple layers and it is very important to know that because there is loose a little tissue and there is a pericranium before we approach to the actual bone. So, bone layer is the most difficult part to approach the brain and that is where the neurosurgery is very different from any other surgical endeavours.

As when we slash open the skin, you can approach an organ without much of a bone work. But here to approach brain one would have to be proficient about craniotomy. Craniotomy is a surgical process where we actually make a window in the skull to… once that comes out then only you will be able to see the brain which is underneath.

So, that is why it is very important to understand to which part of the brain one would want to study and once you decide which part of the brain that you are going to study, then you would want to know how are you going to approach it. That is why the stereotactic approaches would come in where we can open a very small area of the brain so that the mobility comes down. So, in neural engineering a very crucial part is to understand which part of the brain needs to be studied and how are we going to approach that part of the brain.

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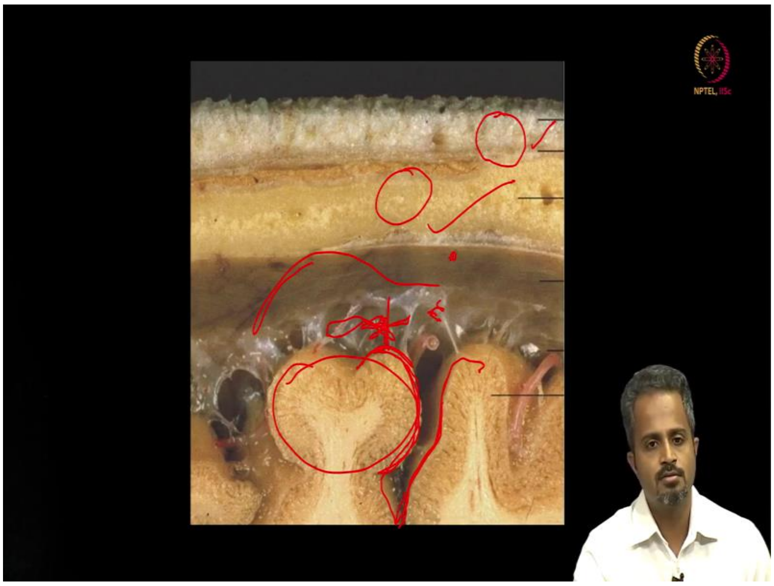

So, let me try and spend little more time on the gross anatomy of the brain. So, this is the actual category slice from top down, so as I was telling the previous slide that, that is the scalp and that is the bone and this is inside your skull. So, the scalp as I said has multiple layers, which is not very obvious here because a categoric anatomy.

Category in the sense, a human body after death we embalm in a solution to preserve the structures, all the structural details. But that is not how the surgical field would look like. I can show in one of my operative videos of a patient how an actual pulsating brain would look like. It is a pinkish jelly-like structure. So, it is a categoric slides to just to make you understand what the slice would… I mean the structures would look like in real.

So, that is the scalp players, that is the bone again and below the bone that is the dura. The first meningeal layers that would come after the bone. Outermost tough layer is the dura mater then comes this white glistening arachnoid membrane which has…the name arachnoid has come from this cobweb appearance. It is like spider web appearance which is called arachnoid trabeculae. So, from here is the pia mater.

So, pia and dura is connected by these arachnoid trabeculations, so paya-matter is something which is stuck to the brain which follows the sulci. So, sulci are the deep fissures in the brain as compared to any other species like rodent anatomy. For example, if you look at the rodent brain, it is a smooth surface which with no sulci.

So, here the beauty of human brain is that these sulci or these divisions covers a large area. If you were to open up the entire brain surface it is pretty large and but still we are able to confine in a small area by means of these folds which are known as sulci. And this is known as the gyrus.

I am introducing many terminologies here because as we go along, we will have to get familiarized with these anatomical terminologies for us to understand better as to where we would implant. That is the basic idea here as to the neural engineering begins with implanting some electrode or for that matter even a non-invasive ways of handling the data even if it comes over the scalp we need to know which part of the brain is being sampled. So, again we will be coming across all these terminologies for us to understand the function better. So, that is the three-dimensional aspect of the structures from top down.

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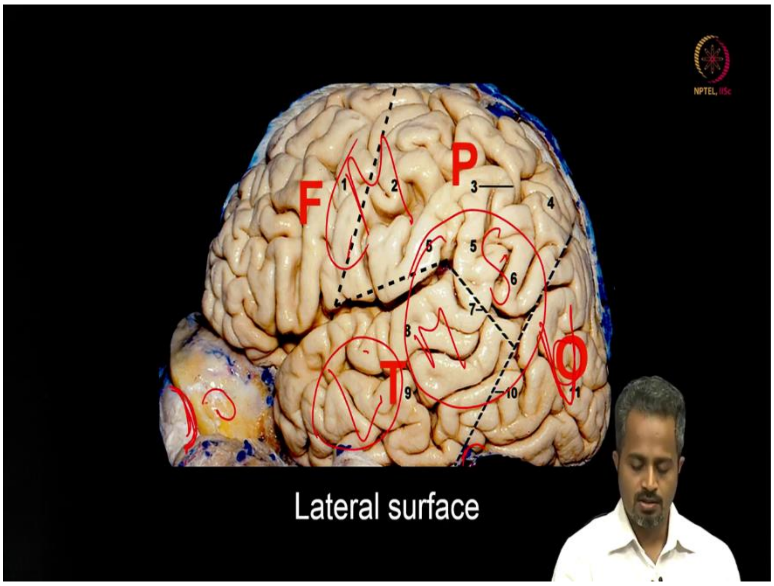

So, now let us look at the gross appearance of the brain. So, this is again a categoric brain where the entire skull has been removed, so there you can see the base of the skull. So, that would be the eye of that categoric body. So, the entire skull has been removed and the dura will be over this like a white tough layer which has to be removed to expose the brain.

So, obviously it is not like a complete white structure there are a lot of blood vessels which runs over this. These sulci there will be multiple blood vessels just to expose all the sulci guy right here, we have removed all those membranes which I showed in the previous slide. That is dura matter which has been stripped and the arachnoid has been removed and the pale structure with blood vessels in it, that also has been removed.

So, once we remove all those layers what we are left with is this whole white brain. So, as you saw in the previous slide, there are no divisions but how do we know that we are exposing a frontal lobe? How do we know that it is a parietal lobe? Those are the areas of the brain that we would be interested in…of course the same anatomy in an animal model will be different but the basic divisions does exist in most of the animals.

So, it is very close in a non-human primate model like monkey. Rodent model yes, there are lower divisions but it is definitely smaller in size of course and the divisions are a little more difficult tenant because there are no sulci guy in it. So, having said that how does this divisions happens? What is… so the overall there are five lobes to know but then what is shown here are four lobes. The four major divisions of the brain is the frontal lobe, parietal lobe, occipital lobe here and the temporal lobe here. Where is the fifth lobe?

The fifth lobe is hidden inside this is known as insula. So, that is an island. That will be visible only if you retract this lobe from this. So, this is this deep sylvian fissure which divides the frontal parietal from the temporal occipital lobe. But the division is not complete here as you can see. So, there are arbitrary lines to consider for the divisions. I mean it is not very important for you all to know the every details of the structures but at least the lobe divisions will help you in the long run.

So, this black line here, so this black line is along the central sulcus. The number one is actually a motor cortex, number two is sensory cortex. So, this central sulcus that is seen here is the deepest sulcus that is there in the brain which divides the brain into a frontal and parietal lobe.

So, again parietal lobe is divided from the temporal lobe by this imaginary perpendicular line that has been drawn here. That is the pre-occipital notch, from there it goes to the midline and the parietal line going to meet the sylvian fissure would make this lope as a temporal lobe and anything behind that is occipital lobe, above that is the parietal lobe.

So, functionally these lobes are very different and all these lobes are very specific functional role. For example, the most anterior part is the executive centre of our brain which is actually the prefrontal cortex that would be the association cortex where the sensory motor cortex, the number one and two as I said earlier. So, that is the sensory motor area of the brain which is very vital for us to move around. For the locomotion, for the hands to move.

So, that is the sensory motor cortex and this association area actually connects this with all the other areas. So that we make a purposeful movement, we make a you know we develop a goal oriented behaviour. For that matter even for a motor learning.

So, association area is a very important role in this sensory motor function of the brain whereas this is the abstract thinking. How we take decisions, how we make a plan for the future, a motivation to move around. All that is taken care by the prefrontal lobe. Parietal lobe is of course is a large sensory part of the brain which takes care of the most of the sensory functions in terms of goal-oriented behaviour for that matter on the left side on a dominant lobe, this has the speech centre.

For example, this is the angular gyrus, that is a supramarginal gyrus and angular gyrus. These two areas very important for sensory perception of the speech. Somebody talks to you and you do understand. So, this entire area would be considered what is known as a Wernicke area. Here this entire area would form a Wernicke area here which include a superior part of the temporal lobe and the inferior part of the parietal lobes. So, that is the speech area sensory perception area where the auditory signals are received and processed to make an individual understand what the other person is talking about.

So, the temporal lobe here is involved in language and memory function. This is the lateral neocortex. the medial part of the temple lobe is the hippocampus which I will be showing in next few slides and that is the occipital lobe for vision. So, if at all I need to break it into the functional aspect within this structural part of the brain then I would say that would be a motor function grossly. That is the visual function this is language and memory and that is speech. So, this whole area is into the speech.

This area is for language memory, sensory motor and vision. At least this gross function with the associated lower structure is very much essential for you all to move ahead in addressing any questions in neural science.

So, today's lecture is all about how are you going to use the technology to answer any scientific questions that would help to either be an exploratory research to understand the brain function better or in terms of a translational aspect as to help the patients to recover from a deficit, a function deficit. So, that is the idea of the today's lecture.

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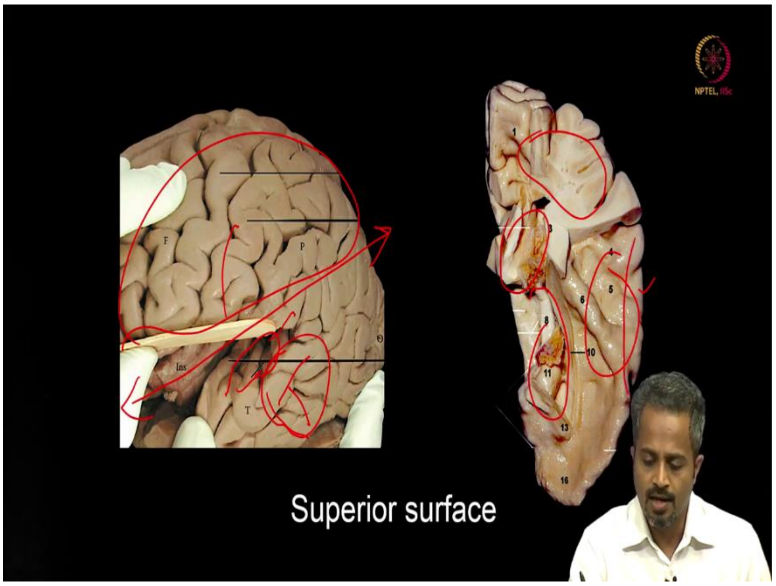

So, once we know what is grossly on the surface let us go you know take a dive a little bit deeper and see as I said that forms the insula here, that is the hidden lobe which is the fifth lobe. As I said that was the frontal opercular. Opercular means the lid, so when we retract that from the temporal opercula what you see here is the surface guy right? As I said, the guy is basically the different folds.

There are different folds in the superior part of this temper lobe which I was talking about, that is the insular lobe. So, for timing we leave the insular apart for today's lecture because the function that is associated with the insula is very very complex with mostly of gustatory function, cardiac function pretty complex function which is not very important for today's lecture.

So, that is the temporal lobe which is way of which the superior surface has been exposed here by retracting the inferior surface of the frontal parietal lobe. So, here is the picture where this section has been of this section of the brain has been removed and this is the top most view. When you look from top, this is how it would look like.

So, as you can see on the surface on the lateral surface that is the outermost surface not many features are there but as soon as you cut open here, you can see a large number of very vital structures that are seen in this cut section alone. So, you need to understand that this large brain is enclosing hundreds of very vital structures within its the globular shape of the brain. So, that is what I was trying to emphasize saying that the three dimensional structure of the brain is pretty much difficult to understand and that is the reason why the entire categoric anatomy has been described here just to briefly introduce the structures which are the area of interest in many researchers involving these neural engineering.

So, as I said this is the lateral temple lobe here and this was the topmost part of the temple lobe here. So, that is called Heschl gyrus which is the receptive area for audition in auditory cortex, that is where all our sounds would end. Any spoken words will be received first here, the auditory pathway ends here which is the Heschl gyrus.

So, that is very important function in the language whereas what you are seeing here the middle most part is the hippocampus, which is the very very important structure with the memory. So, hippocampus again is a very difficult structure to understand because of its three-dimensional predisposition.

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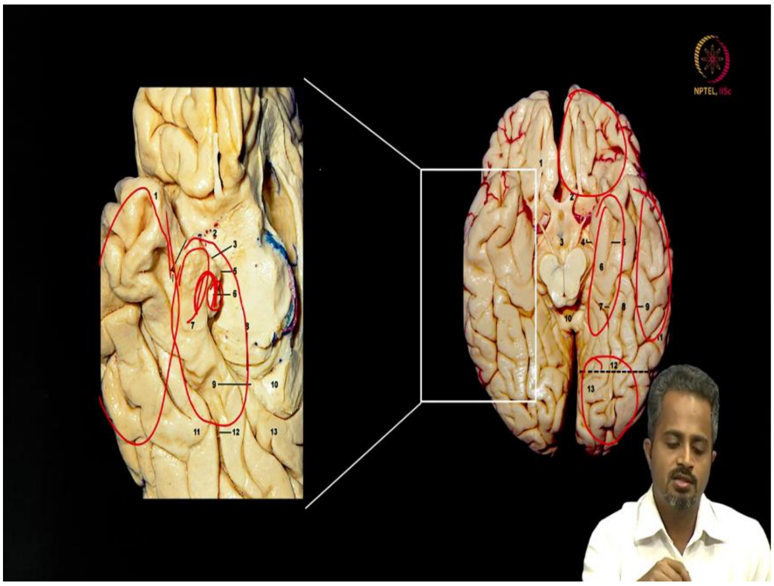

So, that you can understand better probably here where this is the inferior surface of the brain, when you flip the brain from below upwards, so this is what you would see. This is the inferior the lower surface of the brain, if I would want to put it in a simple non-anatomical terminology, flip the brain then you would see the lower surface of the brain.

So, that again is the medial part of the temper lobe, the lateral part of the temple over here and what you are seeing here is the lower surface of the frontal lobe, lower surface of the occipital lobe and the temporal lobe, lower surface or temporal lobe.

Obviously, parietal lobe will not be seen here because that was above the sylvian fissure. So, if you can deeply go into that particular structure here, you can this part of the brain here is again enlarged to show the complexity of the temporal structure that are there which is called the medial temporal lobe here and again lateral temporal lobe.

So, here this turned part of the brain is called ankles. A sickle shape or probably a horseshoe shaped structure there is the ankles. That is a very important structure to understand because that will house the what is known as amygdala and the hippocampus which are the emotional seat of the brain. All our emotions are driven in the amygdala which feeds into our memories into the hippocampus.

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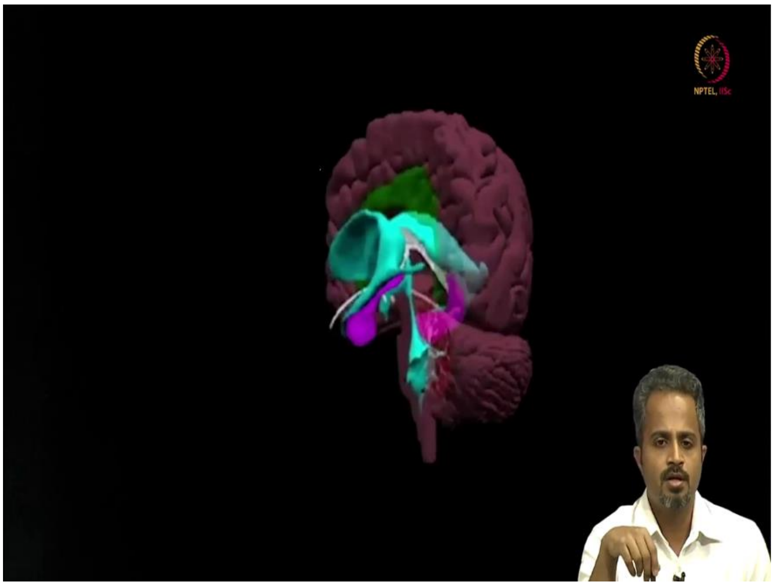

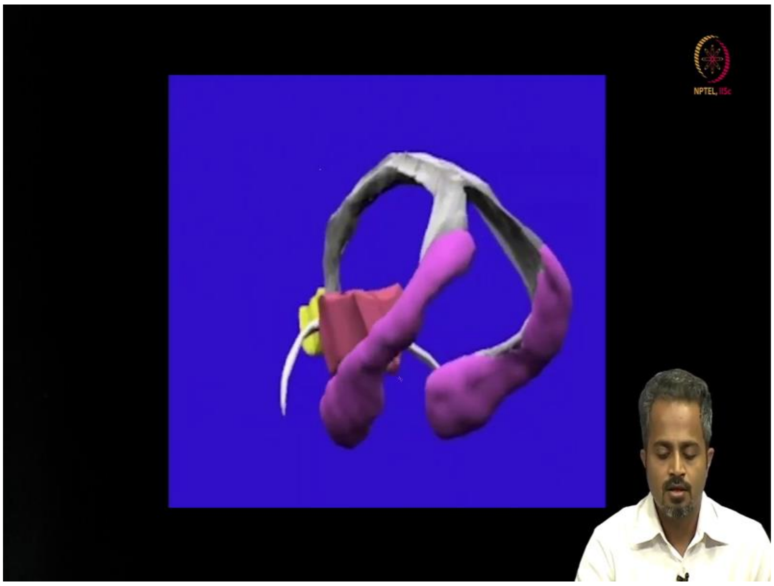

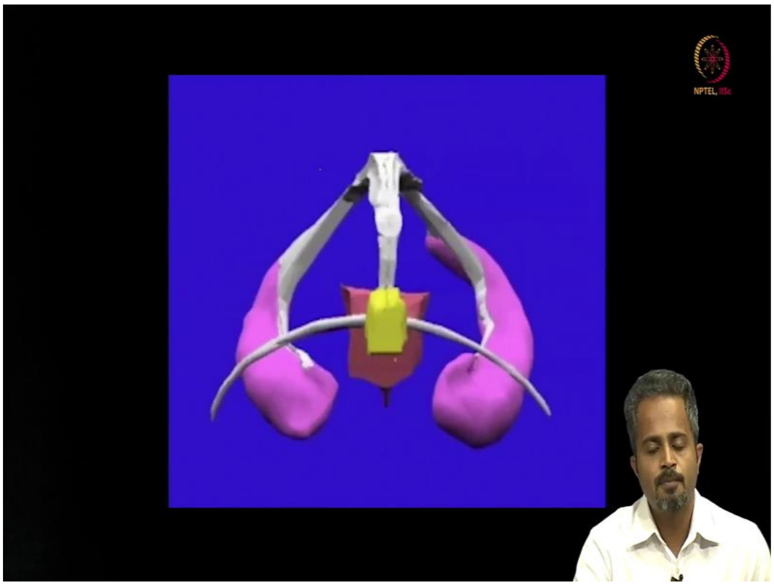

So, a little more detail about the hippocampus. As I said, it is a three-dimensional structure, what you are seeing there is blue structure is actually the ventricles and this pinkish structure that wounds around this ventricle is the hippocampus and as I said earlier, from temporal lobe it begins and it goes along the ventricles to form the entire horseshoe shaped hippocampus with the head, body and the tail of the hippocampus which forms the Pepe's circuit for memory.

So, hippocampus is the golden mine field for research and all of you must have heard about various research papers coming out in terms of a say a one placed fields and navigational networks and memory circuits and what not. So, hippocampus was a very very I would say intricately in evolution. It is very intricately placed and there are lots and innumerable neurons to make up for the evolutionary and complex structure of the brain. So, that is what makes us as humans… as a matter of fact.

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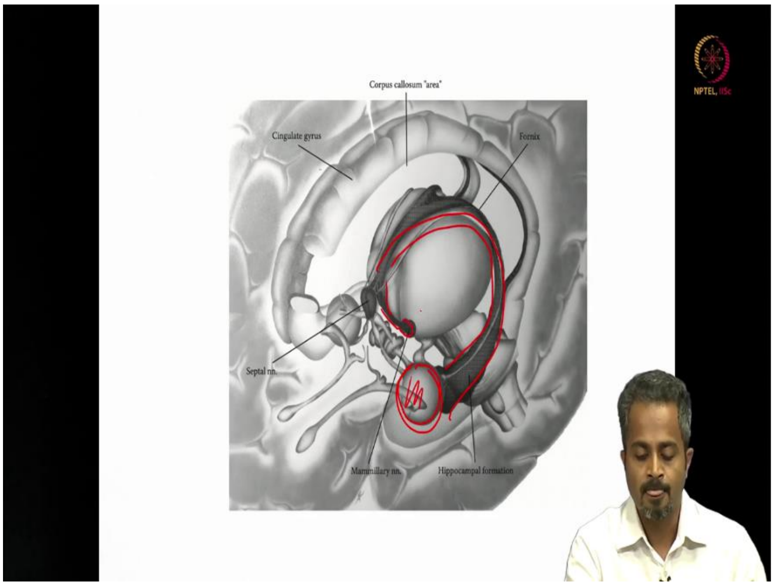

So, not just that if you can… if we can go little more deeper into the central core of the brain, there are further numerous gray matter nuclei situated right in the centre of the brain which is called the limbic system.

So, that is definitely not visible unless visible on surface and unless we take a serial slice of the brain. But what you can see actually here, this is the three-dimensional rendition of the brain, this is not how it is usually seen where they made the surface transparent to get a peak into the deep part of the brain.

So, if you all remember the categoric anatomy which I showed you earlier, this is the amygdala which is actually the seat of emotion and that is the hippocampus which winds around like that and ends up as mammillothalamic track. So, that completes the puppy circuit which is important for memory formation.

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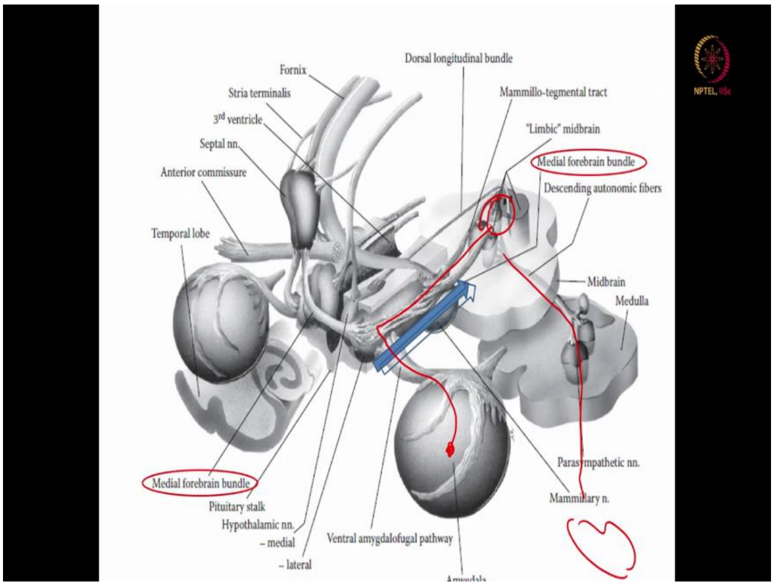

So, what are the other structures that would comprise the basal ganglia and the limbic system. So, this is where you can understand how complex our brain is and how these emotions drive in various sympathetic responses that we see.

And if you all can remember that when one would become angry you would see his pupils getting dilated. Your eyes goes wide, your pupils getting dilated and your heartbeat just raises. This is exactly the reason, the amygdala receives the impulses from the singular bundle and that sends into in through middle four band bundle into the midbrain Vaso Motor Centers here which is actually the sympathetic center of our brain and that is connected to our heart. So, that impulse causes tachycardia.

So, that is just one example of the sympathetic over activity whenever a person becomes emotional and this would constitute an emotional circuit of the brain. Though it is bit complex, it is better to nice to know that what sort of components are there within the deep core or central core of the brain.

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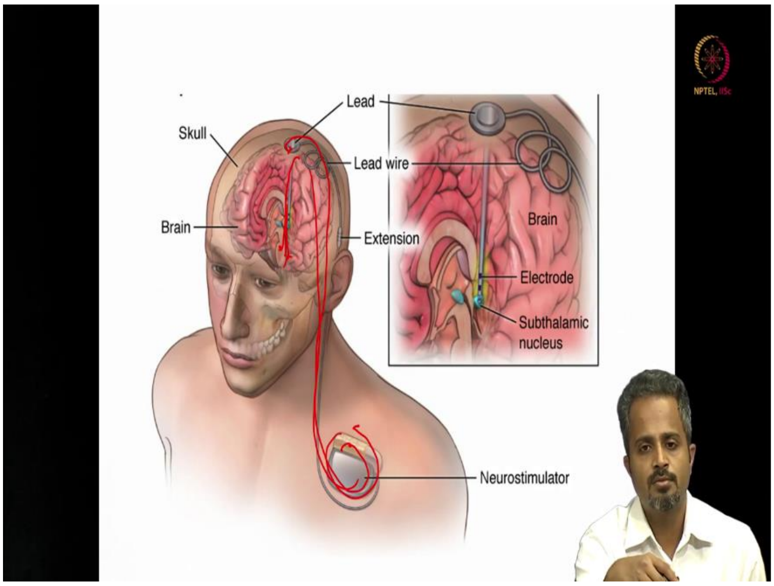

So, after I introduce those various structures it is nice to know that those are the structure we actually target to cure the…. I mean not cure to help them symptomatically in parkinsonism. Unfortunately, Parkinson is not a curable disease. We can only help them with their lifestyle, with their daily activities of living by helping them with the movement. So, for that we implement the electrodes deep into those basal angular structure which I showed. One of the nucleus is the sub thalamic nucleus which we target with these electrodes, that is the gift of neural engineering.

So, that is the whole idea of understanding the structure of the brain and their functions and design various technologies and various sensors, various actuators to make sure that we stimulate that area of the brain to modify the functions ultimately helping them with their various ailments.

So, this is just one example of the neural prosthetics and a product of a neural engineering which has come out of the exploratory research and translational research by understanding the anatomy and the function aspects of the brain. So, this is called the deep brain stimulation where the electrode that has been implanted deep into the basal ganglion nucleus that is the battery which will be implanted below the clavicle, below the left clavicle.

In that sense the impulses into the electrodes in a fixed manner. This is an open loop stimulation. There are other closed loop stimulation where… whatever the changes that are produced there electrically will be sensed by the programmer or the battery and then modify the impulses to which will be sent again as per the requirement of the brain function. So, that becomes a closed loop deep brain stimulation.

So, this is just to… I am just trying to briefly introduce this terminology to keep you all focused as to why we need to understand the various anatomy and function that we are just describing.

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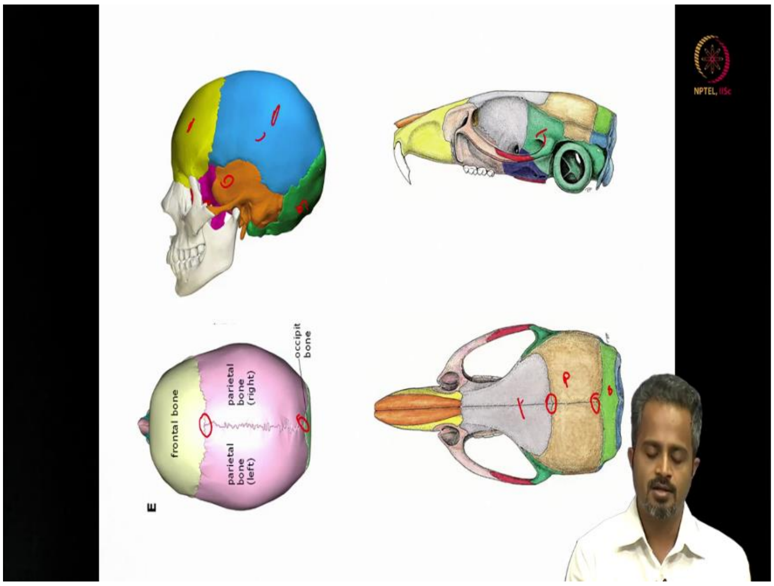

So, now the next few slides I will try to focus on the comparative anatomy. So, on the right hand side what you are saying is a rodent anatomy and on the left hand side the human anatomy and I am sort of… we are planning to have another course where I am one of the faculty for that particular course where we are trying to focus on rodent neural experiments.

Say animal models is very important for us to understand for a simple fact that we cannot do any exploratory research on a humans directly. For a simple fact that the human anatomy is much more complex and anything to do with the brain is very invasive and it is very morbid and can lead to mortality as well.

So, given the complications rate and the high risk involved, we definitely tend to employ animal models first because it is easy to handle and not that their lives are not important but we can rescue after any sort of experiments. So, we do not really have to euthanize them after the experiments but yes there are some… I mean there are many acute studies where the brain has to be sacrificed but having said that it is nice to start off with a simple animal model. Try to understand more and then look at the translational aspect into a non-human primate monkey models and then ultimately into human models.

So, I would strongly recommend for you all to take that course to understand and learn how to do various neural experiments by understanding the anatomy as to where to implant and how to implant, that is very very important because your entire data analysis which comes after that is going to depend on the methodologies that you have adapted.

So, it is very important for us to be proficient about and be professional again to handle the various animal models. So, however in today's lecture I would just briefly introduce the various anatomical aspects in the rodent model, just to see to introduce how we are collecting the data and then to move on to the computational part.

So, that is the human skull there. So, that is the frontal… I mean roughly that would corresponds to the brain structure that which is underneath. For example, that is a frontal bone, that is the parietal bone, occipital bone and temporal bone. There are innumerable bones again, let us not go into the detail of it but overall, it does correspond to the brain structure which is there underneath.

So, similarly here again in rodent, you will have the frontal parietal and occipital here and the green that is seen here is again temporal. So, there are these low bar structures which are divided, which are little bit similar to the human brain anatomy. What is more important are these landmarks of bregma and Lambda. that in humans.

And again, in rodent model again you have bregma and Lambda. So, this is very very important to understand because when we do neural experiments, when we want to acquire the data, when we want to implant those various sensors that you have learned in previous courses… you need to do a craniotomy or at least you need to do a small craniostomy, a small hole. You need to understand the stereotactic coordinates.

Unless you know the stereotype coordinates your implantation is going to fail and not just the failure of implantation the interpretation of those signals and then correlation with the behavioural task and then ultimately your computational part… all of them are going to take a beat… I mean I will take a beat, if you ignore the anatomical aspects and if you miss out on the accuracy of those implantation sites.

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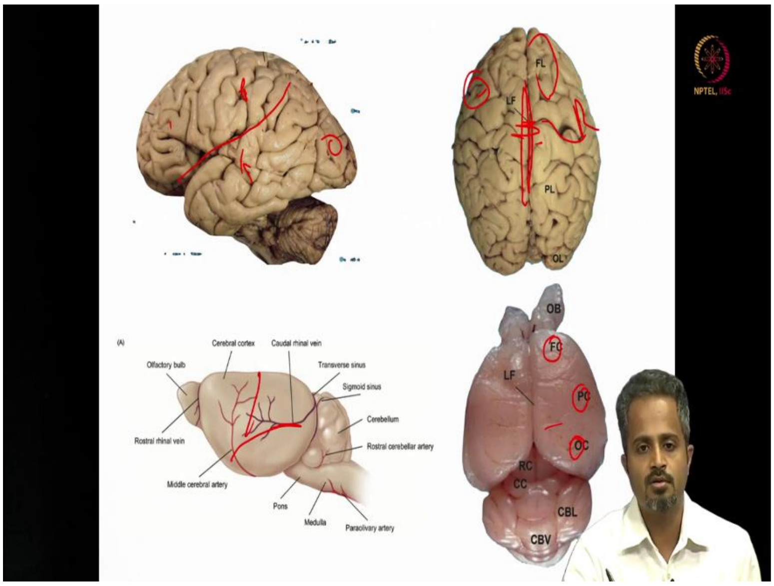

So, for that matter let me continue with little bit about the comparing anatomy again. So, as you saw that is the frontal lobe, so here you can appreciate the right and the left hemisphere which are interconnected by a structure called corpus callosum which connects the two hemispheres and on here again this is very familiar for you again, occipital, temporal, parietal and frontal.

So, similar to that again in rodent anatomy you have a similar division but as you see, this is the categoric rodent brain. The actual brain where we have harvested after the craniotomy. So, again roughly that would be frontal, parietal, occipital. You can see the stock difference between the two where there are various sulci here. There are no sulci at all. It is angaria, I mean there are no sulci gyrus in the rodent brain. So, it is all the more important to follow these stereotactic coordinates and to target various structure in and on to get the information that you are looking for.

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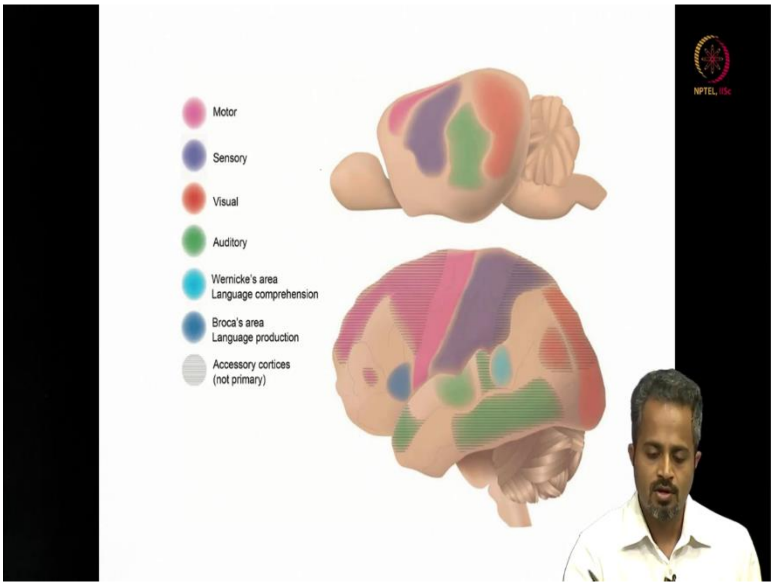

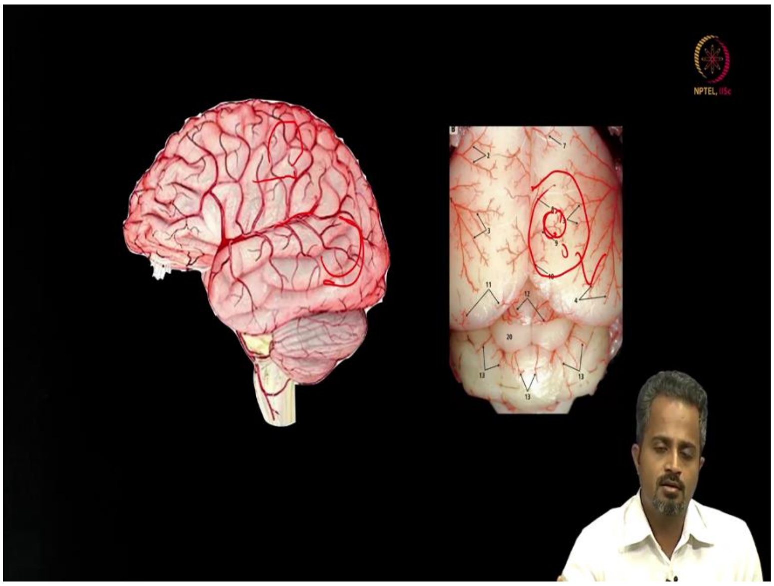

So, again the another functional division of the brain where you can see how the motor area and visual area is compared between the human brain below with the rodent and brain. So, that is the functional division. So, that is how we can draw conclusions from various neural experiments and this is how the regular human brain that would look like.

Though this is again a pictorial where just to make you all understand how significant it is to understand those structures and place the your craniotomy or the exposure for any neural experiment because there are innumerable vessels which are covering those sulci and gyri. This is the rotten brain on the right side where you can see numerous vessels. Any puncture of any of one of these vessels are enough to mess up the entire neural experiment and your sensor will be of waste because obviously you would have implanted it.

For a craniotomy it is still safer because you are able to do it under vision but if it is a small hole and if any of these punctures are made, the hematoma around the electrode will make that sensor useless because you would lose the signal. So, that is another critical point.

So, there are various techniques to make sure that this does not happen but nevertheless, I am trying to emphasize this. You will know more about these experiments in our next course.

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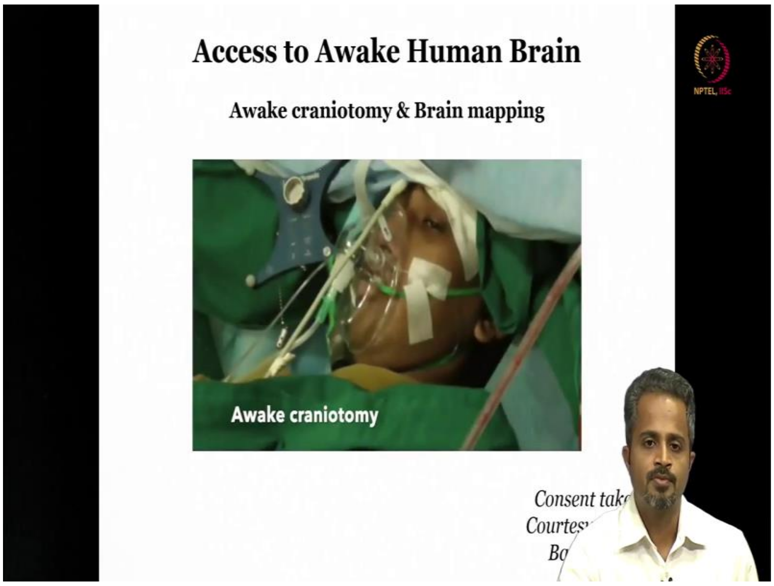

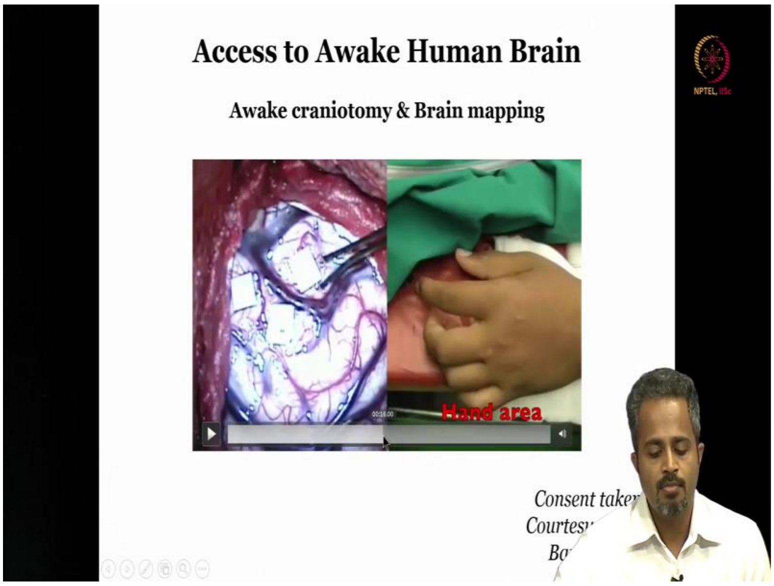

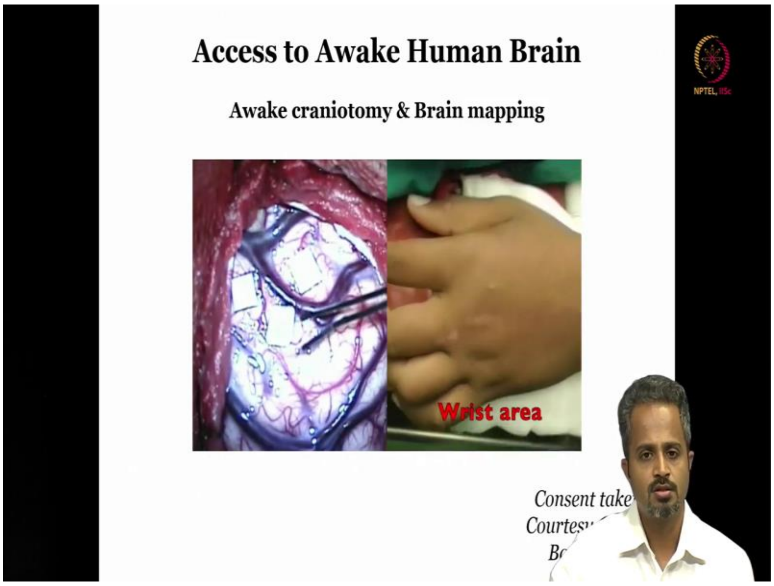

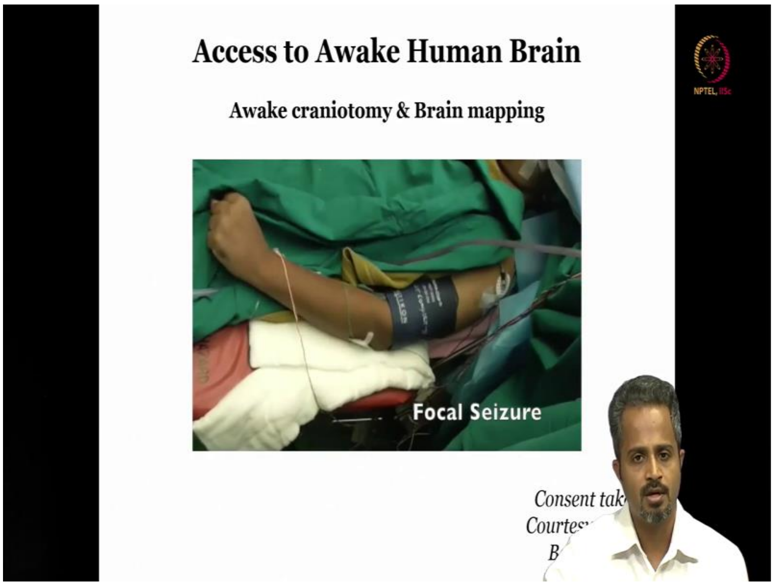

So, here is a small example as to how we can actually tap into the human data. I mean this is of course with the consent, I am just trying to make you all understand the motor mapping or the brain mapping as to how that is done so that is how the normal live adult brain that looks like.

This is a neurosurgical procedure where the patient remains awake while we operate. This is one of my epilepsy surgery patients where the epilepsy was involving his motor cortex. So, when that is the case, I cannot resect the motor cortex entirely because that would lead to a very bad deficit.

So, I need to map the motor cortex very carefully and then look at the epileptogenic zone as to where the epilepsy is coming and then recite that part of the brain and then make the patient seizure free at the same time put protect his motor function of the hand.

So, the emphasis is on the brain mapping technique that we have been using here. Something similar to this we do it in rodent models as well and which is very very vital for us to implant any sensor for that matter in the brain, there are multiple layers of accuracy and check that we need to do to make sure that whatever signals that we are acquiring from that part of the brain is actually what we would want and not from an area of not…. any signal from an area which is no of not of interest would become a noise for you.

So, to make sure the signal actually belongs to the motor-cortex and to make sure that whatever behavioural tasks that you are studying, it is from the area of interest then you need to know how to map it. So, this is one way of mapping it here. I will just play the part of the… sorry, so I will just quickly move to that part of the video where the mapping is shown.

So, as you can see as we stimulate the wrist moves and the hand moves. That is a bipolar stimulation that we are doing and then we try to reproduce the seizure as well. So, that was elbow and shoulder area which we mapped and that is the focal seizure that we produce from that.

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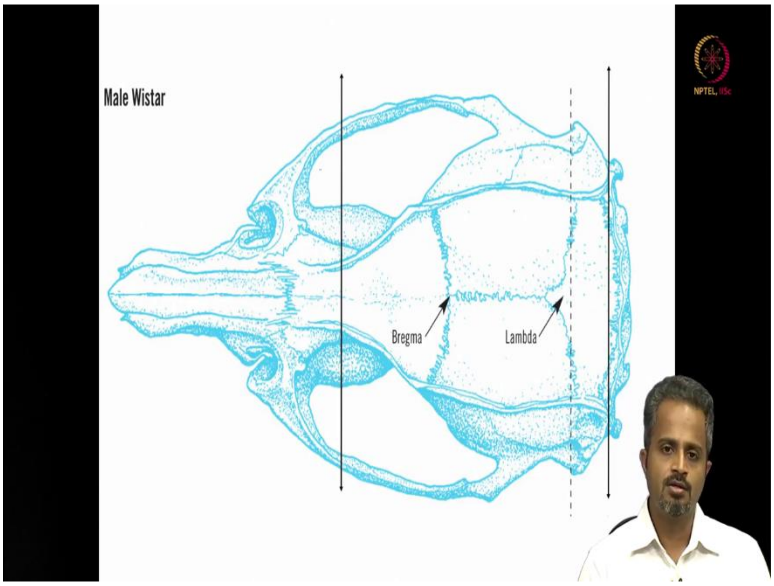
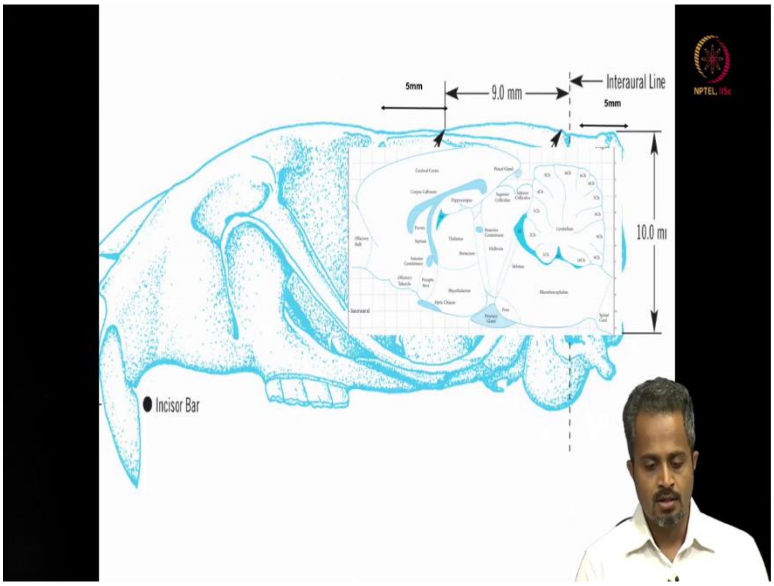
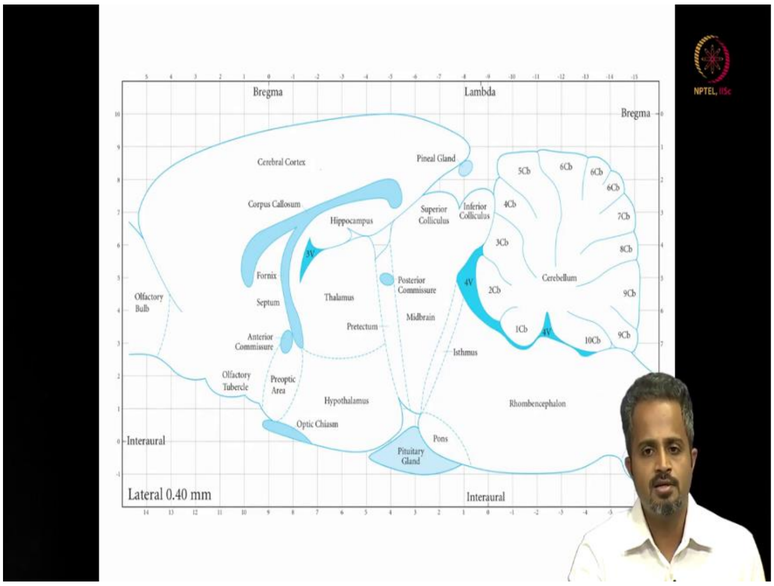

Male Wistar
Bregma
Lambda
NPTEL, IISc


5mm
9.0 mm
Interaural Line
5mm
10.0 m
Incisor Bar
NPTEL, IISc


Bregma
Lambda
Bregma
Cerebral Cortex
Pineal Gland
Corpus Callosum
Hippocampus
Superior Colliculus
Inferior Colliculus
5Cb
6Cb
6Cb
6Cb
4Cb
7Cb
3Cb
8Cb
3V
4V
Fornix
Posterior Commissure
2Cb
Cerebellum
Olfactory Bulb
Septum
Thalamus
9Cb
Midbrain
Pretectum
1Cb
4V
10Cb
9Cb
Anterior Commissure
Isthmus
Olfactory Tubercle
Preoptic Area
Hypothalamus
Rhombencephalon
Optic Chiasm
Interaural
Pons
Pituitary Gland
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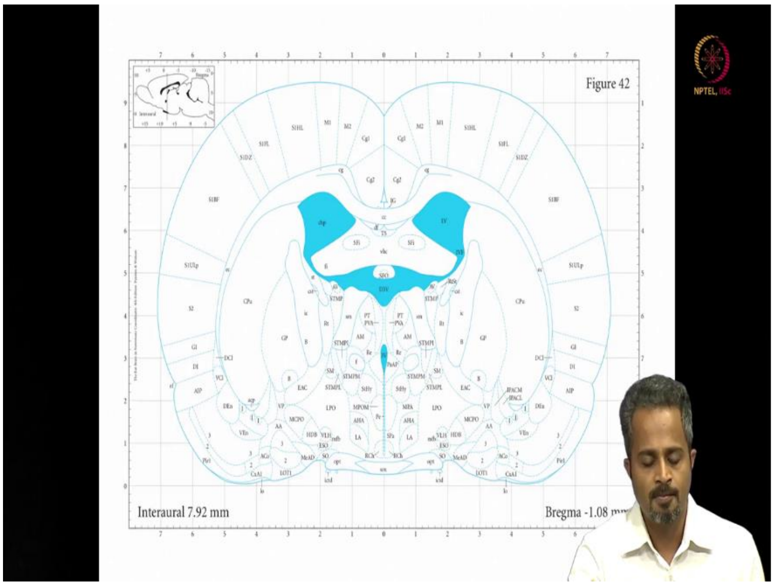
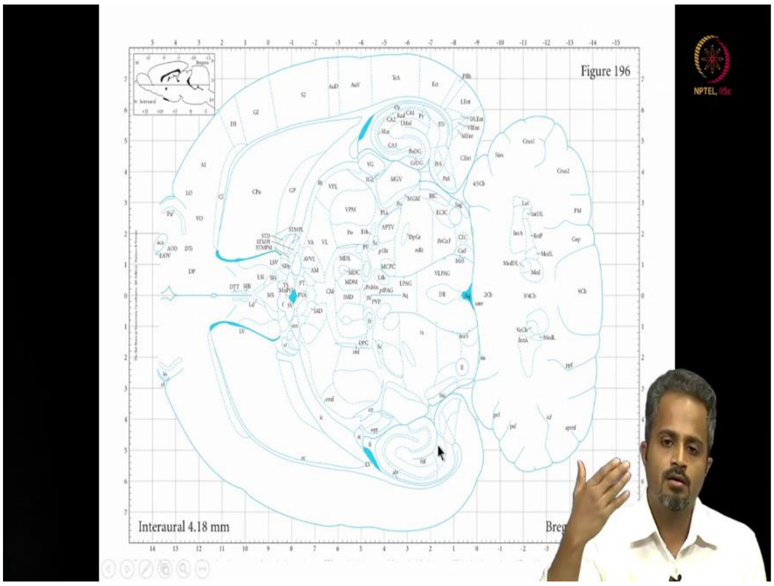
Interaural
NPTEL, IISc





So, that is the human brain mapping but how do we do a similar technique in a rodent. So, we here is what you are seeing here is actually the tungsten electrode that has been implanted in the right motor cortex and… sorry the video is not playing. Actually what you appreciate would appreciate is actually the stimulation of right motor cortex would lead to movement of this left four paw.

Similar to what you saw in the awake brain mapping that was there. So, these are some of the stimulation technique that we would use before we actually implant any sensor thing improve the level of accuracy and how do we do that? How do we approach the area of interest very specifically so that we do not have to really sacrifice the rat.

So, these are the pictures from the zero tactic atlas, Pacino's and white stereotactic atlas which is available for the rodent experiment where there are various…every millimetre there are there is a label pictures that are available and it gives us the coordinate in three dimensions Xy's and Z coordinates where we can actually target any structures deep in the brain and then leave a sensor there and what you saw initially was a sagittal.

This is a coronal orientation and an axle orientation and what numbers you are saying is all in millimetres to the left and the right and then dorsoventrally as well to give us the X, Y and Z coordinates and use those coordinates onto a stereotactic frame and then target those structures.

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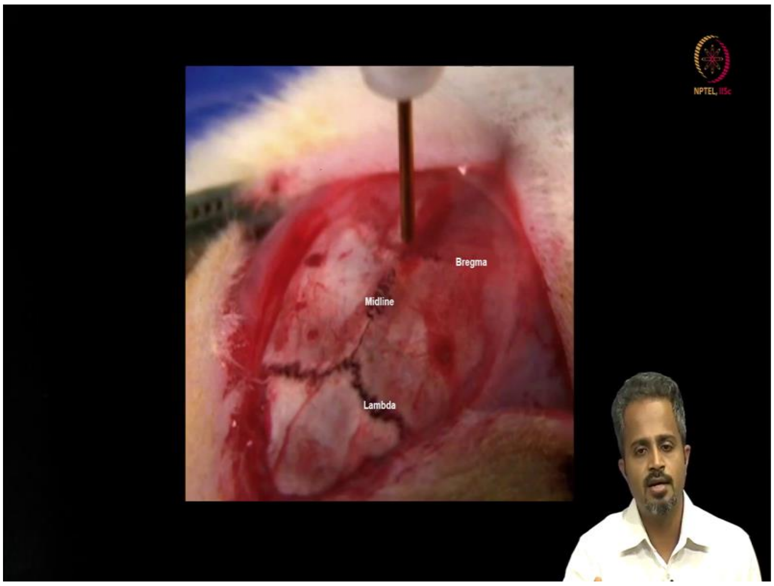

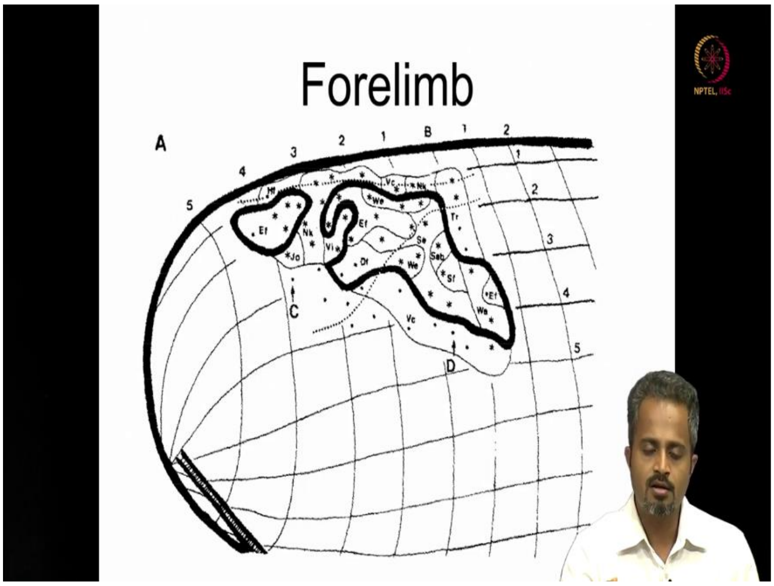

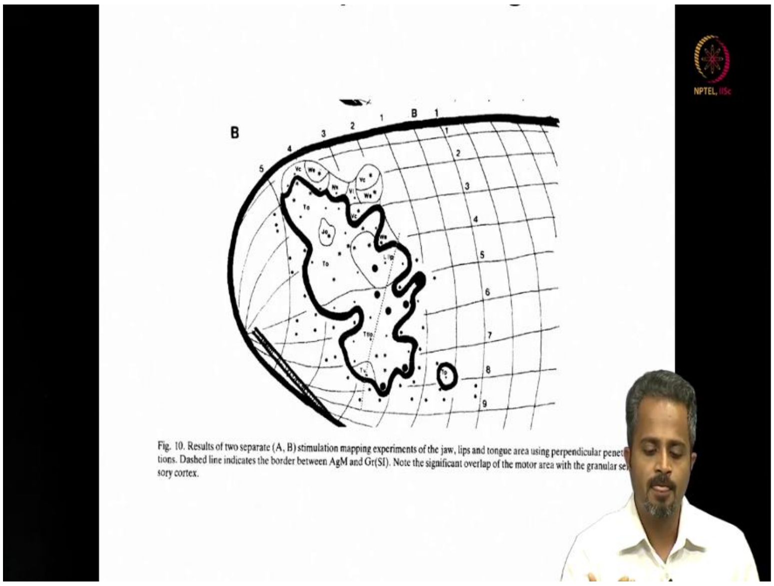

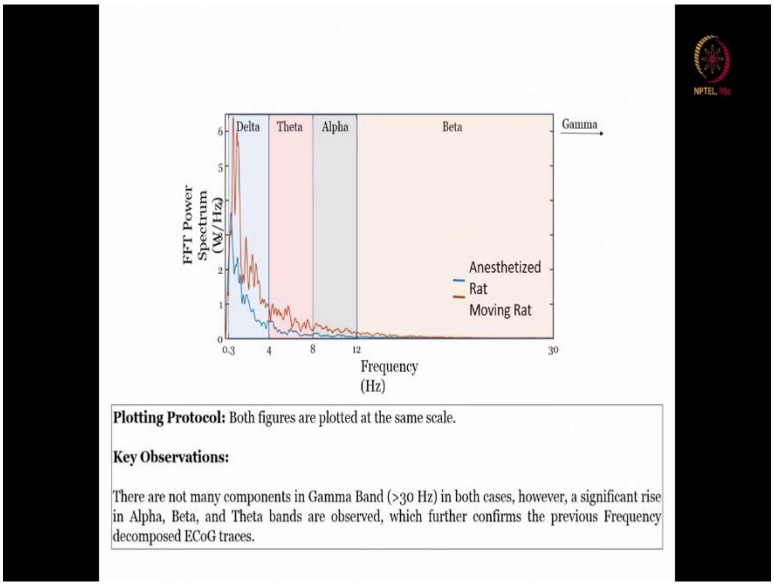

And this is how we expose the skull and then the bregma is identified and then use a stereotactic coordinate. As I said we will be dealing with this in greater detail in the next course which is under review from IIT Chennai.

So, that is the area that we have mapped. I mean this is one of the paper that has published for the rodent brain mapping where the four limb area has been mapped by stimulating and identifying the movements that are occurring as part of the stimulation and that again is the handling limb area that has been mapped, that is the whisker area and that is the tongue area and the whisker area overlap to give the entire mapping using the micro stimulation.

So, this is an example where we have implanted a sensor and then recorded the waveforms from the surface of the brain not from the depth and the difference is going to be, one is electrocorticography and the other one is going to be local field potential versus action potentials.

So, that I guess has been covered already in the previous courses and probably all or if you must be familiar with this. This is a spectral decomposition of the waveform that has been recorded and you can see a nice spectral conversion into various frequency bands here from delta, theta and alpha and beta.

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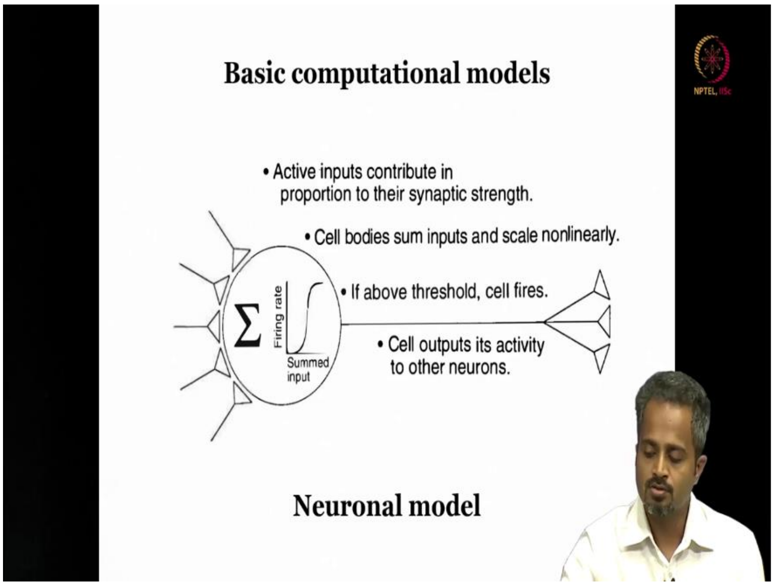

This is very important in next few slides, I will try and show how… this is important to understand and create various mathematical models to make us understand how we can actually decode the action that we are trying to look out for.

So, before I begin the computational part, how is that we can connect all these anatomical structures that we have learned now. So, we have looked at the gross anatomy now and the various areas of the brain are actually connected through various white fiber bundle and those forms the networks. For example, there is visual network and there is sensory network and there is motor network.

So, all these networks are nothing but different areas connected to each other and probably most of your engineers who are listening to this are already familiar with the terminologies machine learning, deep learning and there are something known as deep networks and artificial neural networks and especially artificial neural network is… that is a kind of algorithm or a machine learning technique just mean inspired by the neural systems as to the computation that happens in the brain has been replicated in that form of the algorithm.

So, it is a brain inspired neuromorphic computing. So, brain is kind of a supercomputer and to what extent that complexity extends, I mean not many of us are aware and still it is a huge area of research that is going on. But then whatever I am going to show in next few slides are a super simplified models to understand some simpler functions and to break it down into a smaller cluster so that we try and decode the function that we are trying to study.

So, action potential is the language of the brain. Brain communicates with various areas of the…various other areas through action potentials which will be carried down through the white matter bundle.

For example, person sees an object and through a visual pathway which I showed it is carried down to the occipital lobe and they wear the perception is felt and the person understands and sends the signals to the motor area where the computation happens as to what needs to be done with the vision or visual target that has been seen and then the brain computes it and decides yes, let me grab the cup and then reach out for it as a goal-oriented behaviour and then the purpose is completed.

So, this entire you know circuitry it does an amazing number of computations that happens in fraction of a second. So, let me walk you know walk you through the basic principles as to what exactly happens in these neural networks and how we are using the brain inspired artificial neural networks in turn to decode the signals that we actually recorded from various areas of the brain using the sensor which you all came across in the previous few courses.

So, here is the simplified neuronal model. Actually, to correlate with the actual neuronal anatomy. This will be the cell body that would be the dendrites. I mean those are all cut off and removed to make sure that model lies simple. Just to make sure that the whatever sensory input that would come or for that matter any neural input that would reach the dendrite, here is a input that gets submitted and for that matter the dendritic tree is a huge computational network it in itself where each of these synapses from the various other axons or various other neurons has its own synaptic weightage.

So, the cell body sums it up and then if it is above the threshold, it fires. And once those fires then the output however the activity of other neurons are influenced by the input that it receives at this end. That is where the computation comes into the actual function of the neuron because for example, take an example of a motor neuron which is receiving input from the associative cortex, receiving input from auditory cortex input from the visual cortex, how does it handle? How do we decide that yes we need to grab a cup of tea or let us wait for someone else?

So, that is the computation which keep happening in every single neuron of the brain. So, that is where the input comes into picture and the entire network model comes into picture.

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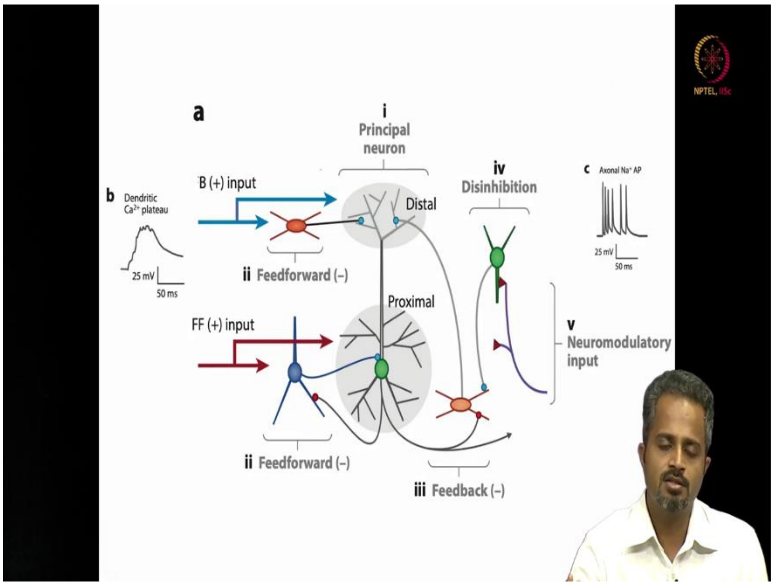

So, to put in a simple word if you look at a neuron this has a feedback input and a feed forward input and various structures which cause disinhibition of this primary neuron which again sends a neuro-modulatory input of the primary motor neuron. The best example would be from cerebellum and basal ganglia.

I am not trying to make it complex but it is indeed a very complex phenomenon where a person decides to move but there are various checks in his brain, be it due to the surrounding atmosphere or surrounding environmental signals or his own past experiences which would guide the movement to happen in a very smooth fluidic way.

That is where the human dexterity comes into picture. So, one of the example, is the cerebellum where it controls the target can controls the movement to the given target and makes the movement really smooth and simple.

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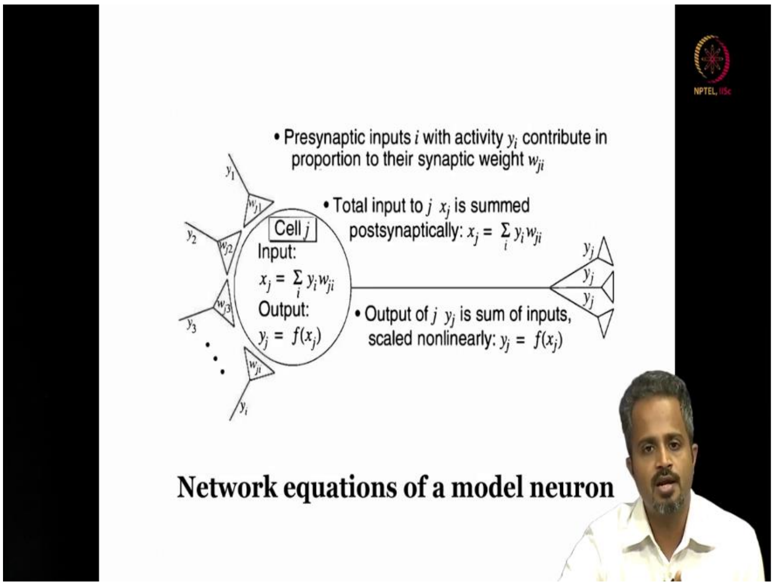

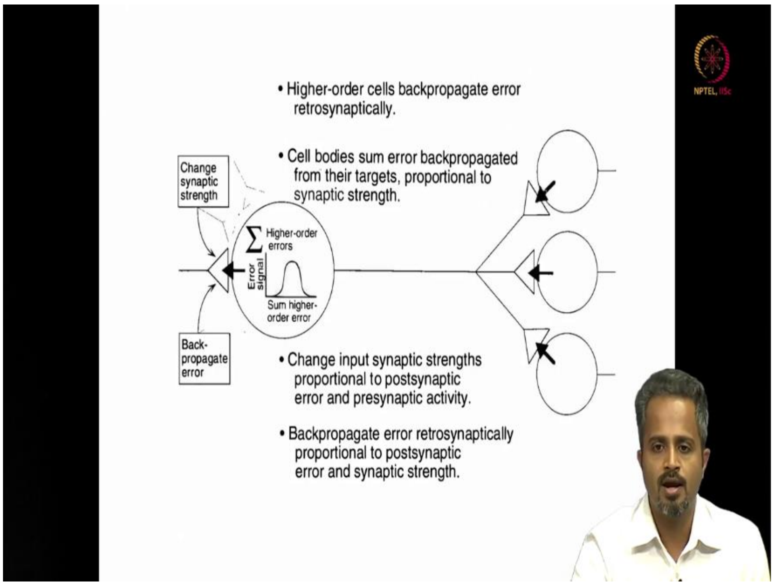

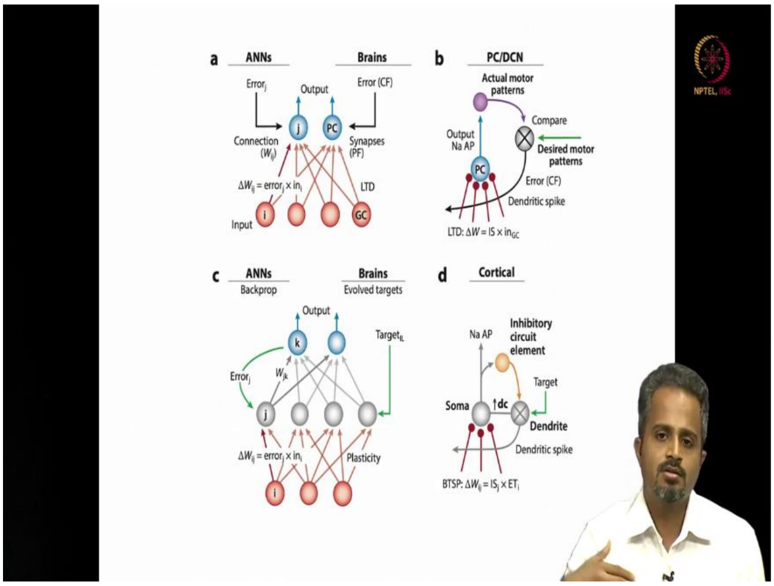

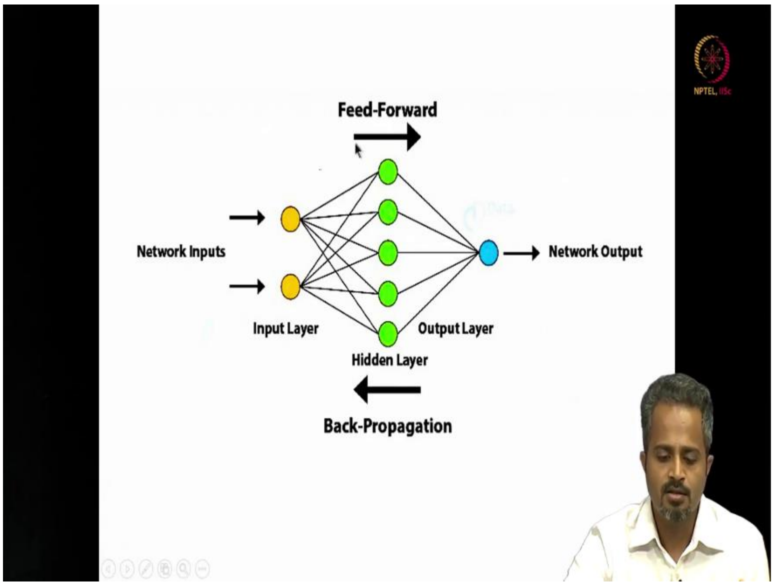

So, when we look at it, so that is kind of a mathematical model of various input that the neuronal cell receives and if you can see the presynaptic inputs with certain activity contributes in proportion to their synaptic weight. For example, there is an input from the occipital lobe, there is an input from the temporal lobe which of that should go here to bring out certain action that is decided by its own synaptic weights.

That synaptic weight is a terminology which comes in into the…. actually there is a morphological changes that can happen in dendritic spines in the synaptic plasticity. There are various structural and functional modifications that happens due to repetitive firing in that particular synapse which happens. That is where the terminology comes into roles synaptic weights. So, every synapse has its own weight based on the synaptic weight the output from this neuron, it is decided and there brings out…which brings out different actions for a similar inputs which is simple by the… simply modified by its own synaptic weights.

So, if you look at there are these higher order cells which back propagate. So, retro-synoptically… for example, first time when you try to reach something the to a target you either overshoot or probably the cup falls from the table. So, that would send an error signal, you modify your action then you go back and reach for the same target.

So, that is the beauty of the neural network and the computation that happens because there is a back propagation which modifies the synaptic strength and synaptic weight. This has a huge role in motor learning, when a child learns to move in a particular way, he want to reach a particular object this is how it happens. So, that brings out a huge change in the synaptic plasticity.

So, cell bodies sums up the error which has been back propagated from their targets and proportional to synaptic strength the output is modified. So, bringing an artificial neural network into picture basically to introduce the term artificial neural network is basically, it is a brain inspired machine learning algorithm. It is a very advanced machine learning algorithm.

There are various I am sure most of you must be familiar with the machine learning algorithms where there are supervised and unsupervised algorithms and there is something known as reinforced algorithm. But artificial neural networks are those algorithms which are… the algorithm developed by the replicating how the brain would function.

So, as a simple fact that… so this is the Purkinjean cell neuron which does the computation which is similar to some sort of artificial neural network where every input has been matched with the desired motor pattern in its memory. It stores the information from the past experiences and every motor output that goes is checked by these Purkinjean cell and modifies its signal and then sends out a copy to it. So, that is where this comes in here.

There is a plasticity that is occurring and there are output that is happening with the hidden layer in between. So, that is the overview of how an artificial neural network would look like, where there is network input coming from various stimuli. Then there is a feed forward because based on the synaptic weights the output is modified and then the output goes into the target neuron. So, that is a very special hidden layer there where n number of computation happens based on various parameters of which synaptic weight is one of the parameter which decides what sort of output goes in.

But in ANN, the specialty is that there is always a back propagation. There is an error signal which goes back and modifies these synaptic weights and parameters of plasticity which modifies what goes again as an output. So, in a natural this is what an artificial neural network would look like and this is how most of the areas in the brain would function and of course this is again a very simplified ways of looking at it. There is in fact an entire book on how…there is an entire book on mathematical model of a brain function which looks at entirely a different Bisayan way of functioning.

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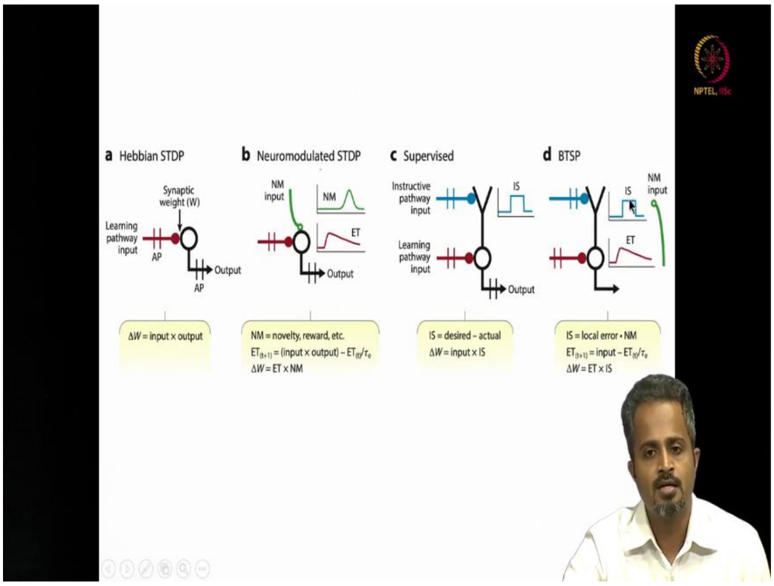

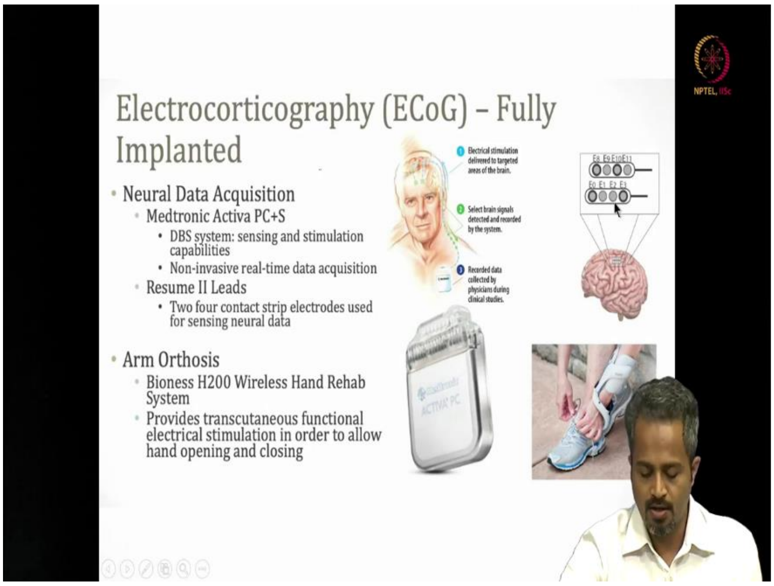

So, these are various forms of plasticity that can happen with various computational models that where Hebbian type which is a very old model of plasticity which has come in evolution it has become a behavioural time scale plasticity where you have a neuro-modulatory input coming in, there is an eligibility traces that is coming and there is an instructional signal that would coming in.

So, these various modulatory inputs will ultimately decide what comes out as an output to modify certain action. So, I would like to sum it up the some of the entire computational through this beautiful example, where the anatomy function and the computational aspect of whatever I dealt today in this lecture has been put together for a translational technology to help the patient with restoration of their motor function.

So, here is a patient who have been implanted with the surface electrode into the brain where the motor signals are gathered and then again using the… again the de-brain stimulation set up there where there is a recording facility from the surface electrode that has been implanted.

And then those signals are decoded and then fed back into the a paralyzed arm through this function electrical stimulator where it stimulates the muscle to bring out action in his hand. So, this is a paper which actually published in the uh one of the Harvard or MIT journals where they brought out the… it made to improve the function of the hand.

He developed hand paralysis as part of the stroke and then they had to collect the motor signals from the opposite hemisphere and then fed into this functional electrical stimulator which is the arm orthosis which is a wireless hand rehabilitation system to stimulate the muscle so that he could make a simple basic gross function.

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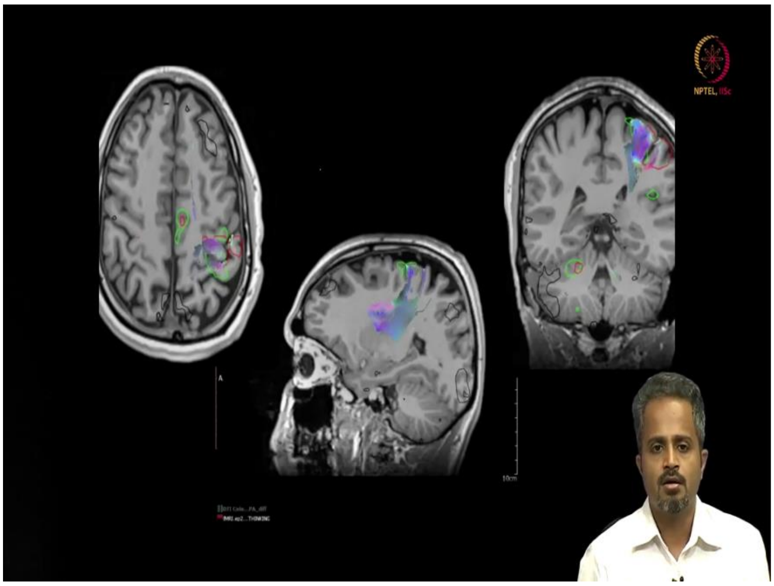
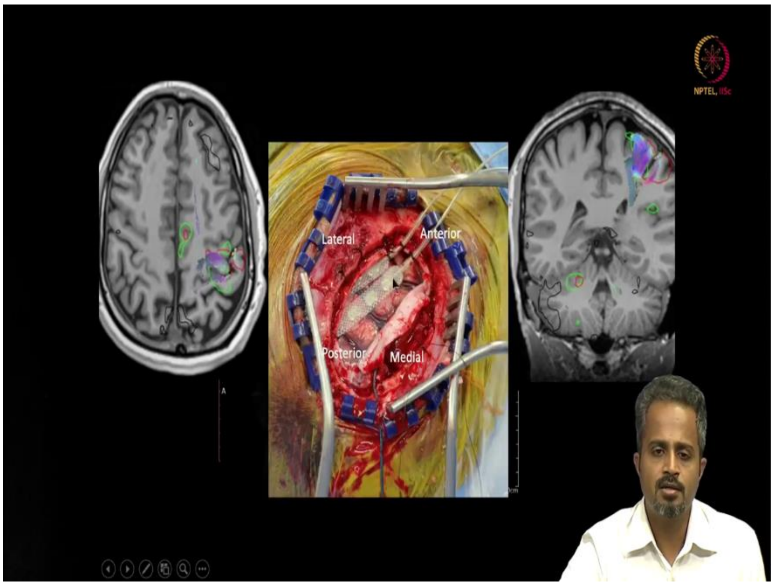
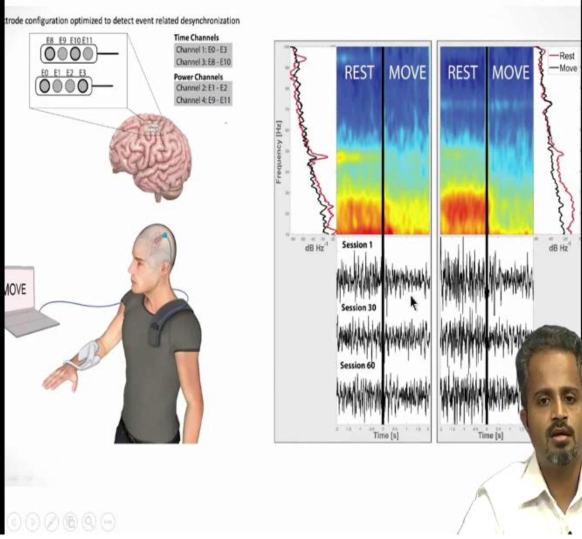
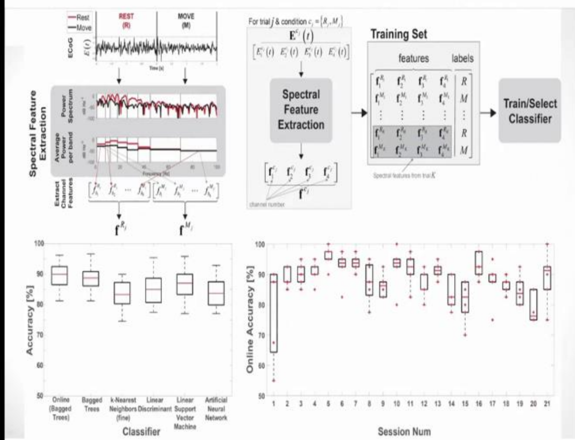


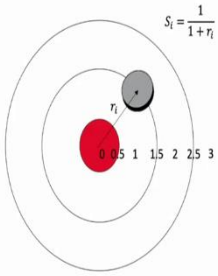


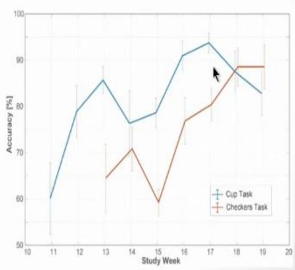




Functional Tasks & Outcomes

$$S_i = \frac{1}{1 + r_i} \qquad S_t = \sum_{i=1}^{20} S_i \qquad \text{Accuracy} = \frac{S_t}{S_{t_{max}}}$$





So, this is another patient where there is a C5 level injury to the spinal cord and then which caused the hand weakness. So, this is also another patient where they imploded the surface electrode and how did they decide to implant a particular area of the brain. This is a again, a healthy individual where the only problem is that he is unable to move the hand because of this a spinal cord injury.

But his motor cortex is healthy, so we do what is known as the functional imaging to map out the motor cortex and then that is the tractography to map out the motor pathway and that is the area they targeted stereo tactically and then implanted the surface electrode.

Once the surface electrode is implanted, then we collected the data of the surface electrocorticogram and what you can see here on the right hand side is the event related desynchronization. Whenever the patient been asked to move, though he is unable to move he can imagine the movement that itself is enough to bring out an event related desynchronization. That terminology is basically that you can see a high amplitude low frequency waveform changing into a high frequency low amplitude band.

Basically, a switch from alpha to beta and gamma band. That switch is enough to compute the signal and decode the signal. Let us see how that is done using the artificial neural network model which I just discussed. So, here you can see the pre-processed data raw signal where the rest and move you can see an event related desynchronization and that has been broken down into eight different bands and that is a power spectral decomposition.

Then you calculate the average you know power in each band then you assign a function and then train the data, that is another terminology I would like to introduce here that any algorithm, any machine learning algorithm needs we need to train the data, identify the correct signals and function so that we connect with various trials of course. This patient of course underwent around 60 to 80 trials before they could finalize what feature belongs to what movement.

So, once that features are assigned you extract those features that is where this would come. This function is again a decoding algorithm function where you extract those features of course with the various computational function and then you train the set. In this particular example the one and three electrode is the rest and the two and four was moving and then once that classification has been done then you train that algorithm to classify automatically as in when the signals are generated, it classifies as what is rest and what is a movement and then that… so here you can see the various classifiers.

These are the various performance of different classifiers, artificial neural network is one of the algorithm and other are support vector machine, linear discriminant algorithm. So, these are the accuracy, measure of accuracy using various algorithm and the best of it will be chosen and you can see as the number of sentients goes on, you can see the performance being improved.

The only difference is that, being this an electrocorticogram, the waveform that has been you know recorded is oscillations which is actually a summated activity of n number of neurons as compared to the action potential which are brought down by the depth electrodes. But nevertheless for a simple function of grasping, this is good enough and it is a proven fact that with the electrocorticography itself, one can bring out a function electrical stimulation of the hand muscles where the rest and move event related desynchronization has been translated into the movement, the stimulation of his own muscles.

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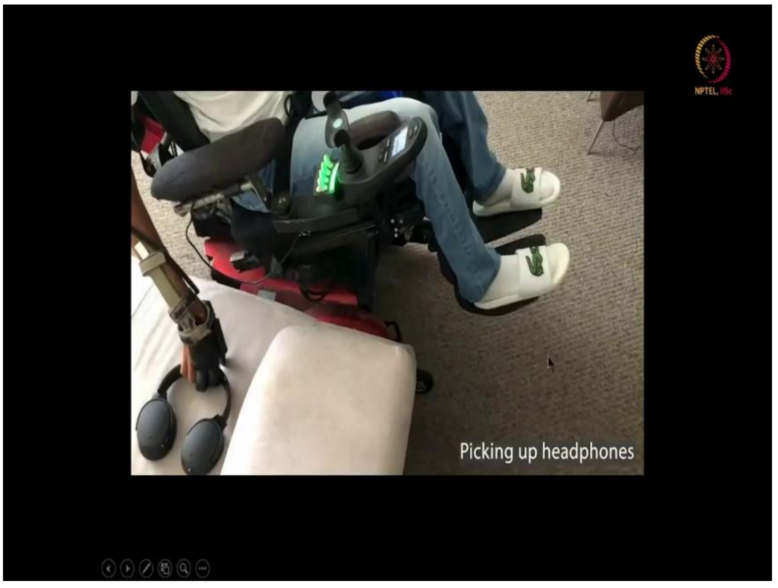
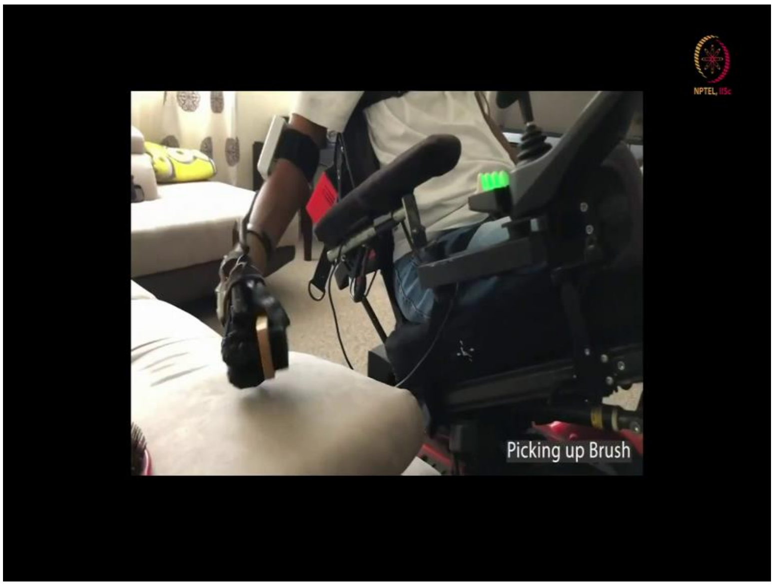



Picking up headphones


Picking up Brush


Brushing Beard

And you can see that as the number of weeks progressed, the data has been trained and the better classification happens and then the accuracy improves over a period of time, so that, that is the result of the decoded algorithm where a person can pick up or grasp or a phone or even grasp the brush to brush his hair. So, that is the beauty of neural engineering. If you can put together the anatomy and the functional aspects with an amazing computational neuroscience. This is something that one can achieve from the neural engineering.

So, now as you all saw that we went from the anatomy to the function and then the brief introduction of the computational neuroscience to understand how exactly we record the signals, from where do we record the signal, how do we interpret the signal and then of course decode what those signals means by way of computational neuroscience and for the benefit of the patients.

So, this is in a brief way as to look at the entire aspect of the advanced neural engineering. So, I guess I hope to see you all again in the next course once it gets reviewed and accepted to see as to how we actually implant those electrodes and what sort of surgical techniques are available, what sort of animal models are available and how exactly we collect the data and then process the neural data that we gather. Thank you all.