Neural Science for Engineers

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Brain Stimulation
Lecture - 30
Introduction to Brain Stimulation

Welcome you to the course on Neural Science for Engineers, this is Sreenivas Bhaskara TA of this course and, today we are going to see how Brain Stimulation concept works and what are the different things that are involved in brain stimulation.

First, we will see what is a brain stimulation then, why people are doing brain stimulation, what are the different research perspectives in terms of brain stimulation, and please be clear that you know this we are not going to deal with the biological aspects and clinical aspects of brain stimulation.

We will restrict ourselves to engineering perspective of brain stimulation, like how to fabricate a device, and what are the currents that are involved in this, what are the circuits that are required to stimulate that particular device, and what kind of materials we need to choose.

So, we are not discussing anything about biological aspects like what kind of transmitters are generated or you know destroyed. So, we restrict ourselves to engineering perspective. So, let us get started alright.

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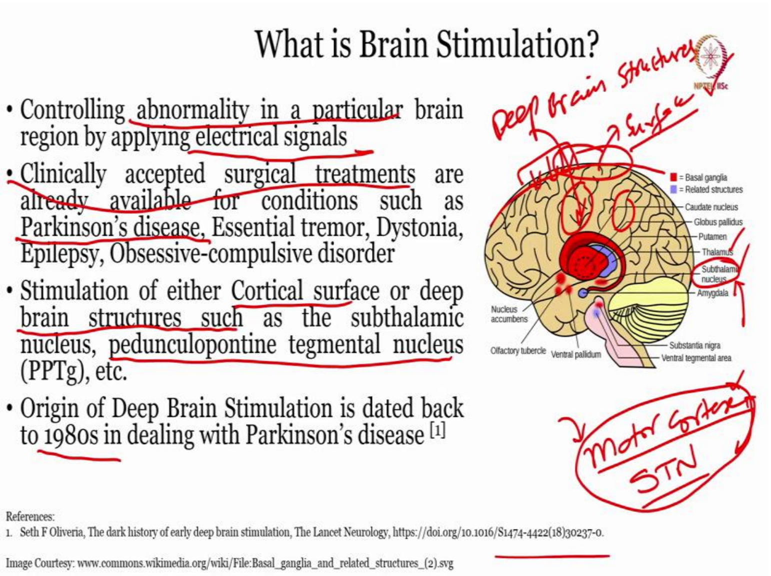

So, if you see the slide, what is generally a brain stimulation like controlling abnormality in a particular brain region by applying electrical signals. So, let us understand what is this abnormality? What I mean by that is, let us say I wanted to move a hand.

So, I think that I want to move a hand, that thought will be created and then it will create some kind of impact in the brain and we by using some imaging techniques people can see, which part of the brain has an impact by thinking something or by sensing something kind of thing.

So, if I want to move my hand, I can move my hand like this, but if there is abnormality in the brain something has caused the brain to malfunction or some abnormality is there, like it is not working normal, that kind of situations what may happen is I wanted to move my hand like this, but because there is an abnormality and the transmission of the signals are not happening properly.

So, what would happen end up happening is I will be like this, it will be like this, something like that. It is not proper, you see my fingers are shaking, it is like that. So, this is kind of abnormality, whatever I wanted to do, a particular action, I am not able to do it, this is a kind of abnormality.

So, what are the reasons for abnormality? There are so many things, we may see some of them and how we can treat it, that is the next thing. So, if you look at my slide here again one thing is abnormalities in particular brain region and clinically accepted. So, to treat it there are clinically accepted surgical treatments already available.

And if you see there are many neurological disorders like Parkinson's disease, essential tremor, dystonia, epilepsy, and obsessive-compulsive disorder. There are many such neurological disorders existing and through brain stimulation we are going to get back to the normality of the brain, but let us see whether we get back or whether completely we can get it back or partially or something like that.

So, the idea is you apply that particular electrical signal to that particular; let us say for example, I may be discussing more about subthalamic nucleus of as I mean not in terms of anatomy, I may be using this word subthalamic nucleus or I may be referring to this sometimes in the course of our study.

So, there is a region called subthalamic nucleus make a note of this. This region is more or less nowadays presently used for treating people with Parkinson's disease. So, we may be discussing more about Parkinson's disease as well, we will take an example and then see how people are doing brain stimulation.

And what we can do. You see if you look at the brain, this is the top surface, let us say this is the surface of the brain and maybe whatever the in deep inside these structures, these structure like subthalamic nucleus, thalamus all other things.

They are something called as deep brain structures. Let us understand deep brain structures. So, there are devices which can stimulate only the top surface, I can also call it as a cortical surface. See once again I am telling we are not discussing the anatomy, and all this is just for understanding, so that we can understand this thing in a better way.

So, we can stimulate either cortical surface or we can also stimulate deep brain structures depending on what kind of applications. So, for Parkinson you can have something called as a motor cortex and you have something called as subthalamic nucleus, STN stands for Subthalamic Nucleus. So, these regions are of much importance, you can stimulate, but motor cortex generally will be on the surface.

So, you can refer to the anatomy of a brain and then you can see where the motor cortex is located and all those things, our discussion is not about the biology, so I am saying these two regions are important. So, people can stimulate motor cortex as well as subthalamic nucleus to see whether we can regain back the normality. So, now, there is another important region called the PPTg region ok pedunculopontine tegmental nucleus.

So, I do not expect you to remember all these names, but as I am just telling these are the names that are referred to. So, the targets these are mainly important targets for Parkinson's disease. So, for Parkinson's disease the origin of the treatment started in the 1980's means you can say roughly some four decades back.

So, if you want to go through you can just have a look at the references here. So, you can just refer to them and then you can see what kind of work that has been done so far. So, now we are very clear the ideal the situation is here like this.

So, we understood what brain stimulation is, you are stimulating the particular region in the brain by using electrical signals. So, these electrical signals how we are going to supply and what kind of circuits that are involved and how to supply that we will discuss.

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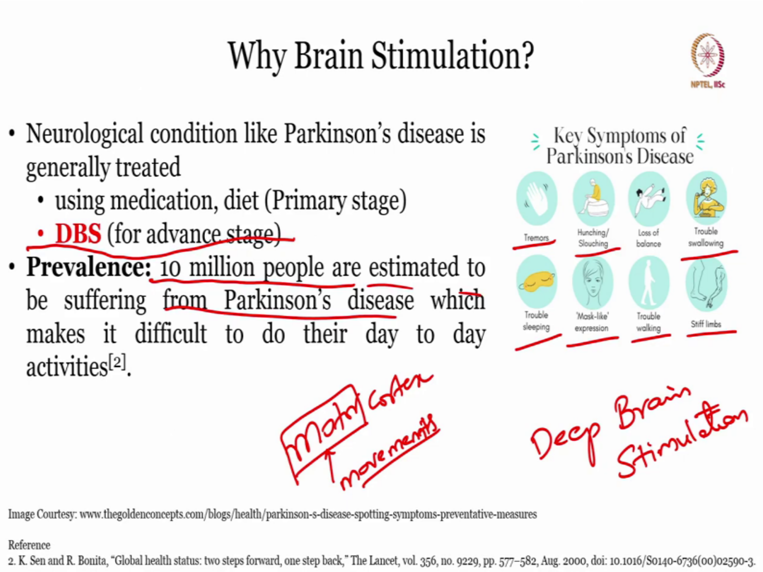

So, the next slide if you see why brain stimulation? So, generally people may think, why do we need to stimulate a brain? So, generally for a neurological disorder initially it is treated by using a medication or a diet at the primary stage.

And this is important, this DBS stands for Deep Brain Stimulation. So, DBS stands for deep brain stimulation if somebody does not respond to the medication then other therapy that is available is a deep brain stimulation means you open the brain and put the devices that are required and you choose that particular location, I already told you subthalamic nucleus or whatever the interest is.

It is not the discussion about which region, my idea is to tell you that just opening the skull and then opening the brain I mean exposing the brain. You cannot open the brain, you just expose the brain and you place the devices in wherever the region that is required and supply the electrical signals. And then stimulate it and people have got the benefit out of it.

So, that is why it is one of the most researched topics right now. So, and you look at the numbers and you look at the slide, there are almost 10 million people. They are estimated to be affected and we do not know how many other people are also there. And these are the general symptoms of Parkinson's disease. Why it is important is, I told you about motor cortex already.

The name itself says that there is something called motor, motor means like movements in a layman term. I am saying this is for engineers. So, whatever is related to the movements disorder may arise from the motor cortex, but the main source could be somewhere else like STN, and it may pass through motor cortex or something like that.

So, the idea is whenever there are movements that happen, whenever we are moving the hands, the cortex region through imaging techniques what people have found out is the region where most activity takes place in the brain. Let us say that we call it as a motor cortex means we may say that if you move the hand or if you turn right or left, some kind of motor action like some kind of movement takes place in your body. So that means, that there is some activity that is happening in the brain. So, that region let us call it as a motor cortex let us say for example. So, if there is any disorder then we have to deal with the motor cortex region.

So, these are the different symptoms and like tremors, slouching, loss of balance, trouble in swallowing, limbs are very stiff, and they are not proper to fold and trouble in walking, mask like expressions, very difficult to move the muscles of the face and trouble sleeping also.

And these are some of the symptoms, but there are many other symptoms. There should be a trained neurosurgeon who has to qualify the patient to be a Parkinson disease patient or not and what kind of treatment is suggested to them.

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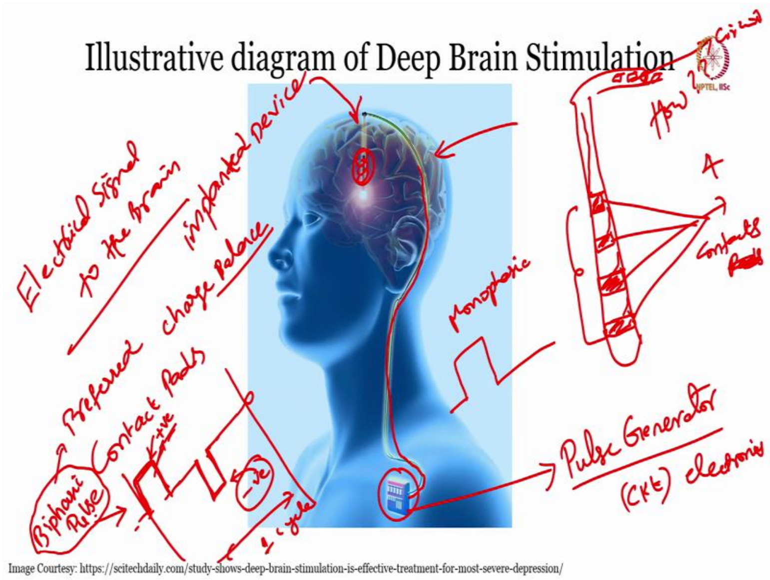

So, if you see the next slide how the deep brain stimulation is done. So, there is something here if you look at this part, this is a let us say pulse generator. So, what is the idea, the idea is you have to send electrical signals right to the brain, this is the idea. So, now the neurosurgery has been performed on the brain and they would have opened the skull and they would have exposed the brain and using some stereotaxic operators or any other surgical operator that is available.

They would have understood that they had already placed this device. Because we are not talking about surgery, we assume that surgery is taking place and then you have inserted this device or you can say implanted. So, you have implanted the device now, you see this. The device structure looks like this, there is some kind of cylindrical shape.

Now, I will also tell you why cylindrical when we discuss further and there are some kind of dots here you can see or as rectangular pads. So, that you can see, so those rectangular pads are like this. So, these are nothing but contact pads, all these 4, all these are contact pads and internally there are wires, internally there is a wire of course. All the 4 are not short circuited, understand that otherwise it is not going to work.

So, there are 4 contact pads that we can see and internally there are wires and here there is a connector, somehow all the 4 contacts are taken like this through a wire and understand that all the 4 contact pads are available.

These are contacts and there is something called contacts and there is something also called as contact pads. Because how you need to supply the current through this? I mean how you need to supply the current through the electrodes? By having some contact pads somewhere at the end.

Now, these contact pads will go to the circuit. So, you have the contacts here, 4 different contacts like this and you have the wires that are connecting them to the electrical circuit. Let us say this is a pulse generator, I can also say circuit, now that is how the connection is established. Understand that I am just trying to explain how the things work here.

So, now this pulse generator has some electronics that are inside and you can generate the waveforms. Whatever electrical signals that you want we can generate like that. And this kind of signals we can generate, this is nothing but a biphasic pulse right.

If you look at this you have positive side of the it can be current or voltage whatever it is. We will discuss about that later, also you have negative side, also let us say this is 0. This level is 0 and we have equal positive amplitude and negative amplitudes of current or voltage, whatever it is and they call it as biphasic pulse and this is the preferred one.

So, you have monophasic also. So, monophasic looks like this. So, the idea behind this biphasic is whenever you stimulate something, whenever you send this positive signal or positive voltage for example, understand like that in a layman terms I can just explain.

So, when you send a positive voltage what happens is you are transferring the positive charge and you are retrieving a; I mean you are transferring the positive charge; that means, that you are sending some extra charge that is. Means the brain is already there and you are transferring some extra charge to that. So, that extra charge should not damage the electrolyte that is present in the brain.

So, what you do in the next cycle, you retrieve this; I mean in the same cycle only, this is the cycle, let us say I call it as 1 cycle. So, during that cycle you send the positive charge and you retrieve the same positive charge; that means, in terms of like this negative. So, that you are having something called as charge balance. So, the basic idea is you are not sending extra charges to the brain electrolyte.

You are stimulating, you are sending it and again you are retrieving it back and in this way of doing it the people have observed that there is a normality that is maintained from abnormal nature, means there are some deactive neuronal region, something like that it would have got normal or activated something like that. So, that is the effect that is felt.

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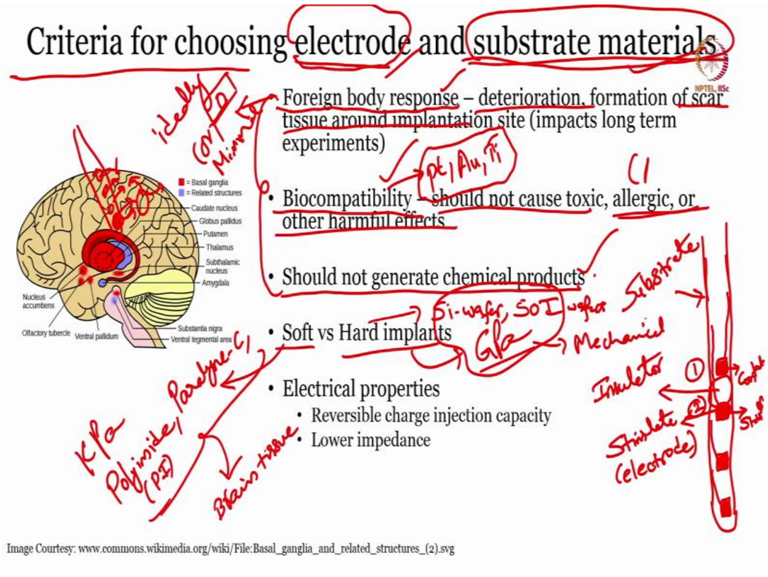

So, this is how generally a deep brain stimulation works. Now, what kind of electrode material I can choose, what kind of substrate material I can choose? Let me tell you one thing. I have drawn that cylindrical structure like this here and there are contact pads and there are wires that will go without any short circuiting with each other, there is a whole lot of engineering that is involved in fabricating this device.

Now, only this part, whatever I am highlighting with the red, only this part is contact, I mean this part only can stimulate right. Let me write it here, only this part can stimulate. The white color region whatever is present in between these two contacts 1 and 2. So, that is an insulator, this whatever the white space that is present between the contact 1 and contact 2 is just a insulator.

So, only that part is an electrode, that will act as an electrode. Now whatever the body that is containing all these electrodes, this entire structure let us say we can call it as a substrate, the material that is supporting.

So, this substrate will not conduct anything. So, it is like an insulator, only the electrodes will contact. So, this is how the structures are, but what kind of materials that I can use or what is the criteria, is there any criteria? Can I choose randomly whatever I want?

So, the answer is yes, there is a criteria for choosing the electrode and the substrate materials. So, the first criteria is you need to understand this is not just an electrical system and then you just give an electrical circuit connection and then the electrodes will start generating the current or voltage whatever is required. So, it is an implantable device, you have to implant it finally.

Where you are implanting it, you are implanting it in the human brain, it is in the body. So, you know there is something called as immune response and all those things whatever that comes from outside the human body the brain sees it as a foreign body.

So, look at the slide the first criteria is this, whenever you implant anything there is something called as some kind of foreign body response, that foreign body response will cause scar tissue formation around the implant and there will be deterioration also, that takes place. If the foreign body response is too much, suppose if you want to use your electrodes inside the body this has to be ideally 0 there is no response at all, or if not possible minimal as minimum as possible. So, there is a whole lot of research going on developing the materials based on this and the second requirement is the biocompatibility. So, whatever the material that you are putting inside the brain or inside the body should be compatible.

And what it should not do? It should not cause toxic, allergic or other harmful effects right. So, for example, some of the biocompatible materials I can give platinum, gold, titanium which are known, I mean I am talking about material metals only, like electrode things. And some of the other things are like you know there is something like silver, there are debatable things also there in that.

So, there are other materials which are not biocompatible. So, you have to make sure that they come under the biocompatible category and there are a whole lot of studies to decide whether the material is biocompatible or not and the another requirement is it should not generate any kind of chemical products or byproducts.

Means you inserted in the brain, you have inserted the device in the brain it should not react with the brain whatever the materials that are present inside the brain and then what happens when it reacts with this then of course, there is a byproduct and because of that byproduct it may cause another effect on the brain or because of that there is a degradation that happens in the brain I mean, degradation of the electrode material may takes place or substrate material can take place.

So, these are the basic requirements of choosing an electrode and a substrate material both, if it is inside first thing is it should create a very minimal foreign body response. Then second thing is it should be biocompatible, both electrode as well as substrate material, and it should not generate these chemical products or byproducts as a part of the reaction.

So, next these are the basic requirements. The other things are something called as soft versus hard implants. So, if you take any material, it has some kind of stiffness, I can say it may have something we can characterize using something called as Young's modulus.

So, if you see the brain tissue the Young's modulus of the brain tissues for example, I am just giving some number do not quote me on that, in the range of 3 kilopascal, if you take for example, any brain tissue of a rat or something like that in terms of kilopascals.

But if you take silicon for example, because most of the time we use a silicon as a substrate material, where on top of that we are going to fabricate these electrodes according to our geometry requirements. Now if you talk about silicon or silicon dioxide something like that their Young's modulus is in the range of gigapascals, I can give some numbers like it is around 140 gigapascal.

You have a smooth surface and it is very smooth and you have very hard material and if you poke it what will happen? It is going to rupture all over you or you will end up damaging it. Not only that, mechanical property why it is so important is, there is something called as micro motion of a brain.

Your brain will not be stable like this, it will keep on vibrating. If you can see my movement of the hand. Now you are putting this soft substance, my hand let us say this is a brain and you are putting an implant which is hard implant like a silicon.

And this is moving, what will happen? This implant is going to rupture the brain and this causes something called as local irritations. And because of that there is a local irritation, and your brain will start doing whatever it has to do to recover. It is like you have something called immune response. So, wherever there is a damage in the brain there is something called or not only there in the brain wherever in the body there is something called immune response that is triggered.

And this immune response is going to protect the brain and there a local irritation is happening, these things are happening parallelly. So, you may not get a perfect contact of this particular electrode material with the brain, means there are a lot of things that are involved in this because of the immune response there is lot of other things that are formed between the electrode and the tissue.

So, that is why whenever you choose an implant you have to choose in such a way that it should be as soft as possible and it should be compatible within the ranges of the brain. So, let me give some examples. Now, hard I already explained you have something called a silicon wafer, if you take a silicon wafer that considers as a hard implant I mean, I am saying Young's modulus in the range of gigapascal and there is something called SOI, Silicon On Insulator wafers.

Then let us talk about soft. So, you have something called as polyimide, we can call them as PI short form of polyimide and there is something called paralyne-C. These are very much compatible with the brain tissue, the brain tissue when compared with the silicon and silicon wafer, Si-wafer.

So, there is lot of research that is also taking place in terms of inventing or discovering the softer implants. And this comes under mechanical aspect. So, another one which is most important is, let me erase everything, these are electrical properties. So, finally, these are related to the electrode.

So, we have seen what the different criteria's are of choosing electrode material and the most important thing is the electrical properties, what are the things to be considered for electrode also I mean other different properties that we may we need to look into it, that we will see in the next lecture.

Thank you.