Neural Science for Engineers
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Lecture - 13
Architecture of the Nervous System Contd

This is in continuation with the discussion on the anatomy, that is the structure of the central nervous system. So, we will go into greater depth of understanding. I am spending a lot more time on the anatomy because initially my plan was not to dwell too much on anatomy.

But then I realized that the audience would contain students from biomedical background and there is a lot of engineering focus on imaging of the brain and signals acquired from the brain, and lot of other things say apart from the core ML group, who are looking only at the functional part of the brain.

So, what happens is unless you understand a lot of this structure it is difficult to attribute things. Now, neural anatomy in general is assumed to be very difficult and very hard to grasp. One reason is because as compared to several other parts of the body there is a lot of structures, which are very compactly placed. So, even for surgical students, neurosurgical students, it is a very long process when you get an actual understanding of how things are arranged within your own head.

So, it is with that background I am trying to set up things. So far what I have discussed is very gross structures of the nervous system and how the hierarchy is built up, we discussed about the brain, spinal cord, different parts of what we call as the brain, that is the cerebrum, cerebellum and various internal parts of the brain.

Now, that is for declaration you know I just declare that these things exist, but it is not sufficient enough for understanding. So, what I would be conveying subsequently is how to have an understanding, how to remember these things and how to answer a question or even when you are putting up an experiment or doing some study or analyzing data and reading a paper to figure out you know.

If somebody says something about the substantia nigra you should have an understanding that it forms which part of the nervous system, where it is approximately located and what should be its function. So, that is the idea of the discussion now.

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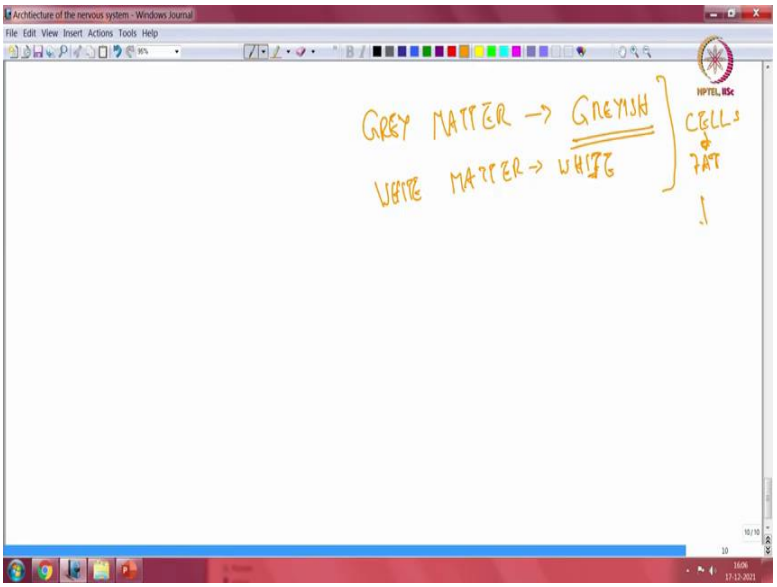

So, as usual fundamentals first, I have already spoken about grey matter and white matter and how they are different. So, grey matter is greyish. I will be showing some videos later on which will prove this point and white matter is white. So, ultimately all of this is cells and fat filled. So, sort of resembles fat in its general appearance.

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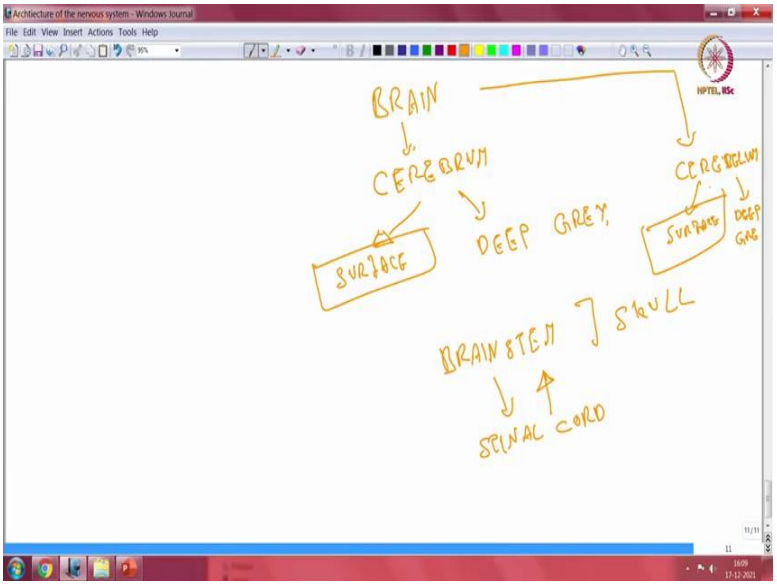

Now, some terminologies need to be understood. So, we discuss about the brain first and then proceed on to the brainstem and spinal cord. So, when we say brain, the idea is that we usually refer to cerebrum. The cerebrum as I told you consists of the surface and the deep grey. And you have cerebellum which also has similar architecture – surface, deep replicating, but the surfaces there are differences between that and then you have the brain stem.

So, brain stem continues into the spinal cord or vice versa. It is sort of at the uppermost extent of the spinal cord and this is within the skull. So, that is a key difference. Where it is located is within this part of your head, spinal cord is in the back. It is all covered by bone.

So, in fact, one of the other problems I have to deal with is how much of skull stuff which you need to know, but for the sake of clarity I would be explaining a lot more stuff than what would be necessary, only to help you relate stuff. Anatomy basically is about relations; what is an entity and where is that entity in relation to so many other stuff which are around.

So, it is not possible to learn something in isolation in the context of anatomy. So, whatever is relevant and what I feel would be easily understood is what I have tried to project. Some of the stuff is pretty graphic maybe surgical videos or specimens which I may or may not get, but I hope you would not have a problem viewing those things.

Please do understand it that is with good intention, as much as possible I try not to put gory stuff into it, but you know I cannot explain anatomy without actually showing a skull so, which I did in my first class. So, I think you should be comfortable with the idea of viewing a skull as of now. So, we will focus on the first part. So, we will look at what is surface and then I will dwell into some other parts of the stuff.

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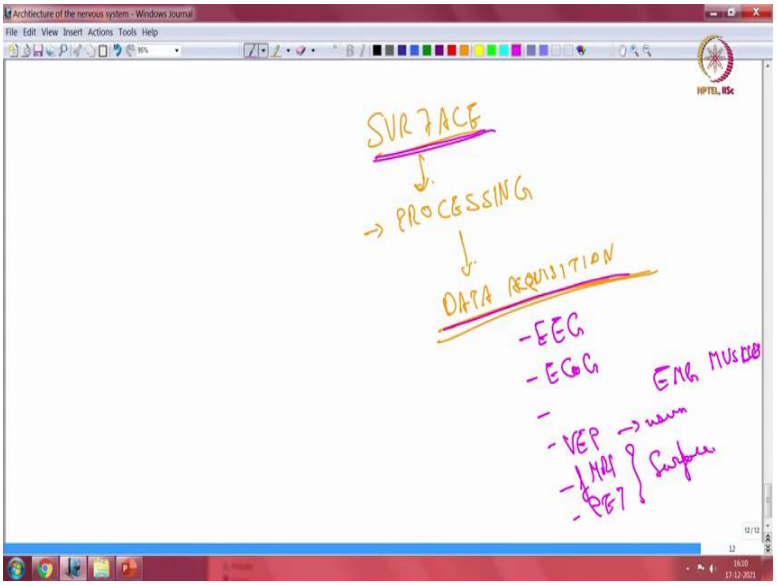

So, the surface of the brain is where most of the stuff of interest happens. So, what I mean is most of the higher-level processing happens in the; this one which also means that you are interested in data acquisition. So, most things look at data acquisition from the surface. So, you would mostly be looking at surface data in lot of things.

So, whether it be EEG, ECoG or actually EMG is from muscles which is relevant muscles, which I would be dealing some part of it. Then you got VEP which is for vision and even in terms of FMRI and PET you have surface which is of surface analysis which is of importance. So, you need to find out what part of the surface is getting activated and how do you correlate it with actions or something else.

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So, the cerebral surface in turn is divided into folds. So, all of us are familiar with this, but I need to explain this because it is important. So, you have folds like this, and they are called gyri and sulci. So, individual is gyrus, sulcus. So, sulcus refers to the depth, gyrus refers to the whole stuff.

So, in another fashion this is an exaggerated view. So, we would be saying that this part is the sulcus, this part is the gyrus. I suppose nobody should ask me the question that where is the boundary between a gyrus and the sulcus, it is not so. So, I think it is easier to show.

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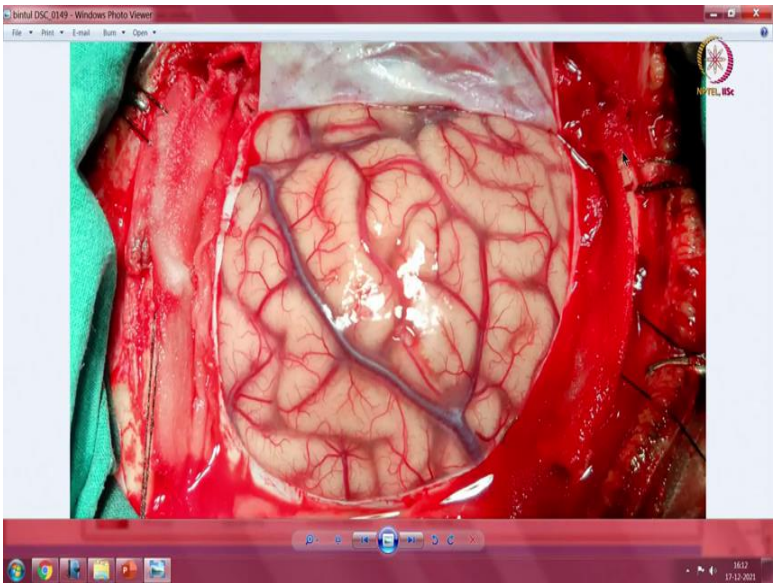

So, this is a picture. So, it is like this, it is an actual picture from a neural. So, there are several things which I have to highlight over here. When you look at the surface of the brain it looks this is an intraoperative photograph. So, it looks exactly like this, and the gyri is what you are seeing.

So, these things in the center, how do I mark this? So, this is the sulcus, sulcus, sulcus, sulcus, sulcus because a vein is seen on the surface; the this whole stuff is a gyrus. So, when you are seeing on the surface of the brain through either an MR image or if you are seeing operatively, this entire thing is called a gyrus.

So, the lines in between the gyri are the sulci. So, sulci, sulci, sulci, smaller sulci, very small sulci. So, and the pattern is something which I need to note. Now, if you look at

anatomical descriptions and even what story I am going to say, it looks like the brain is very well organized, but something which I have to highlight, this is the surface anatomy which we are discussing.

So, though your hands are very similar in symmetry and things like that if you look at the veins on the back of your hand you would notice that even both of your hands do not have symmetry and there is a lot of difference between the vein architecture between the two hands. It is almost something similar to your fingerprints you know. All five fingers have very different fingerprints. So, similarly is in the brain. Surface anatomy of even two sides of the same person do not match.

So, what we discuss anatomically are abstract concepts of regions and these regions have some relevance of course and what is you understood is the diversity.

So, the surface anatomy is very diverse, and the diversity extends to even between two sides of the same person, to two different people who look very different, but they are like in the hands, they have their limits in which the diversity occurs and that is something.

So, how do you understand something as diverse as this? So, neurosurgically speaking it is very difficult, which is why we have several kinds of investigative modalities to help us solve problems, physical problems within the surface of the brain. So, having said that we go step by step.

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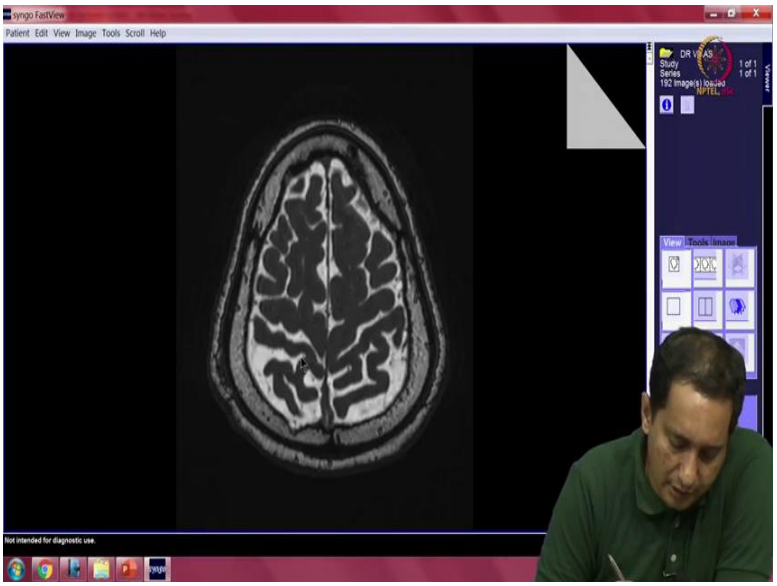

So, we look at MR imaging. So, I am making it complementary because I do not want you to have an understanding, which is independent. So, you should not understand only structure without having the ability to map it on to some kind of data stream which you have seen.

Data stream may be EEG, it may be imaging. Imaging is important because like in one of my previous classes I discussed there are structural imaging and there is functional imaging. So, functional imaging, functional data is some idea of the activity of the brain. So, it can be electrical activity, which is EEG, EMG, etcetera, VEP which is for the ear, BERA for the ear and things like that and there are functional imaging.

So, a functional imaging is you map on a map the probable function at various points in time. So, that is through FMRI which is Functional MRI and PET which is Positron Emission Tomography. I think I have discussed it in a little more detail earlier. I would cover a lot more detail about this because it is in the context. So, first you have to understand the brain. So, that is the reason I am showing this particular one.

What I would like to highlight, here is the absence of absolute symmetry, but the presence of similarity. So, if you can see here, you can find out that this particular thing is very symmetrical, but the curvature and the location, dimensions are literally changing millimeter to millimeter. So, that is what I meant by even differences existing between two sides of the same person.

So, each of this is a gyrus, gyrus, gyrus, gyrus, gyrus, a lot of this empty space is what we call as the sulcus. So, there is a lot of empty space in between which is the sulci and then the gyri are the brain tissue as such. The it looks different from the surface stuff which I showed in from the intraoperative photograph.

So, I showed because what you see on imaging is pretty different from what we see on an operating table of the same thing. See, ultimately what is in the MR imaging is the same stuff, which I showed in the intraoperative imaging, but the look and understanding which you get of the same stuff; the gyri and sulci are completely different.

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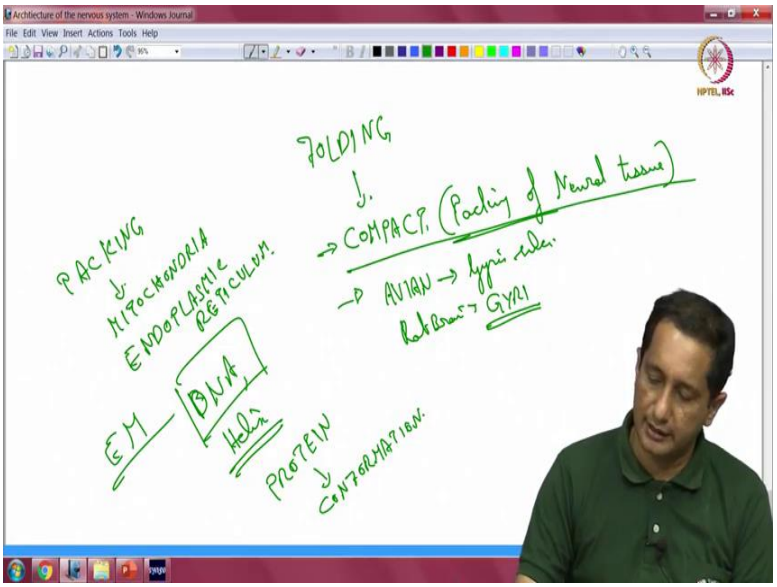

So, coming back to our discussion gyrus, sulcus, so, what are the purpose of this folding? So, folding is apparently to make packing compact, packing of neural tissue. You can apparently accommodate, I am not very convinced about this because if you look at another place where packing happens is in mitochondria, mitochondria we have just met in one of the previous lectures.

Mitochondria are responsible for maintaining the electron transport chain and aerobic power system. It is the power cell of the entire cell. So, in a mitochondria you have different kind of packing, then there you have something called as endoplasmic reticulum. I would invite you to give searches on this and look at photographs from the internet in the electron microscope photographs by which you see how packing is done in these structures.

So, these are incidentally biological packing. These are biological packing mechanisms. The bigger and more different packing is in DNA which has this double strand Helix and if you look further into that. So, packing is prevalent across the biological systems for several reasons and why we go to DNA then there is protein packing.

So, protein packing is called conformation. We are familiar with this term because we have seen sodium channels change conformation, potassium channels change conformation and MDA channels do funny stuff. And so packing is universal in biological systems, but why we have gyri and sulci in the neural in the brain, but it is not there in the spinal cord, why packing is very dissimilar to mitochondrial packing? Those are points of research.

So, what happens in the brain is that this is meant to make it more compact. So, but this folding has been pretty much there evolutionary for quite some time. In fact, I think I should be able to show pictures of that. So, if you look at bird brains. So, even they do have some amount of gyri and sulci. If you look at rat brain, the gyri's business is still there.

So, it indicates that evolutionarily it has developed along that line. So, we as of now current research is not sufficient enough for us to explain why gyral pattern of packing is superior to say endoplasmic method of packing for neural transmission, processing, etcetera. So, there is something which we may not yet have figured.

So, the idea that gyri exist for making information processing compact is not there, but we study it as a feature. I showed you from MR and MR imaging and operative that these are pretty different.

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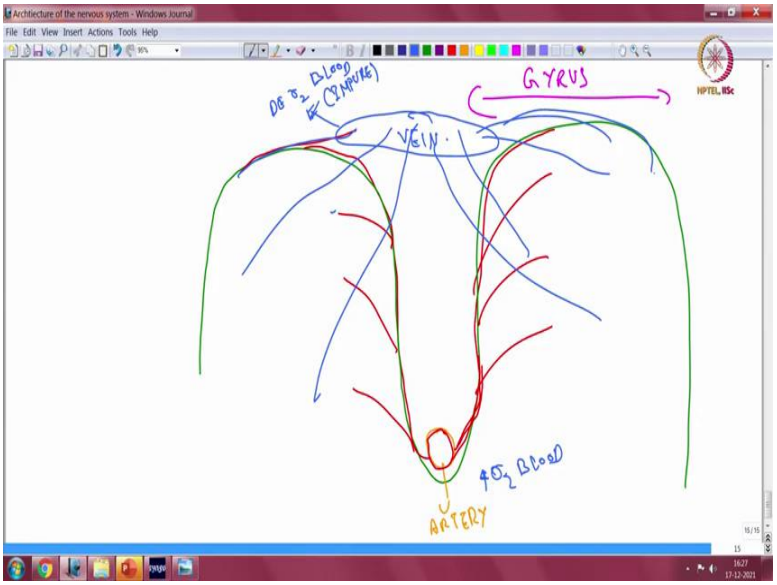

So, what actually happens within a gyrus is this. So, we look at a structure of an individual gyrus and a sulcus again blown-up images. So, as I told you this would be a gyrus. So, in the depth of the gyrus is the blood vessel. So, this is an artery; artery is in red, and veins are in blue, ok. Artery is oxygenated blood, vein is deoxygenated. For people who have really forgotten basic stuff in biology.

So, deoxygenated blood also called impure blood. I think time to show the photograph again. The blue thing here is vein and the arteries are this red stuff and this is the vessels which are coming out from the sulci.

So, arteries are from the depth and then they go across. So, this is the artery and then they supply the entire gyrus on one side and gyrus is referred to a longitudinal structure. So, this is a cross section. Cross section in the sense that it is cut across the surface. So, that is how you are viewing this. In the long axis it would look like the picture here.

So, when we speak about a gyrus, so, this entire thing is a gyrus. This section if you have cut over here is what looks like this. So, gyrus vessel blood artery goes from here supplies one half of the gyrus both the sides. Now, the vein is funnier; it takes in supply from a larger area.

So, there is a dichotomy of arrangement. You would expect the artery and the vein to go together it is not so. Veins are usually on the surface and then they take a different pathway as opposed to the artery which is in the depth of the sulcus. A brain tissue is

very richly supplied with blood as I have told you in the power systems class because of the very simple reason that the brain cannot survive without glucose or oxygen.

So, there is a rich supply of blood vessels which ensure that the concentrations of glucose and oxygen at every given point within the brain is met and adequately taken care of. So, we proceed further.

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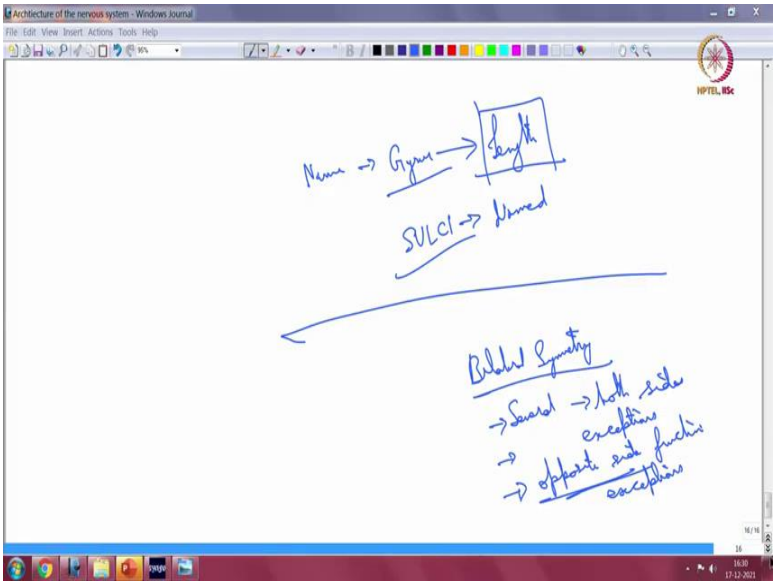

So, other specialties between this gyri and sulci. So, there is a general architecture of the brain that we name. So, we name a gyrus for its entire length. So, there is a particular length of the gyrus, which is named and that is how we would be looking at the nomenclature subsequently on.

The sulci are also named. Some of the important sulci, there are important sulci which have their relevance and so, sulci are also named. So, you would from my earlier part of the talk, it is not where is the boundary you know that is a very obvious question, but there are no defined boundaries as such.

So, the depth of the space in between two gyri is where it is called as a sulci and the whole mountainous thing is called as a gyrus. It is a longitudinal structure, and you have names for both gyrus and sulcus.

Now, there is bilateral symmetry to some extent. So, there are several structures which are on both sides. And, so, bilateral symmetry the first thing is there are several

structures; some structures are single, you know midline or one. So, some exceptions. Then the common rule as such is opposite side function. There are again exceptions to this.

So, opposite side means, this is something which I think most of you would be aware, your right side of the brain controls the left side of the body and left side of the brain controls the right side of the body. There are functional differences between the left and right which is very prevalent in popular culture on right headed people and left head and left head and left-brain people. So, there are functional differences between that, differences between how information is handled and processed.

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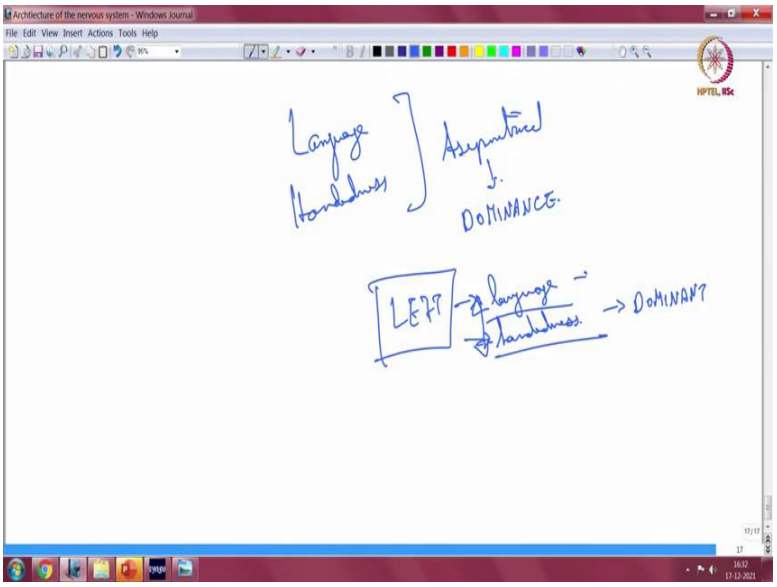

And, uniquely say for example, language, handedness are all asymmetrical or in the sense that there is something called as dominance. Most people are left dominant for a language and handedness obviously. Now, handedness is the dominant hand for function; say dominant hand in the terms of how often we use a hand for say writing, for drawing various different kinds of tasks in which the dominant hand is usually one you would.

Very few people are ambidextrous in which they have very equal function on both sides. There are also left-handed people who have the left hand as their dominant hand and there are very good examples that numerical superiority is not equivalent to any other kind of superiority. So, handedness is a feature. So, it is a property which is there and that is about it.

Language again it is usually left hand sided. So, it is important for neurologists, neurosurgeons and anybody working because it is one of those things which are very difficult to acquire from structural imaging. So, functional imaging is necessary to find out handedness where speech is localized and located and things like that. So, that is the point of knowing the difference between what the handedness of the person is, and what is the speech.

Now, generally both of these are connected to each other. So, you would have left dominant people being right-handed and speech located on the left hemisphere. Of course, I do not know statistics of how many left-handed people have left sided speech areas. I have not checked it up, I have not heard of any studies on that issue. So this is about how things are within the gyri and sulci and how regions of the brain are divided.

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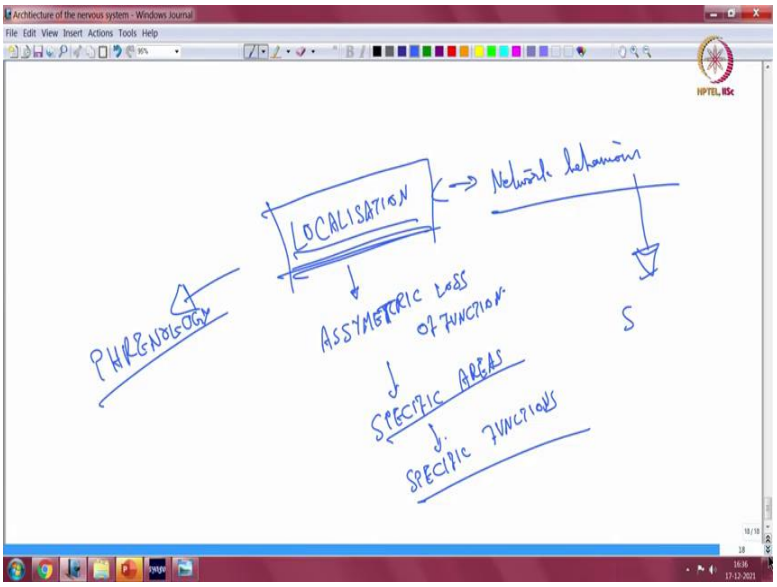

Now, another thing which I have to tell are more general, is the concepts of localization versus network behavior. So, I will start with localization because when people started studying the brain, it was thought that you know brain has a unitary entity. So, the brain has such does all the tasks which is attributed to it starting from talk to speech to anything else which can which is done by the brain and every part of the brain is equally important.

But anybody who has been in the medical field meaning ages back would have noticed that damage to the brain causes a symmetric loss of function. So, asymmetric loss of

function, so what does that mean? So, that means, that specific areas have specific functions. Now, that is important because you would be able to relate damages to diseases.

So, structural damage can cause a particular structural disease vice versa when a person has a specific neurological disease, it is possible to find out where in the head is the disease without actually doing imaging and in fact, localization was the technique adopted until high quality MR images could actually discern stuff happening within the head.

You could localize to some extent with CT scans, but MRI gives you more accurate structural imaging which is superior to clinical localization. Clinical localization is when a patient comes with a problem you find out from the patient through talking and through clinical evaluation as to what part of the brain is damaged and that is the art of localization in a neurological examination.

Now, would have heard that this also resulted in some field called as phrenology in which people actually attributed bumps on the skull to better function in various parts of the head, but as of now we understand that, that is not the case. So, the skull shapes, bumps, etcetera do not correlate to functions underlying that area. So, there is difference.

So, phrenology as such no, but what is important is that localization of functions are there within the brain. Now, although I said that network behavior is something of an older concept it is not completely true. There are several entities which do not have a definitive focus and which I will be looking into in a greater detail in the relevant topics.

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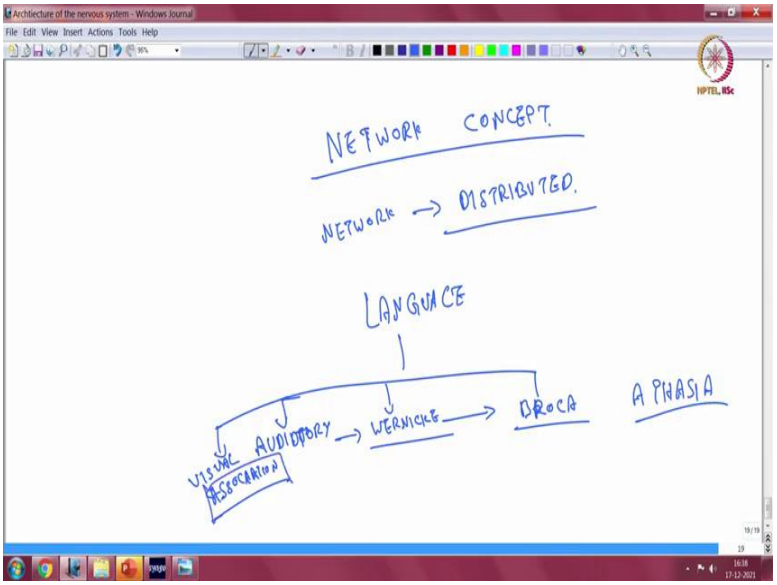

Say for example, if we again look at speech so, we look at the network concept. So, network concept there is a network in place. And the network may be distributed. Simple example for that is if we look at the language network, we have different areas.

So, we have the auditory speech area, which in turn goes to Wernicke and then goes to Broca. So, these are defined areas which are examples of localization. In fact, when you have damages, you call them as specific aphasias; aphasia is a speech problem. So, you can have patients who can have Wernicke's aphasia, they can have Broca's aphasia, they can have some combined problems.

But, if we look at it, it's not so, the network is bound by various distributed areas in the auditory area even those higher speech association areas. So, auditory and visual association. So, association is the higher area of sensory modality. So, you have auditory association areas, you have visual association areas.

And these association areas converge to Wernicke's where speech processing conceptualize the core thought and the higher level speech decisions are made and that is transmitted to Broca, where the actual output is finalized you know, what kind of tone, pitch, the words are decided and then it is distributed to various parts of the face and throat and all that. We will deal with that later. So, what I wanted to show is it is still a network and damages to the network causes loss in function to that extent.

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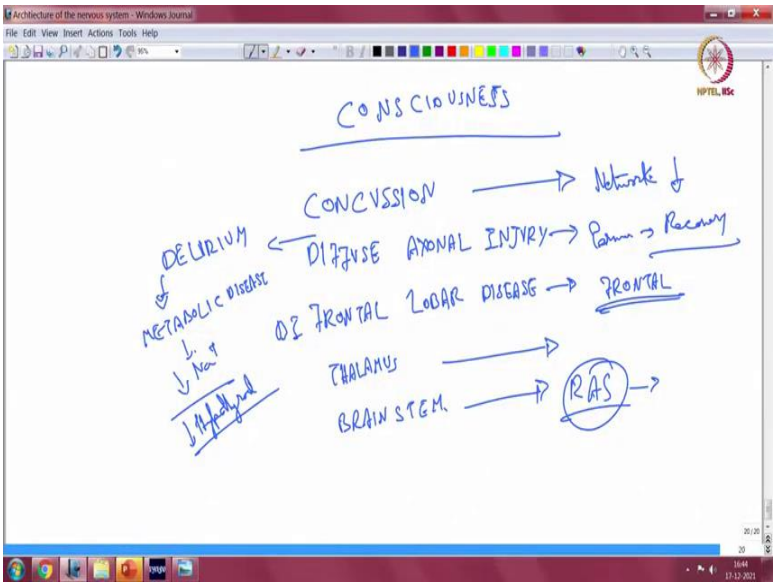

A different example and something which may be controversial is in terms of consciousness. So, a logical question from the localization discussion is where is consciousness localized to. So, there are people who would say thalamus reticular activating formation and things like that, but as a neurosurgeon I can tell you that we see people lose consciousness for anything from concussion, diffuse axonal injury, frontal lobar disease or bi-frontal, and thalamus brainstem.

So, if you look at the previous discussion where I discussed about speech, you would imagine that these are places where conscious speech is localized and so, if you look at the same model when there is loss of consciousness you would imagine that consciousness should be or could be attributed to one of these areas.

Concussion is basically you know it is a temporary reversible loss of sensorium and the person becomes unconscious and then becomes completely normal. There are things which say that there are long term implications of this.

But if we look at it basically concussion is something like a network issue you know network comes down. There is no structural damage as such to the brain, but you know the injury is sufficient enough to cause a general degradation of this one.

A parallel discussion which I think I should put over here is the idea of delirium and maybe there is altered states of consciousness say from metabolic disease. So, metabolic

disease say for example, reduced sodium or hyperthyroidism, these are different disease states you know they are very diverse disease states which can affect sensorium.

People who would say that hypothyroidism related loss sensorium occurs in some poster patients who have had compromised thyroid function. So, these do not if you look at MRI data of these people you would not find very obvious damage concussion does not show obvious damage to the structure of the brain but, consciousness has come down.

Diffuse axonal injury is little more permanent; permanent in the sense that recovery takes months. There is structural damage. There are MRI tags of diffuse axonal injury. It is a type of injury which happens in head trauma and patient is unconscious for fairly long duration of time, but they recover.

So, this is another state of consciousness which is you know come down and takes a long time to recover without corresponding structural damage. You do not find that much amount of damage within the brain as opposed to this.

Bi-frontal disease is a headache for us because we do operate on tumors which affect both halves and then suddenly you find that the patient is not waking up although surgery has been done well. Now, that is again something which we notice and so, we attribute that the frontal lobes do have important contributions to the overall consciousness of this one.

Thalamus again is one of the known areas where we will discuss that when we discuss the thalamus. So, thalamus is one of those areas where there is a lot of to and fro activity which happens which is responsible for the state of activity meaning a state of activation of all of us.

Brainstem again is the seat of the reticular activating system and this itself is a is not an entity as such it spread all across the brainstem and is responsible for consciousness. So, what I have tried to highlight is that there are two fairly differing theories of functional behavior of the nervous system.

So, you have got localized areas which are very hyper focused, hyper specialized for a kind of task, but that does not mean that they are you know whole and sole entities. And surprisingly many of them are very distributed.

We would assume that for something which has evolved and thought of something like you know gyri, sulci compacting and things like that should have even thought about getting all these regions together because closer they are you know, computational efficiency is better, but it is not the case.

We still do not know why say the language areas are so distributed. Why Wernicke's did not subsume Broca's and then take over the function of Broca's and leave it to something else. So, these are mysteries which we obviously, have not solved and we do not have an idea about, but what I would like to highlight is that there is a distributed philosophy of nervous system function. There is a hyper localized philosophy of nervous system function.

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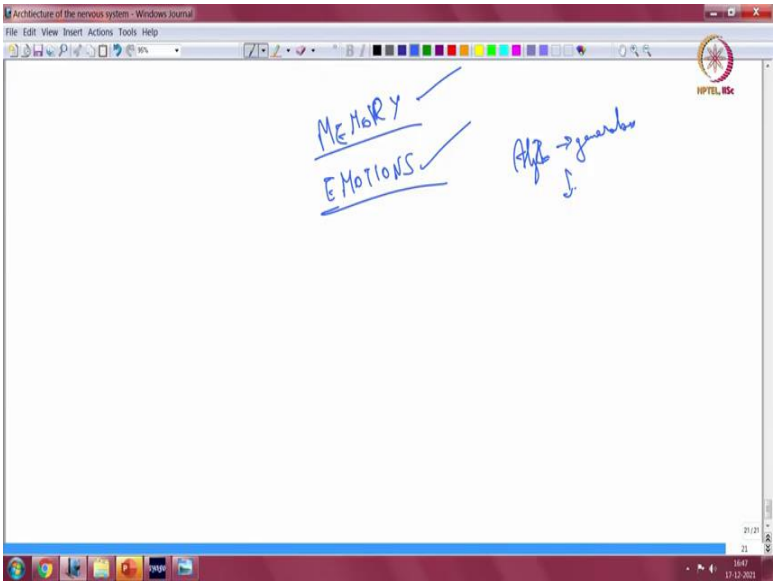

A similar idea exists in the idea of memory. So, memory there are different parts than emotions. So, the processing of memory, emotions they are not localized. So, we do see diseases which have structural problems, but it is not that, that structural problem is always associated with a particular disease.

To give you as a hippocampal change in memory loss you have Alzheimer's, which is generalized. So, of course, which have more loss in different areas of the brain. So, there are there are several such entities which do not have a structural basis which indicates that they are network functions of the brain.

So, the entire brain in some fashion contributes to that particular task and you cannot pinpoint a particular area to which you can attribute that thing. So, both of these are important, and this understanding is important because as I told in my previous talk, when you get a single stream of data and you are expected to make an inference on something, please do keep in mind that the data which you are getting has it is own problems.

Not only because the acquiring technique method frequency of acquisition has issues, but we also do not have a clear understanding of how the brain functions for that particular entity. So, there are so many unknowns in the equation. Please do keep in mind that these unknowns exist, and they exist in whatever equation you are dealing with when considering the nervous system function.

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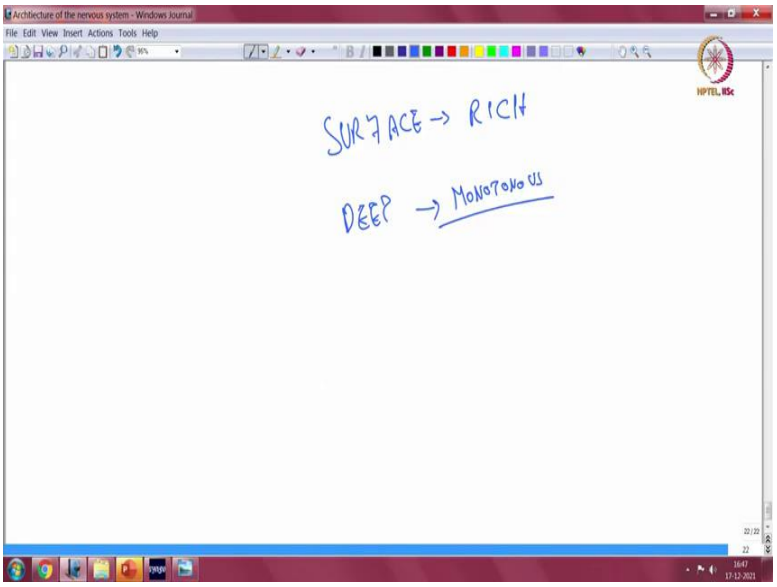

So far, I have just started about the surface anatomy of the brain and how it is arranged. The deep brain surface is rich, the deep grey is fairly straight forward in the sense that I should almost call it monotonous, in the sense that you do not have that difference between individual sides of the brain.

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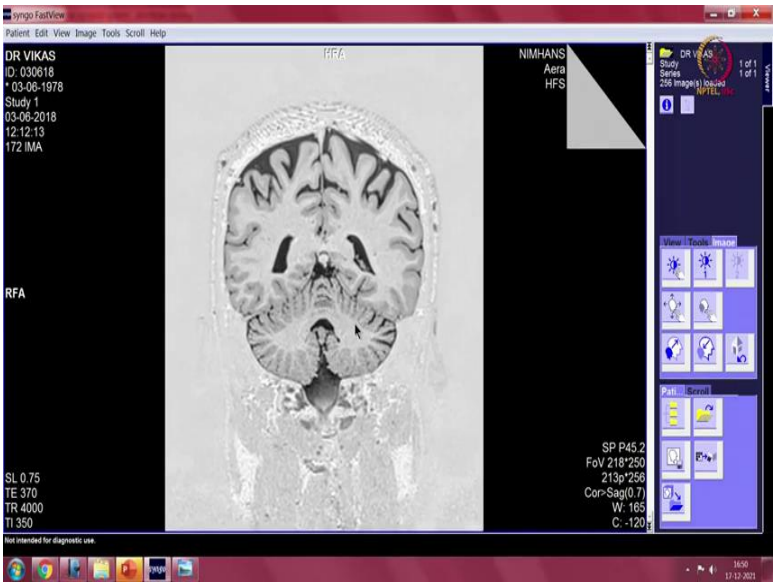

So, this whole stuff is the surface anatomy of the brain, will go lot detail and this is the deeper part. And, so, we look back deeper part, deeper part, surface face. So, that is how it is organized. Coming to a cerebellum similar architecture, the grey in the cerebellum is not very easily made out.

So, this is the surface stuff of the cerebellum, and I do not know if it is possible to see on the screen, there is some small change here which indicates that this is the grey. So, that is how the anatomy is there. We will dwell a lot more into each of these parts in subsequent classes.

Thank you.