PROFESSOR: We're going to continue with some neuroanatomy today. Leading up to the next anatomy unit, we've been talking about what happens when you remove large parts of the brain, like the [INAUDIBLE] brain, the chronic decerebrate animals. I talked a little bit about corpus striatum, what about the limbic system? If-- let me get my pen up here.

This shows the Shmoo Brain. I put the outline there of the neocortex, which is what we're adding now. But here, I've put the limbic system structures in red so you know what we're talking about. You'll see the close connection to the olfactory system. This is representing olfactory cortex and cortex closely connected with it.

Behind the basal forebrain there is the hypothalamus. And we define the limbic system as structures that are-- we closely connected with the hypothalamus, which is really the highest part of the brain, our ancestral brain here, the Shmoo one. Limbic systems generally concerned with motivation and emotion.

Whenever we experience something rewarding, either positive or negative, pleasures and pains, we activate that system. Now there is part of the corpus striatum that is pretty closely tied to the limbic system also, but we think of the striatum more in terms of regulation of movement and especially what we call implicit learning, habit formation. But today we want to add to the Shmoo Brain. We want to add a neocortex to it and talk about the major ascending and descending connections that appeared with the evolution of neocortex. And give a general view of functions, question in the back?

AUDIENCE: [INAUDIBLE]

PROFESSOR: The corpus striatum is in-brain. OK, it's above the diencephalon. When the distance receptor pathways-- other than olfaction-- begin to invade the in-brain, it was the corpus striatum that they were projecting to. OK and even in our brains, we still have such projections. Although, that's not-- we think about the thalamus as projecting to neocortex. But actually, there's an old thalamus too that gets sensory inputs and projects to the corpus striatum, left over from that earlier period in evolution.

So here's the Shmoo Brain that you should-- this is what I want you to know, I don't expect you to remember everything in there, although, the type of connections I've shown are pretty simple. So here's the Shmoo 2. I have numbered these. And you should be able to tell me what all those are, let's see how many you can right now. There's number one. What is that? Spinal cord, OK.

Above the spinal cord, I have two and three there. Somebody said cerebellum, that's right, that's cerebellum, which is part of the hindbrain or rhombencephalon. And above that, number four, the midbrain, or mesencephalon. So everything rostral to the midbrain here is forebrain. And we've got it now divided into even more divisions.

The two major ones, we usually talk about, all those actually four divisions of the diencephalon, are what? Thalamus, and hypothalamus, what's that thing? OK, the pituitary, the part connected to the nervous system, the neuron hypothesis, or neuro pituitary. And then the glandular part, which is often called the anterior pituitary, although the way I've drawn it here it's both anterior and ventral.

OK and then above the tweenbrain. Seven corpus striatum, Casey, I've drawn it as a subclinical structure. OK and then what is number nine, olfactory bulb. And now we have a few more things here, eight and nine belong together. They're all part of what the limbic system of the inbrain, closely connected the hypothalamus. But this part is the hippocampal formation.

Note that if we go to the very edges of the neocortex, this is neocortex now, we go to the very fringes, we're in limbic system, there, and at this end too. And even if we look at a cross-section of the cortex, that same thing will be true. As we go to the fringes, we're in the limbic system. In fact, the word limbic means the fringe, just like the hem of the skirt.

OK, this is the picture we saw before. You should be able to relate this picture, the Schmoo 2, directly to this one. The only difficulty will be, where's the corpus striatum? That's because the corpus striatum really was a thickening of the ventral part. And I've done this as a horizontal section further up, but where would you find limbic system? Let's put it in right here. Remember I said at the edges.

So this would be limbic cortex here, at the very edges of the cortex, and so would this be. And then this is all neocortex on both sides, of course. So neocortex and limbic cortex. So now we're going to talk about two major long pathways that we associate with neocortex. The lemniscal pathway, the sensory pathway, called the neo-lemniscus as opposed to the spinothalamic tract, which was the paleo, or old lemniscus.

The dorsal column in the lemniscus pathway. And then the descending pathway comes from neocortex. Now there are many descending pathways coming from neocortex, all the neocortical areas or most of them have descending-- actually all of them have descending pathways many of them have very long pathways.

The one we often think of is the one that goes most directly to the spinal cord. Many connections directly to motor neurons, the corticospinal tract. So let's look at the dorsal column medial lemniscus pathway first. We start here with a primary sensory neuron. And we can follow it in and we see that some of those neurons have branches that go all the way up to the top of the cord. They follow the dorsal columns.

So one there you see his dorsal columns. Just make it a little more just to emphasize it there. So that's how it starts. And you should know that, we'll see it also in cross sections and so forth. So it's different from the spinal spinothalamic tract. How is it different? Well, the spinothalamic tract contacted secondary sensory neurons right away, as the pathway came into the cord. Whereas this one, the primary sensory neuron's axon goes up the spinal cord to the very top.

In fact, some people say that the dorsal column nuclei there, number two there in the diagram, nuclei of the dorsal columns, they say they're in the caudal end of the hindbrain. Now that puts them in the rostral end of the spinal cord. So they're in between there. I'll just use another [INAUDIBLE] here. We'll put the next neuron. The neuron that those axons make synapses with, the secondary sensory cells now, are there in the dorsal column nuclei. And that axon decussates. This is the decussation. It's called the decussation of the medial lemniscus. Why would it get such a name?

Remember what lemniscus means? Don't draw the axon there. What's the word lemniscus mean? Ribbon, it's a ribbon of fibers. The medial-- it's medial because of its position-- where I've got the number three there, as it goes along the ventral part of the hindbrain. Travels in the medial part of the ventral hindbrain. So we call it the medial lemniscus.

So this pathway often gets called then the dorsal column medial lemniscus pathway. That's the neo-lemniscus, it's a rapidly conducting pathway. It reaches that same structure in the thalamus, the ventral basal nucleus or the part of it we call the nucleus ventral posterior, it's the ventral-- the posterior part of the ventral nucleus, the thalamus. And that's where we find the cells that goes to the neocortex, as I show there.

Neurons going right up to the somatosensory cortex. So that's the dorsal column medial lemniscus pathway. Now let's do the same thing. On this view, we did the same thing for spinothalamic tract, now we'll do it here. So again, there's our secondary sensory neuron. I show it coming from a pacinian corpuscle in the skin. OK, it branches, goes up and down the court, but the long branch follows the dorsal columns.

It moves more and more medial as it goes up. And terminates in the dorsal column nuclei. Synapses with cells there. You see that there's two of them. This input is coming in to the caudal enlargement of the cord innervating the limbs. OK, so that could be coming from our foot. Those axons-- axons from there are going to terminate in the medial nucleus, the dorsal columns.

OK, it's also called the slender nucleus, nucleus gracilis. You don't have to learn that now. Just remember that these are the dorsal column nuclei, and they're secondary sensory cells. And those axons then cross over, so there's the decussation. And there's-- travels medially in the hindbrain. OK, I'm following the wrong one, aren't I? And there it loops.

So there it goes, immediately in the hindbrain. All the way up, because we followed it before to the next synapse in the ventral basal nucleus, ventral nucleus and thalamus, which then projects to neocortex, as we saw in the previous diagram. So again, this is coming from the left foot. The left foot would be represented in the right, the somatosensory cortex. In one part of it, remember, the homunculus, the map of the world there.

So one part of that cortex, it's always going to get input from the foot. Now if this were coming from-- if this were coming, let's just for fun here, do that from the upper part of the body. We'll draw another one, comes in there. Terminates in the lateral nucleus, the dorsal columns.

That axon similarly crosses over. And this sends also into the ventral nucleus. And that, again, would have an axon going up to the cortex, but to another part because it's a topographic representation. That one would go more ventral in the cortex. So that's the dorsal column medial lemniscus pathway, seen in the top view.

I note here that the decussation of the medial lemniscus, they're sometimes called the internal arcuate fibers. You don't have to remember that. This is just a term anatomists give it because the way they look in a fiber stain. What now? Now we're going to follow the corticospinal tract in that same diagram. You correctly have to bring in color pens.

These diagrams, I used to think I've simplified these to the ultimate degree and then students said these are much too complicated. So it helps now to trace these pathways with colors. Remember each of the thing I'm drawing here represents thousands of axons. So now, we're going to start up here in the cortex.

That would be a pyramidal tract. A pyramidal neurons, sorry, giving rise to pyramidal track. And note that it descends, it connects to all levels of the nervous system. It crosses over it, right at the caudled end of the hindbrain. About the same place the medial meniscus presses. And the axon ends then in the spinal cord. Now if that were in the foot area of the motor cortex, that neuron, it would end and the more caudal part of the spinal cord, what we call the lumbar enlargement.

Note that they have that axon ending here in the thalamus, I have it ending in the midbrain. There would be other terminations here in the hindbrain before it gets to the spinal cord. Now I draw another descending axon on the other side. That's also part of the corticospinal tract. That's this one.

If you have that trouble, if you have a tablet and you have the trouble I was just having, it's because you're pressing on the button and it makes-- it's like clicking on the right mouse button on your computer. All I'm showing with that other one is that there are pathways that descend and go to the sensory side, not only motor sight. It actually connects there in the ventral thalamus. It also connects in the midbrain, and hindbrain.

It connects to the dorsal column nuclei. And also connects to that same region of the spinal cord that gets sensory input, the dorsal horn, right among sensory for secondary sensory cells there. But that's all corticospinal tract, it refers to all of those descending axons. For now, focus on that one. I'm going to review some things now from the earlier part of the lecture because people easily get confused about the diaschisis phenomenon.

So let's just go over that a little bit before we-- and then I might be able to start lecture 12 today. For those of you with tablets, lecture 12 is only up on PowerPoint on the web. This one though is there in journal format. So diaschisis is a term used to describe quantitative effects of large lesions. It refers to effects of deafferentation. What does that word mean, deafferentation.

It's easy for me to skip right over this, I don't even remember if I put that term on the flash cube program yet. Yes?

AUDIENCE: You cut it somehow.

PROFESSOR: Well deafferentation means lesions, yeah, you cut something. But what did you cut? It doesn't mean you cut the axon, it doesn't mean you cut the dendrites. It means you cut off the inputs to the cells. Afferents refer to inputs. So if we talk about the afferents of the ventral posterior nucleus, we're referring to those inputs I just talked about, the afferents of the ventral posterior nucleus are at the spinothalamic tract, in the medial lemniscus, the afferents of the somatosensory cortex.

Many of them come from the thalamus, from the ventral posterior nucleus. It's a quantitative effect, so if the relative-- if the removal of afferents is not quantitatively great, you won't get much depression of function, probably none that you will notice.

AUDIENCE: [INAUDIBLE]

PROFESSOR: Yes, it depends on how many-- well we'll get to that now. I'm going to show you the pictures. I referred to the spinal shock as a diaschisis phenomenon, do you remember what spinal shock is? Has a very specific meaning. An animal or a person suffers a lesion of the spinal cord. Say in the middle, mid thoracic region, here.

He hasn't lost the connections of reflexes in his legs. What are reflexes is in the legs? Well, if we burn the foot, the foot will withdraw. It'll hurt too, and you say, well, of course you'll withdraw. Yes, but you'll withdraw without thinking about it. You'll withdraw even if you didn't notice it.

It's a reflex, the withdrawal reflex. And we'll be talking about it again. You pinch the foot, the same thing. That's a spinal reflex. It doesn't require connections above the spinal cord. In fact, it's segmental reflex. It only requires local reflex connections. And yet, spinal shock, if I suffer a lesion up here, I lose the reflex controlled by the more caudal part of the cord, why?

So we call it spinal shock. The spinal cord is in shock, it's deafferented. It's somehow not functioning right. It's depressed, functionally. But over time, you get recovery. And I reviewed these two mechanisms for recovery, which I am showing again here. But let's just go through the pictures. I show a very simple diagram of corticospinal connections in two species.

We know now that the cortex connects directly to spinal cord. So I can show it in this very simple diagram, showing spinal reflexes at the bottom. It could be a monosynaptic reflex, like the stretch reflex. You suddenly, like the nature, suddenly stretch your muscle, you get a contraction of the same muscle. So we can just deal with that simple one involving only one synapse.

And we're showing two different species here, one with a lot of neocortex. One with less neocortex. And this is the lesion. We cut those axons. It could be in it the lesion of the cells up here. It could just be of the axons. So we cut them, we remove a lot of excitatory connections.

Now what happens? This is a little odd because when it printed from-- when they printed the journal, it didn't translate this picture entirely correctly. But it's mostly correct. These cells have lost less input than these cells if we get rid of these connections.

All these terminals are degenerated, here and here. These cells having lost so many excitatory connections now are functionally depressed. That's what diaschisis is. And then with collateral sprouting, we get some recovery. We know that will happen within two weeks time. You'll get a lot of sprouting, at least you will notice the functional effects of sprouting within two weeks.

And I'm showing here formation of new collaterals, replacing some of the lost connections. And it happens more in the case of the animal with larger cortex because more synaptic connections have been lost. And that will stimulate the sprouting phenomenon. So you'll get more excitatory connections. And we know there is anatomical and physiological evidence for that happening in the spinal cord.

And I'm just representing denervation supersensitivity as a change on the surface of the neurons here. Increased receptors, which will happen more in the case of the larger cortex. With more denervation. Just a little more about this, when we talk about behavioral recovery we usually mean a return to normal, but it's not generally true, especially in the case of spinal reflexes because these recovery effects go too far. And you get hypersensitivity of the spinal reflexes.

There's less known about that kind of hypersensitivity. Over activity of pathways in the brain, it probably occurs there too because we know we have this diaschisis effects happening in many parts of the nervous system. OK, now those long pathways we talked about. These are the pathways going towards the cortex are very rapidly conducting.

What was the major one we talked about? Dorsal column, medial lemniscus pathway, it was also called the neo-lemniscus. And then there's-- we now have a pretty direct pathways from neocortex to the spinal motor mechanisms. As well as to the sensory side. I depicted that in the diagram there. Projections coming from both motor cortex and somatosensory cortex.

I put the one four motor cortex in blue, remember. The one has sensory in orange. A little bit about [INAUDIBLE]-- yes, questions?

AUDIENCE: [INAUDIBLE]

PROFESSOR: Now if you have severe diaschisis, as you have in spinal shock, or in the human if you just lose a lot of motor cortex, the spinal reflexes will all become depressed. Now it's true, you might have some reflexes that don't depend much on cortex. But in animals like us, with large neocortex, but all our functions seem to be influenced by the brain. And when we lose those influences to such a marked degree, quantitatively large degree, the spinal reflexes become depressed.

Just reflexes below the level, the deafferented-- reflexes depending on neurons that are now have lost a lot of their inputs. It's really not as mysterious as many people make it out to be. Why? Well we know neurons need a lot of spatial summation to fire, right? So if it's getting a lot of excitatory input from multiple sources and we remove more than 50% of that input, it's going to take the cells a while now to recover the state where they can fire to the remaining inputs.

That's really what we're dealing with. And we they do recover by these kinds of mechanisms. We're talking about collateral sprouting and denervation supersensitivity. OK, so now when I talk about a projection, what am I meaning? I mean the outputs from a group of neurons via their long axons, usually. So we talk about the projection of the retina. Where does the retina connect in the brain? The projection of the motor cortex, where does the motor cortex project?

So we say it projects to the spinal cord, it just means axons run from there to there. So that's a term I'll use a lot in the class. So we talk about the projection for motor cortex and spinal cord, that's the corticospinal tract. There's a lot of things in their anatomy, it has more than one name. It's also called the pyramidal tract. Why would it get such a name? Well, because the cross section has a pyramidal shape when it goes through the hindbrain.

So anatomists called it the pyramidal tract. But they are corticospinal axons in the pyramidal tract there are aslo cortical projections to the hindbrain. Cortical rhombencephalic axons. This pyramidal tract refers to the entire bundle, corticospinal just refers to all those axons heading towards the spinal cord.

So we talked about spinotectal. We mean from spinal cord to something called the tectum. The tectum almost always refers to the roof, tectum means roof. It means the roof of the midbrain. We'll talk about spino-tectal projections, spino-tectal pathway. Their axons from the cord, they come by way of the spinothalamic tract and midbrain tectum. This is just the use of words in anatomy.

OK we have a few more minutes. And I didn't print this journal for a reason. I have to use this PowerPoint because I'm going to show you some video clips. I'm going to get far enough today to show you the video clips, but you can print this journal yourself, or I can put it up later in that format. So this is really for next time, and I'll go over this again next time. We're going to take a little more detailed look at the spinal cord.

Oh sorry, yeah, we did have this handout today. But we'll do this again next time if you don't have it. We're going to look at spinal cord structure and the autonomic nervous system. We'll start with some embryology, looking at development. I'll survey the adult human spinal cord and then we'll cover the autonomic nervous system. And I hope you're reading about those things too.

So first, we'll look at formation of the neural tube from the embryonic ectoderm, the surface of the embryo. We'll show how we divide that into dorsal and ventral parts, the alar and basal plates. And then we'll talk, we'll define neural crest cells that form the autonomic nervous system. OK now these are cross-sections of the embryonic, of the embryo right along the back.

I can't draw on this, I'm forgetting here. Here's where the notochord is. Remember, in all chordates, they have this cartilaginous rod that forms along the back. And just above it is the surface layer. The notochord forms in the mesoderm, the same part of the embryonic nervous system that forms our bone and muscle.

And the vertebrae, the vertebral arches, the bones will form around that as development proceeds. Above the notochord, the ectoderm at a certain stage in development begins to thicken. And we call that the neural plate because it is going to form the central nervous system. And I show that here as the cells that have become a little longer. It's just one cell thick, but they're becoming thicker. That's the neural plate.

And then something very interesting starts to happen. There's an invagination of that thickened ectoderm. We call that the neural groove. There's a little groove that appears along the back of the embryo. And that-- the invagination proceeds to the point where the two lips here come together. And you end up with a tube. There's some cells there at the edges that don't get included in the tube. They remain outside.

That's called the neural crest. Those are the cells that will form the peripheral nervous system. Now, a lot of these processes depend on molecules that come from the notochord that induce these changes. Yes?

AUDIENCE: [INAUDIBLE]

PROFESSOR: Sorry? This is all the same thing here, notochord, notochord, notochord. These are three different stages of development. Here we just have the ectoderm and the underlying mesoderm, including the notochord. Then we have this invagination occurring. And now what used to be this thickened ectoderm here has become the neural tube. And the neural crest.

These are pictures from your book, little complicated, but you can see they show a section there through the embryo, and this is really meant to show you the same thing I've just been showing you. They show it here at 18 to 20 days. And then when it's gone a little further, the extra things I didn't show here are the somites going to form muscle and bone. Just take a look now at this animation. I want you to look-- you can look at either one, or both. It's slow enough you can look at both.

Here is a dorsal view. And the purple there is the neural plate. So you see it like in my picture here. The only thing different from my picture is they're showing us somites there. So there's the notochord. There's a neural plate and the rest of the ectoderm. So now it's proceeding. I see the neural groove has formed. There you see it there. And there's the neural crest cells that are staying outside the neural tube.

Now you see the coming together of the lips as it closes. And note that it's closing in the middle first. It closes first in the cervical spinal cord. Now it's zipping up rostrally and caudally. The very last place to close will be here in the tail region. And you already see the brain forming. There's a larger neural tube. What's happened here now?

The cells, the dorsal root ganglia are out here, the autonomic ganglia. And then there's some other cells that are moving away from the neural crest. These form pigment cells in the skin, for example. Now they show this view, they should turning. And there you see the umbilical cord. We'll see that again next time. This is an actual film from Xenopus, the clawed frog. And I want you to just to look at the egg here, look at the surface of this little embryo as it forms.

There you see the neural, you look right there. We'll look at it again, you see it in all of these. You see the neural groove there. Pretty hard to see the neural plate, but you see it zipping up. So that's neural, that whole process is called neurulation. Neurulation. Those neural crest cells, I took this from-- Carolyn Moran is a scientist in England. She puts this on her website. She's been studying the fate of neural crest cells. And she's looked not only at the neural crest cells in the spinal cord region, but also in the head region.

And she's noted here the various things that had formed. We talked mainly about the sensory cells, which are the dorsal root ganglion. But also the autonomic nervous system. The Schwann cells-- what are Schwann cells? Yeah?

AUDIENCE: [INAUDIBLE]

PROFESSOR: Well they covered the axons of the motor neuron axons. But they are the glial cells that form the myelin sheath, but not only of motor neurons, but also the sensory. And not the spinal cord. It's only in the periphery. Schwann cells are in the peripheral nervous system. They surround the axons, the peripheral nervous system.

OK now the neural crest also forms the adrenal cells. Not actually, only the adrenal medulla cells that secrete epinephrine or adrenaline. But other cells there too. They form melanocytes. I showed you some of those cells that were migrating dorsally into the skin from the melanocytes. They also form other parts of the autonomic nervous system that we'll be talking about in the head.

They form sensory ganglia in the head. Also the Schwann cells peripheral nervous system. And other structures too. So then we have the neural tube. I'm showing the dorsal root ganglia here outside. And in the next big thing that's going to happen that we're concerned about is these x axons are going to grow. Initially when they form, there's no axons. But now, this cell will take this bipolar shape and it will start-- this little growth cone will appear, very active growth tip will appear going out into the periphery and towards the spinal cord.

And Meanwhile, very early, you'll find some cells in the ventral part here of the neural tube, will send axons out. Those are the motor neurons. You don't even have to take any notes now, we're going to do this all next time anyway. I just want you to get used to this. Spinal cord, we're almost finished for today. This cross section of the spinal cord and a myelin stain, you'll see the myelinated axons around the outside.

In the spinal cord, we always have the gray matter in the center, That's what happened to all those cells of the neural tube. They now end up-- the axons collect on the outside. The original neural tube as you see right there, and just about the size of my red dot there. And then it got bigger and bigger and bigger and bigger as all the cells proliferated. And a lot of mitosis, and then they formed the axons. And it ends up looking like this.

Dorsal part is where the secondary sensory cells are, the ventral part is where the motor neurons are. On the right side it shows collections of motor neurons. And here, just the outline of the spinal cord at many different levels. And note huge amount of white matter here, those are the axons. Here they show it as white. Here, some myelin stains, we're staining the myelin black. And here, they're showing the gray matter in dark.

I just want you to notice a couple of things. A lot of white matter here, getting less and less and less and less as we go down, why? It's very easy. As we go up, remember, more and more fibers there in the dorsal columns. All of the secondary sensory cells. More and more axons, the spinothalamic tract, they're being added at all levels of the body. So the further up the cord we get, we have more and more axons in the dorsal columns and the lateral columns.

And similarly, the descending pathways coming from the brain, those fibers are entering the gray matter. And the further down you go, more and more of them have disappeared because they've already terminated. So we get less and less white matter. But just by looking at a cross-section of the cord, you can tell about what level it is.

The other thing to note here is that the gray matter is much bigger in the cervical region here. And here again in the lumbar region. Those are the enlargements, correspond to limb innervation. We need a lot more neurons to innervate our limbs. So that's why there's-- those are the cervical and lumbar enlargement. And I summarized that here. And we'll go through this again next time.