Neuroscience of Human Movement
Department of Multidisciplinary
Indian Institute of Technology, Madras

Lecture - 64
Basal Ganglia – Part 1

Welcome to this class on Neuroscience of Human Movement. In today's class we will be introducing Basal Ganglia and this will be part 1 of our discussion and Basal ganglia.

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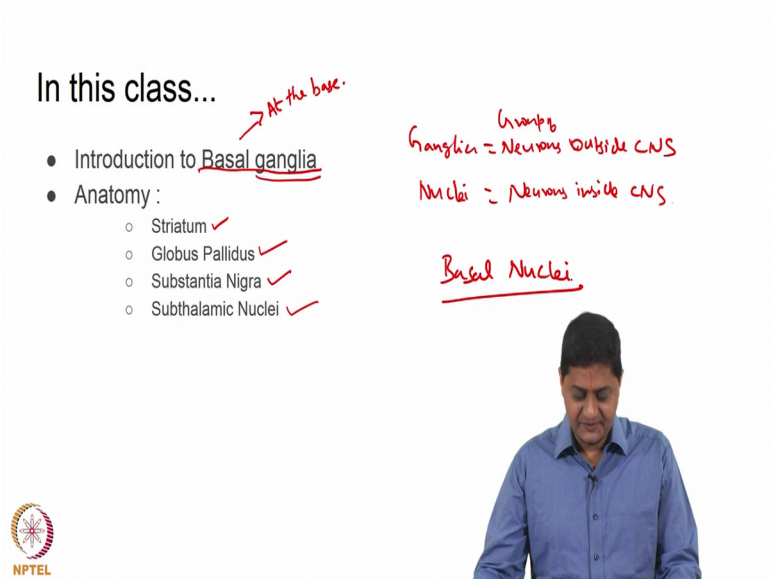

So, in this class we will introduce Basal ganglia, we will discuss anatomy of the Basal ganglia, we will discuss the various regions Striatum, globus pallidus, substantia nigra, subthalamic nucleus which form part of the basal ganglia.

Where does this name basal ganglia come from? Basal means at the base at the base means what? At the base of the cerebral cortex right so, these are nuclei these are ganglia that are located at the base of the cerebral cortex. Ganglia refers to this relatively older terminology, which refers to groups of neuronal cells. Actually now ganglia means neurons in the peripheral nervous system or neurones outside CNS are groups of neurones outside CNS are called ganglia whereas, within the CNS the word nuclei are frequently used.

So this is also the reason why nowadays Basal Ganglia is frequently referred to as basal nuclei. This is the modern name; however, traditionally we will be referring to basal

ganglia as basal ganglia. So, in this class we will refer to basal ganglia as basal ganglia and not basal nuclei, the text books also referred to basal ganglia as ganglia.

So, the basal ganglia is located at the base of the cortex, actually it is comprised of nuclei that is spread across multiple locations. So, some of these are in the telencephalon some of these are in the diencephalon some of these are in the mesencephalon how is this we will discuss that.

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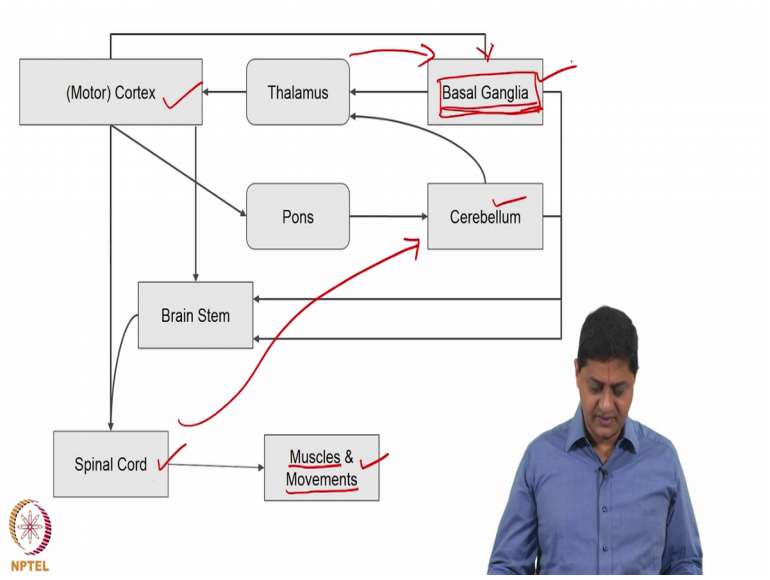

But before that let us discuss the role of basal ganglia in movement generation because this is a course on neuroscience of human movement; let us go back to our original slide on movement related structures and their contributions right.

We said movements are generated by muscles we have discussed the physiology and neurophysiology of muscle function, and muscles themselves are controlled by spinal cord or spinal motor neurones we have discussed the role of spinal cord in that we have discussed motor cortex and the role of motor cortex in regulating the input to the spinal cord. And we have discussed the role of cerebellum which receives input from the cortex and from the spinal cord etcetera and outputs to the motor cortex via thalamus. Note that the cerebellum does not output to the spinal cord this does not happen right.

So, essentially cerebellum modulates the movements likewise you have another structure called Basal ganglia which receives input from the motor cortex and from thalamus

basically thalamus receives inputs from multiple structures. So, basal ganglia receives input from multiple structures, primarily from cerebral cortex and it outputs to the thalamus. And through the thalamus it outputs to the cortex and from cortex there is modulated output going to spinal cord which then control circuits movements and muscle function.

So, essentially basal ganglia does not interact directly with the spinal cord, this does not happen right. So however, it modulates the outputs through interacting with motor cortex how does it perform this function? What is the role of basal ganglia that is going to be the theme for the next few classes. We have seen all the other parts, we have seen muscle function we have seen movement related details, we have seen spinal cord we have seen cortex we have seen cerebellum. So, basal ganglia is about the last topic in this discussion on neuroscience of human movements. So, we will discuss this in relatively great detail for the next few classes right.

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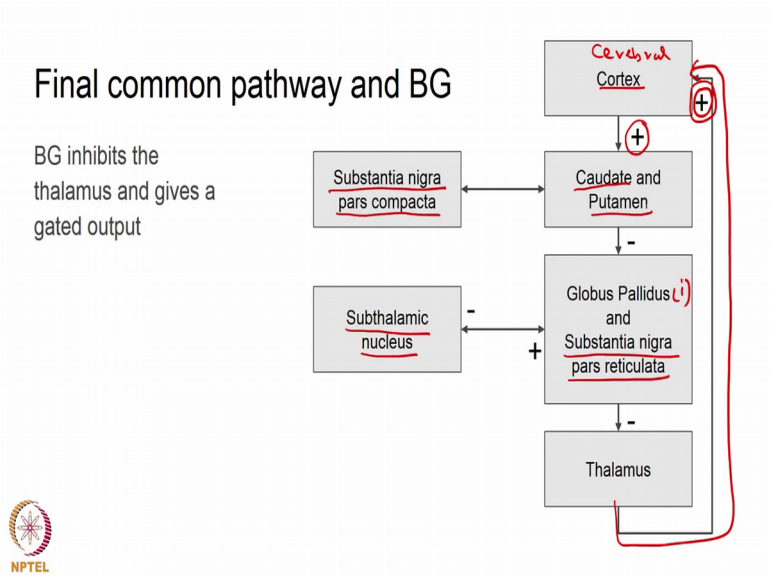

So, what does the Basal Ganglia itself do? Once again it receives inputs from the cortex; cortex means cerebral cortex in this case from cerebral cortex and these inputs are usually excitatory plus and it projects to the globus pallidus actually there are two nuclei distinct nuclei within the globus pallidus, these are called as a internal and external segments of the globus pallidus, these have distinct functions.

So, the internal nucleus actually acts as the output structure. What it does is it tonically inhibits thalamo cortical neurones. So, from the thalamus that is neurones that activate the cortex. These neurones are constantly or tonically inhibited by the globus pallidus internal and substantia nigra pars reticulata these are the output nuclei of the Basal Ganglia, they constantly inhibit the thalamo cortical neurones. And when there is a need they release some neurones from this inhibition, that appears as excitation here and that causes movements right.

So, in this sense it is believed that the basal ganglia acts as a gate to release movements so, in this sense basal ganglia is believed to perform the important role of movement selection or gating of movements. So that means, asal ganglia is also preventing unwanted movements from happening. So, the so, immediately we are able to hypothesis that dysfunction in basal ganglia sometimes could cause unwanted moments to happen also the other possibility is that, if the gating is too much then wanted moments can also not be performed is a guess that we are immediately able to make.

What is not discussed is the important role of subthalamic nucleus and substantia nigra pars compacta, these nuclei perform two different functions, substantia nigra Pars compacta produces dopamine which is a powerful chemical powerful neuromodulator, which modulates the output of the striatum this caudate and putamen. We will discuss all this things in greater detail in future classes for this slide its sufficient to know that the thalamo cortical neurones are tonically inhibited by the output of the basal ganglia, and they are released from time to time and then they are released the movement appears right.

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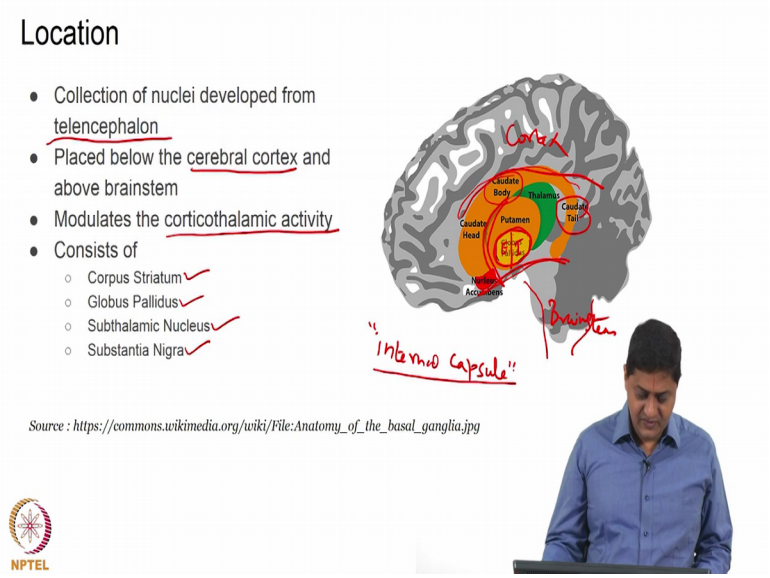

Where is the basal ganglia located? These are nuclei and many of these nuclei are actually developed from telencephalon right as a forebrain. So, importantly there is the caudate nucleus which is this, this caudate nucleus the one that I have now highlighted or outlined with red is a rat like structure; is a rat like structure with the head here and with a tail here and there is a body here and that surrounds nuclei called putamen, which houses within itself a distinct nucleus called globus pallidus and this globus pallidus itself has two parts external and internal.

So, this is placed below the cerebral cortex inferior to the cerebral cortex located at the base of the cerebral cortex, which is why it is called as basal nuclei, basal ganglia right, but above the brainstem. So, the brainstem is here right. So, it is located above the brainstem, but below the cortex. So, this is cortex it is brainstem. So, this is the Basal ganglia. The most important function is modulation of corticothalamic activity or thalamo cortical activity right.

It consists of several sub parts called corpus striatum, globus pallidus, subthalamic nucleus and substantia nigra. It turns out that the caudate and putamen are actually divided maybe it is not visible in this picture in future pictures I will show you that the Caudate and putamen are very similar structures that are divided into two separate nuclei, by what is called as internal capsule what is this internal capsule? This is white matter from the cortex going to lower structures; white matter means groups of axons

right whenever you say grey matter, you are referring to neuronal cell bodies and when you say white matter you are referring to neuronal axons.

So, groups or bundles of axons going from cortex to lower structures, a very big bundle is called as internal capsule this internal capsule separates caudate from putamen otherwise caudate and putamen perform similar functions we will discuss the functions in future classes.

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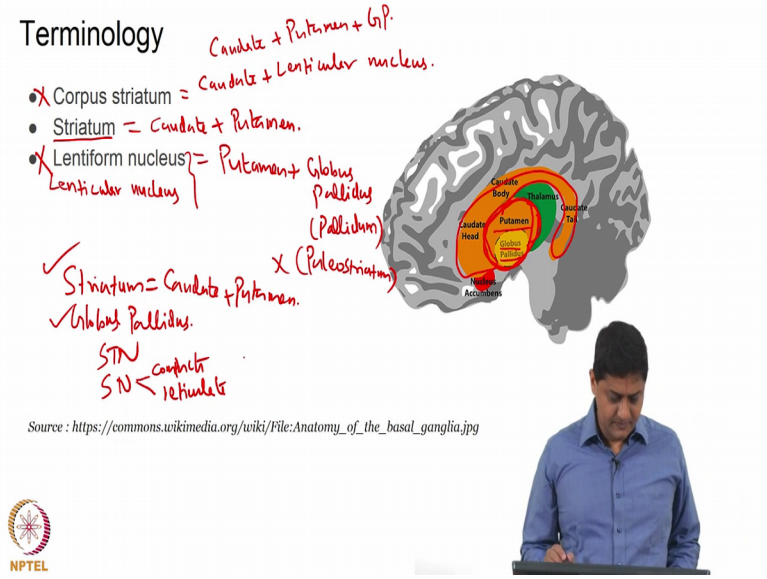

So, there are several terminology that are used in several texts; traditionally the putamen and globus pallidus together is called as lentiform or in fact, some text referred to this as the lenticular nucleus, this is basically putamen plus globus pallidus. Sometimes globus pallidus is referred to as pallidum sometimes this is also called as paleostriatum or the old striatum this terminology is no longer used.

Lentiform and lenticular nucleus is this, that is composed of putamen and globus pallidus. Striatum on the other hand refers to caudate and putamen. caudate and putamen are striated or they have cytoarchitecture that are similar and they perform similar functions right. So, together they are called as striatum, some terminology some text books refer to corpus striatum, which is basically Caudate plus the lenticular nucleus or this is basically Caudate plus Putamen plus the Globus Pallidus. So, all these things is referred to as corpus striatum by some people.

So, lots of confusing terminology what will we use in this class? In this class we will say striatum, whenever I say striatum I am referring to caudate and putamen I will referring from using phrases such as Corpus Striatum I will just say striatum when I say striatum I am referring to caudate and putamen and when I am referring to globus pallidus I will refer to that as globus pallidus or pallidum. we will not use terminology such as lentiform lenticular nucleus or corpus striatum for clarity we will only use striatum and globus pallidus and we will use subthalamic nucleus which is not shown in this picture, but I will show it in future pictures and Substantial Nigra which is composed of two parts compacta, reticulata right.

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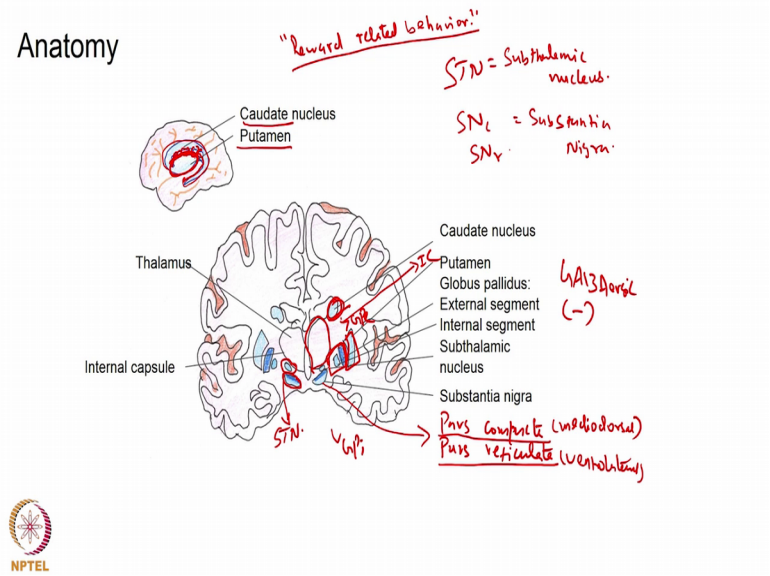

So, once again here is this Caudate nucleus with its tail here and head here shown. There are these holes I hope you are able to visualise this holes here as a hole here hole here that is a gap here, gap here, gap here, gap here these gaps are the gaps through which internal capsule axons of the internal capsule are going through. So, essentially these separate Caudate from this is putamen right from putamen right.

So, you have caudate nucleus here, this is a coronal view you have caudate nucleus here and you have putamen here, what is here? This is the internal capsule this is the internal capsule essentially. That separates caudate and putamen medial to the putamen you have globus pallidus, that is divided into two distinct nuclei called as a globus pallidus internal and the globus pallidus external. The most medial of the nuclei is called the globus

pallidus internal. So, that is that one GPi and the more lateral one among the two the more lateral one is called as a globus pallidus external or GPe right.

Of course the most medial among them is the thalamus, which is not part of which is not exactly part of the Basal Ganglia, but conducts output from the Basal Ganglia to the cortex though thalamo cortical loops. Now just below the thalamus you have a relatively small nuclei here both sides, this is called subthalamic Nuclei; STN here I am using STN to refer to subthalamic nucleus. Sometimes this is also used to refer to substantia nigra, but in this class we will refer to subthalamic nucleus as STN and substantia nigra SN c or SN r for clarity.

The subthalamic nucleus consists of densely packed neurones that are fundamentally different from the rest of the Basal Ganglia in that it receives inputs from multiple regions of Basal Ganglia both from external and external globus pallidus and also from cortex. And it outputs to both segments of the pallidum basically to GPi and GPe other than the input that is coming from dopamine, the subthalamic nucleus glutamatergic neurons form the only excitatory connections right.

That means the globus pallidus internal striatum globus pallidus external all of them are fundamentally inhibitory, many of these are actually GABAergic. GABAergic means inhibitory right. So, in the mid brain you have what is called as substantia nigra. So, this forms the mesocephalic part of the basal ganglia that is composed of two parts Pars compacta and Pars reticulata.

The ventrolateral side; the ventrolateral part of the substantia nigra is called as Pars reticulate, the mediodorsal nucleus is called as Pars compactta they perform fundamentally different functions. The substantia nigra Pars reticulata is similar in cytoarchitecture and function to globus pallidus interna. Let us remember the globus pallidus interna outputs to be thalamus and through that it modulates the activity of the thalamo cortical neurones.

So; that means, the globus pallidus interna is the major output structure of the basal ganglia, substantia nigra Pars reticulata is also a major output structure of the Basal ganglia. In fact, these two can be considered to be the same nuclei separated into two by internal capsule. So, these are functionally and cytoarchitecturally very singular structures separated into two distinct nuclei through internal capsule.

So, substantia nigra pars reticulata and globus pallidus internal perform similar functions, which is basically to act as the output structures of the basal ganglia. Whereas, Pars compacta comprises of very important neurones, it consists of neurones that produce dopamine. Dopamine is the brain special chemical that is very important for modulating movements. Its functions extend beyond movement modulation to reward related behaviour very very important function.

So; that means, it modulates how you respond to reward and punishments. So, in that sense it could potentially modulate or affect the way in which we respond to habitual actions and the way in which we respond to rewards or punishments; that means, addiction and related functions. Its various functions are beyond the scope of this class, we will only restrict ourselves to the movement related functions of dopamine we will discuss the functions of dopamine in much greater detail in future classes.

So, essentially the Basal Ganglia is composed of this rat like structure, which is the Caudate with its head and tail. And this rat is having its head and some foot or in some nucleus called as putamen, more medial to the putamen more medial to the putamen is the pallidum which is divided into two parts. So, this is the Putamen this is the Caudate and more medial to that is the pallidum that is divided into two distinct nuclei, the external and the internal, more medial of these the most medial of this is the globus pallidus internal which acts as the output structure.

And the lateral among these two is called as the globus pallidus external, which is basically and part of the internal circuitry. Basically it receives input from the caudate and putamen and it outputs to the globus pallidus internal. And then there is subthalamic nucleus which is a small nucleus with containing densely packed neurons that is located just below the thalamus that is reason it is called the subthalamic nucleus.

And in the midbrain you have substantia nigra, which is divided into two parts Pars compacta and Pars reticulate. Pars reticulata is similar in cytoarchitecture to the globus pallidus internal and its function is also similar to globus pallidus internal which means its a output structure of the basal ganglia whereas, Pars compacta comprises of dopaminergic neurons that modulate movement related functions and reward related behaviour. So, essentially Basal Ganglia is composed caudate nucleus. putamen, globus

pallidus external, globus pallidus internal, subthalamic nucleus, substantia nigra pars compacta, substantia nigra pars reticulate.

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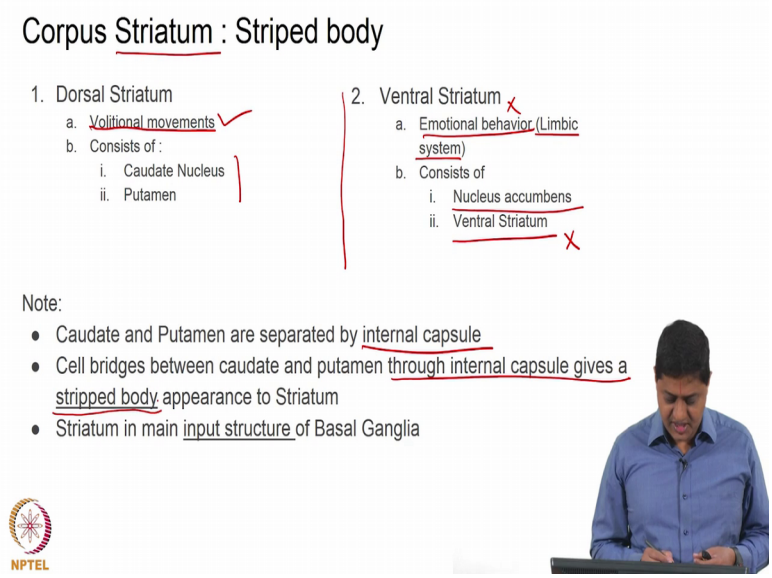

So, striatum itself is this striped body when you say stripe striatum, you referring to striped body its function is believed to be modulation of voluntary or volitional movements. So, the dorsal striatum is believed to perform important functions related to movements and it consists of Caudate nucleus and putamen. Ventral striatum performs limbic functions nucleus accumbens also called as ventral striatum. This is something that we will not discuss. The limbic function and emotional related behaviour is something that we will not discuss as part of this course movements is something that we will discuss as part of this course.

Let us remember that caudate and putamen are separated by the bunch of axons called as internal capsule. However, there are some bridges between caudate and putamen through the internal capsule right. So, this gives strip like appearance, a striped body appearance to the striatum like we like we saw in this picture. So, there are cell bridges here cell bridges here and then there are holes in between this through this holes the internal capsule axons go through, but between this holes there are bridges between the caudate and putamen that gives the appearance of a striped body.

And striatum is the major input structure of the Basal Ganglia basically it receives input from cortex and thalamus and sends outputs to the pallidum and through the pallidum modulates output of the thalamus or the thalamo cortical neurones.

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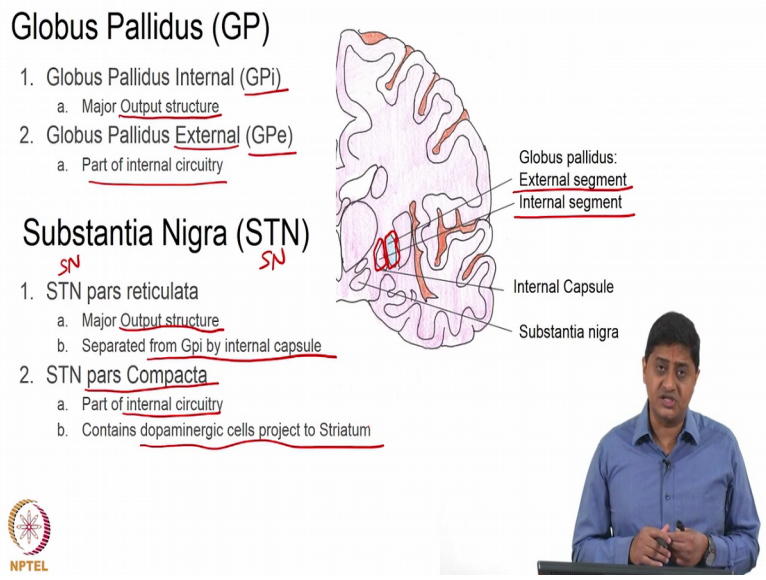

Globus Pallidus itself consists of two parts the internal part are the more medial one is the internal segment, and the more lateral one is the external segment. The globus pallidus internal is a major output structure and globus pallidus external forms part of the internal circuitry.

The substantia nigra I am going to call here as SN just to prevent confusion from subthalamic nucleus. SN Pars reticulata is a major output structure this is similar to the globus pallidus internal, it is actually the output structure separated into two parts as the globus pallidus internal and substantia nigra pars reticulata. Whereas, substantia nigra pars compacta forms part of the internal circuitry and contains very important dopaminergic neurones the project to striatum what is the function of this dopaminergic neurones we will see in a future class. We will dedicate one entire class to the function of dopamine and several classes to dopamine related dysfunction.

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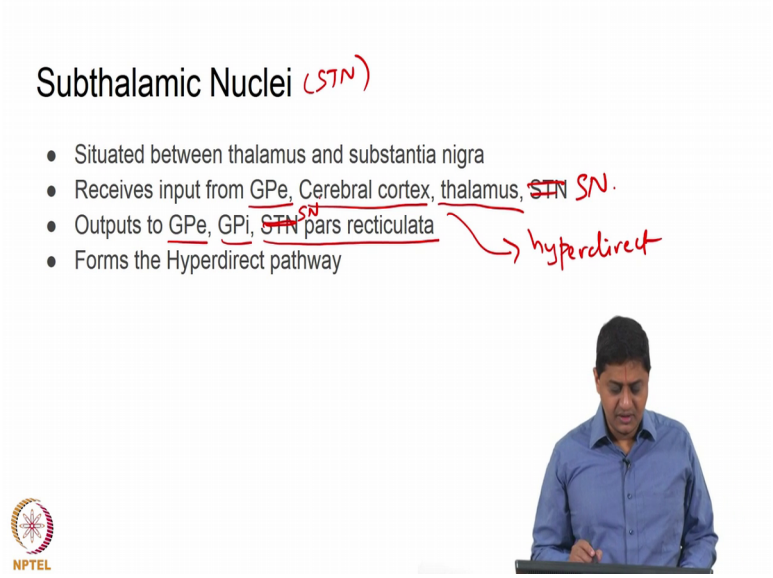

And we said what is thalamic nucleus this I am going to call as STN here I am going to call as substantia nigra as SN. subthalamic nucleus is actually located between the thalamus and substantia nigra it basically receives input from multiple places from the globus pallidus external. From the cortex also; that means, if it receives input from the cortex in and it directly projects to GPe; that means, it forms more direct pathway it by passes the striatum which is a major input structure right which is why the pathway that comes from the cortex through this subthalamic nucleus to the globus pallidus internals is also called as the hyperdirect pathway.

It also receives input from thalamus. So, it receives input from multiple structures, it outputs to both pallidal segments both to external and internal, and also to substantia nigra pars reticulata now substantia nigra pars reticulate is similar to GPi. So, if it outputs to GPi which is basically the output structure, it also outputs to substantia nigra Pars reticulate. Just for confusion just to prevent confusion I am going to call this as SN Pars reticulata and it forms the hyperdirect pathway.

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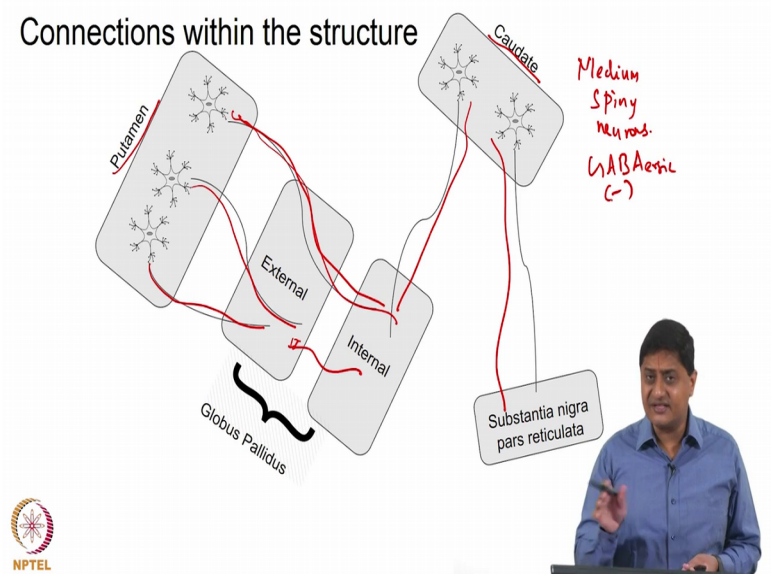

So, within the structures so, there is caudate nucleus here and putamen here and there are neurones that project to the globus pallidus external segment, and then there are neurones that project to the globus pallidus internal segment likewise from the caudate there is projection to GPi and to the substantia nigra Pars reticulate. If the projections come through the external segment and from here to the internal segment that is called as the less direct or the indirect pathway. If the projection is directly from the putamen to the globus pallidus internal it is called as the more direct pathway.

Note that caudate and putamen are the striatum is composed of very distinct special type of cells called as medium spiny neurones which are GABAergic. So, inhibitory neurones that output to the globus pallidus right they have a special name medium spiny neurones because of the presence of spines on their dendritic structures. So, these are called as medium spiny neurones have very special feature of the striatum; striatum means both caudate and putamen.

These output to both GPe and GPi, if it outputs directly to GPi, that forms part of what is called as the direct pathway if it outputs to GPe and through GPe there is another cell that takes the information from GPe to GPi, then it is called as the indirect pathway we will discuss this in future classes.

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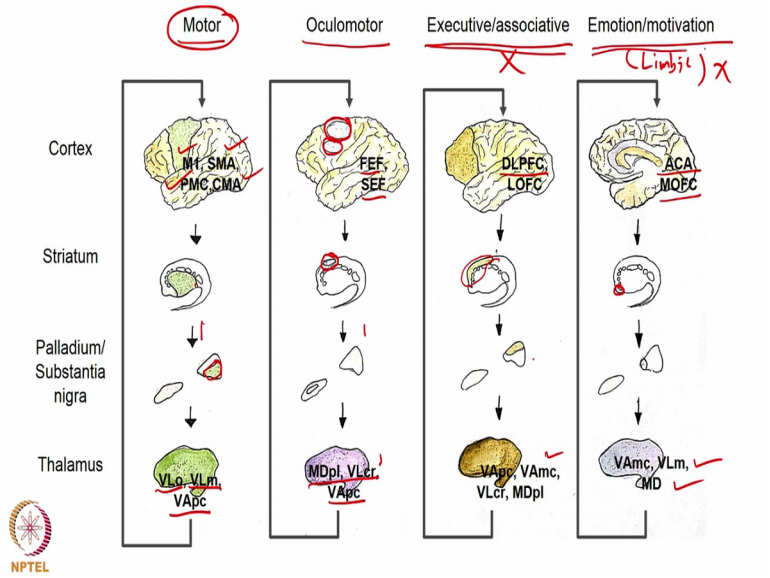

So, essentially the following functions are attributed to Basal Ganglia, motor functions basically here in this case inputs to the striatum actually comes from motor cortex supplementary motor are pre motor cortex, cingulate motor areas from all this areas it comes to putamen not caudate it comes to putamen. Please look at the highlighted area, the highlighted area is not caudate it is coming to Putamen then it goes through the pallidum, goes through to the pallidum and the substantia nigra Pars reticulata and from there it projects to the thalamus in the thalamus it projects to distinct nuclei here.

Then oculomotor oculomotor means eye movement related. So, when we are moving our eyes. So, the inputs to these come from other areas, areas other than M 1 for example, from frontal eye field right from there it comes not to the putamen, but to a specific region within the Caudate and from there it comes to the pallidum and substantia nigra pars reticulata from there it outputs to the thalamus, but in regions different from the motor areas.

It is also believed to perform important executive functions. So, basically it receives input from dorsolateral prefrontal cortex and projects to caudate and outputs to pallidum and substantia nigra pars reticulata and outputs to the thalamus, it is also believed to perform emotion, motivation or limbic functions it receives inputs from MOFC and outputs to Caudate and through the pallidum and substantia nigra pars reticulata outputs to the different regions of thalamus.

So, essentially the basal ganglia is believed to perform multiple functions, motor oculomotor executive and limbic functions. In this course we will only focus on movement related functions or motor functions. We will not be focusing or we will be focusing much less on emotional or limbic functions and executive and associative functions of the basal ganglia. Basal ganglia has been traditionally viewed as a motor part of the brain or the motor organ of the brain. So, and also it is the motor related dysfunction that are more studied among the dysfunctions of Basal ganglia.

So, we will be essentially viewing basal ganglia function as motor functions of basal ganglia or we will only be discussing the motor functions of basal ganglia and we will be discussing much less of executive and emotion or motivation related functions. The only exception being the role of dopamine where we will discuss important reward related behaviour.

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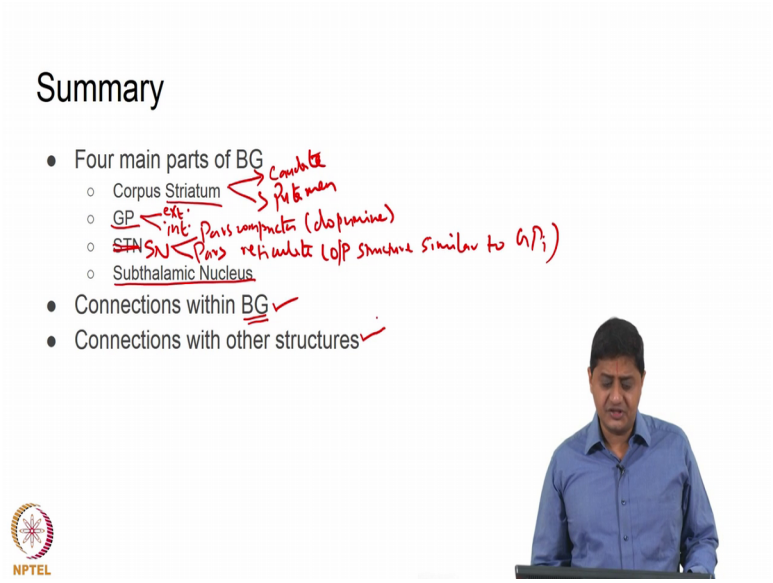

So, in summary Basal Ganglia is composed of four parts striatum so, basically caudate and putamen, globus pallidus which is composed of two parts. So, let us write out all the subparts of this striatum basically composed of caudate and putamen globus globus pallidus is composed of external and internal, I am going to call the substantia nigra as substantia nigra as SN, this is composed of Pars compacta which is dopamine producing part of the substantia nigra and pars reticulata this is the output structure; pars reticulata is the output structure similar to GPi.

And subthalamic nucleus and there are connections within BG that we also discussed very briefly and connections with other structures also we discussed very briefly as part of this class with this we come to the end of this lecture.

Thank you very much for your attention.