GERALD SCHNEIDER: This was the only slide left from the previous talk, so this is the one you've gotten today. I just want to finish this from the previous lecture. We were talking about autonomic nervous system. And we described the sympathetic and parasympathetic innervation of the intestinal tract. But work in the last decade, especially on the innervation of the intestinal tract, has uncovered some surprises.

There's more than just parasympathetic innervation of postganglionic neurons that release acetylcholine and increase peristalsis. There's, in fact, interconnected neurons that basically function as a nervous system that's modulated by inputs from the brain. But it amounts to a little nervous system in itself, with synaptic connections, interconnections. There may be-- this is an estimate-- there may be as many neurons in the enteric nervous system as in the whole spinal cord. I don't know how those counts have been made. I've not checked that.

But anyway, in the wall of the intestine you have these plexuses of fibers and neurons interconnected. They are innervated by the vagus nerve in the way we describe for autonomic nervous system, but they also have their own activity, and they get their own inputs. They can function without the nervous system, without the brain, without the central nervous system.

It's also been discovered that something similar is true for the cardiac ganglion. There are interconnections. There's a possibility that your heart has a little brain. All right, so that's still an area of active investigation. There are various neurotransmitters involved, not only acetylcholine, in that system.

OK, we have this lecture and the next time still devoted to a survey of sort of an introduction to a neuroanatomy of the various parts of the nervous system. We're going to talk about the brain. Now, we've talked about the spinal cord and the autonomic nervous system.

Today, we'll talk about hindbrain. We may get to some of the midbrain, but we'll do that next time, where we will discuss the forebrain. And then we will talk about development. OK, so here's our picture of the embryonic mammalian nervous system with the expanded neural tube, with the expanded hindbrain, midbrain, and forebrain, with the endbrain bulging out from the forebrain.

Today, we'll talk first about this level, the hindbrain, which looks this way in cross-section. We'll see that it's basic organization is very similar to the spinal cord. So I call it a glamorized spinal cord. We'll go over its basic functions and cell groupings. Then we'll talk about the sensory channels for the sensory input from the face, that comes directly into the hindbrain through the fifth cranial nerve, the trigeminal nerve.

And then I'm going to talk about some distortions in the basic organization that happen with the growth of cerebellum, primarily. We saw some of the distortions in the hindbrain that happen with the development of certain sensory systems in fish. So now we'll see what the distortions are in the human brain.

OK, so the embryonic spinal cord and hindbrain have a very close relationship. This is the neural tube at the spinal level. We talked about the alar and basal plates. In early development, you have a layer of cells around the ventricle, and that's where cells are born.

We're going to be talking about development and the mitoses that happen there, and the process of migration from the ventricular zone. Intermediate zone is where the cells then end up. They migrate into that region. And then the very outer layer we call the marginal zone. It has mainly fibers.

Now, you have the same organization in the embryonic hindbrain. But there's a difference in that the roof plate, which is just very similar to the floor plate in the spinal level, in the hindbrain level, the roof plate expands. It's like you just pull this open. So what happens then is that the alar plate ends up more lateral and the basal plate more medial. Otherwise, it's a similar organization.

The secondary sensory cells, though, become more clumped together than in the spinal cord. So we end up with different cell groups, or we often call them nuclei, like the cochlear nuclei getting the auditory input from the primary sensory neurons in the cochlea. So they form in the alar plate.

And similarly, in the basal plate, you have groupings of motor neurons. You have those in the spinal cord, but they don't form these compact nuclei the way they do in the hindbrain. In the spinal cord, we know there was a dorsal root and a ventral root at each segment of the cord.

What about the hindbrain? Well, there are inputs and outputs there too. But the law of roots doesn't hold anymore. There are some nerves that are just like ventral roots. There are some, like the auditory nerve, that are just like dorsal roots. But there are other mixed nerves. In fact, some of them penetrate right through the side here.

So let's go over this a little more. This is what I just said. Now let's go through the functions a little bit. And then we'll come back to the anatomy.

Mostly we think of hindbrain in terms of what I call the routine maintenance functions, the janitorial service area of the central nervous system, vital functions, control of breathing, blood pressure, heart rate, and other visceral control. Remember, the main CNS cell groups of the parasympathetic nervous system are in the hindbrain.

We know that many fixed action patterns are organized and controlled by organized neural circuitry in the hindbrain. Our smiling is a fixed action pattern in humans. It would be controlled by not just the motor neuron organization but the interneurons that connect to them and basically form a program of control. So when it's triggered by some adequate stimulus, then you get the action pattern.

What other action patterns would you have in hindbrain? Well, our facial muscles are controlled from there. One would be-- and we'll see the circuit for it in a later diagram-- for the eye blink. You say, but that's just a reflex. But actually it isn't. It's also a fixed action pattern because it has a motivational component.

The longer you go without blinking your eyes, the more you have a tendency to blink your eyes. You develop a stronger and stronger motivation. That's what staring contests are all about. You see how long you can keep from blinking your eyes. It's harder and harder to stop it, which is typical of fixed action patterns. When they don't get executed, a kind of something builds up, an excitation builds up in the nervous system and makes the probability of their execution more and more likely.

The hindbrain is important in higher functions. Not it can't do these things by itself, but, in fact, on the output side for speech, our tongue, our lip, tongue control, lip control, and breath control is done primarily through the hindbrain.

And that's so critical for speech, our emotional displays obviously very important in higher social activity, for our facial expressions, at least. That's controlled through the hindbrain. And, of course, part of that is eye movement control, which is very important for a number of things. And orienting movements. also is controlled by the hindbrain and also by the midbrain.

OK, so now it gets a little complex. I don't expect you to memorize all this, at least not at this point. Although after you study nervous system for a long time, this becomes sort of automatic. But now, remember, we talked about the groupings in the alar plate and the groupings in the basal plate. So let's just see what these groupings are.

So here would be the position of the cochlear nucleus. Similarly, it would be the position of vestibular nuclei. So input comes in through a nerve, a cranial nerve, that's just like a dorsal root, OK. And the secondary sensory cells that receive that input from the primary sensory neurons in the cochlea are located in that position of the hindbrain. Now, they're not all the way up and down the hindbrain. They're just at one level, OK.

Similarly, the input from the face comes in, context secondary sensory neurons. Located in a different position. And that's the trigeminal nerve. And I'm going to go over that in more detail in a minute. In addition, there are secondary sensory cells or the visceral system, visceral sensory. So those would be the main three groupings of secondary sensory cells in the hindbrain.

And then, among the motor neurons, we have motor neurons innervating muscles in the face. For example, swallowing and vocalization is controlled by a group of motor neurons in this level. More rostrally, we have motor neurons related to control of the jaw and also control of all of our facial muscles, the facial nucleus.

Facial nucleus is cranial nerve VII. Chewing movements are part of cranial nerve V, whereas the swallowing and vocalization depends on control of the tongue, ninth and tenth cranial nerves and XII, in addition.

Somatic motor column, located right here, and this group of neurons, the motor neurons, has output very similar to a ventral root. They always go out about in the same position that the ventral root would be in the spinal cord. And that's how the neurons controlling our eye movements, there's three different cell groups that do that, two in the midbrain and one in the hindbrain. And also the control of tongue movements, the caudalmost cranial nerve nucleus.

OK, so those are the motor neurons and the secondary sensory cells. And then, in addition, whenever you look at brain stem, you're seeing a lot of axons going through. So the axons that we talked about before-- what did we talk about before?

We talked about spinothalamic tract and we talked about the medial meniscus. So here they are. Here's the spinothalamic tract, position of the spinothalamic tract, and over at the medial side there, the medial miniscus. That's the way they travel, through the hindbrain, in that position.

And then we have various descending tracts as well. OK. And I've indicated those here. Let's just look at this one, a big group of axons here at the base. It's much larger in primates, as the corticospinal fibers. A synonym for the corticospinal tract in the hindbrain is the pyramidal tract, and it's because of the sort of pyramidal shape of the cross-section there of the corticospinal fibers.

OK, so let's talk about the sensory channels in the hindbrain by talking now in more detail about that trigeminal nerve. And I'm sorry the next picture is a little small in your handout. But it is on the web. Look at the figure, and let's follow the pathway for the eye blink.

Now here's the somewhat enlarged view there of the upper part of the brain, the nervous system. And here's the hindbrain, showing some of these motor neuron groups, medially, and the secondary sensory cells laterally. But look first at this cross-section, OK.

Here's the fifth nerve nucleus. Input comes in and joins a little tract in the side, and goes up and down the hindbrain, and terminates in that nucleus at various levels. Now, that input, if we look over here, you can see how it comes in. Here's the trigeminal ganglion coming from the face.

Now you can see why it's called trigeminal because there are three main branches that go to different parts of the face. One branch goes from the upper eyelid up to the beginning of the spinal input, which is in the back of your head. And then that's the first of the three branches.

And then there's a middle branch, the maxillary branch, that innervates the upper lip. And then the lower branch, the mandibular branch, the lower part, the lower lip, the jaw, and part of the neck. So that's the distribution of the trigeminal nerve.

And these are primary sensory neurons. This is just like a dorsal root ganglion but it's in the head. It sits right under the brain. So if you are doing a brain dissection of, say, the sheep brain in a class, you will find that right-- basically, it's when they lift the brain up, there it sits. And sometimes they get it-- usually they end up cutting it about here. And it's possible to get in brain removal.

So here come the axons. They penetrate right into the side of the rostral part of the hindbrain. And they terminate in the principal nucleus, the trigeminal nerve. But some of them terminate further down because that nucleus has a descending component that goes all the way down, in fact, into the upper part of the spinal cord. So that's why that's so elongated.

So if we take a cross-section right there, we're going through the secondary sensory cells. And that's what I show here. And there are reflex connections from-- there's a reflex pathway from those cells that, by way of interneurons, go into this motor nucleus, the facial nerve, the facial motor nucleus, which has axons that take this peculiar looping route and then go out the side to innervate the facial muscles.

And some of those would go to the eyelids. So you could get reflex contraction of the eyelid. That's just eyeblink as a reflex triggered by sensory input. And it will be triggered that way, but then, in addition, it gets endogenous input, so we blink spontaneously.

OK, so that's the local reflex channel, just one example of it. Let's now look at the lemniscal pathways. And here, they're very much like the spinothalamic tract and the dorsal column medial lemniscus systems. And they go up to that same nucleus in the thalamus that the spinothalamic tract and the medial lemniscus-- where those two tracts from the spinal cord terminate.

But they go to the more medial part, the ventral posteromedial nucleus. We generally wrote that in Latin. And the abbreviations that you'll find in any textbook are always given this way, VPM, because it's from the Latin, nucleus ventralis posture posteromedialus, the medial part of the ventral posterior nucleus.

In this class, we can just call it the whole thing, the ventral basal nucleus, because its positioned ventrally and basically in the thalamus. But remember, this sensory part is the caudal-- the posterior part of that nucleus. Now let's look at it in this picture.

We have to start with the secondary sensory neurons in the trigeminal nucleus, and we see where their axons go. I talked about the ones that form reflex pathways. But now what about the lemniscal pathways? So we see some here in the principal nucleus that simply send their axon across the midline and ascend right up to the ventral basal nucleus, just like spinothalamic tract.

They also arise in the descending nucleus at various levels where, again, the axon of the secondary sensory cell crosses over and ascends. So this forms, then, what we call often call the trigeminal limniscus. And we think of the axons arising in the rostral part as being more like the dorsal column system, whereas those of descending nucleus more like the spinothalamic tract because of the functions of those axons.

But you can think of it as a single pathway that originates at all levels of the trigeminal nucleus and ascends to the ventral basal nucleus. There are branches-- just like for spinothalamic tract, there's some branches that terminate along the way, especially in the midbrain tectum.

I do show a few other things on this. I show, for example, the several motor nuclei, including salivatory nuclei. I show both the masticatory nucleus and the facial motor nucleus here in the hindbrain. And I show this little nucleus that's very long, that controls swallowing and vocalization. It also gets input from the trigeminal system.

All right. Now, I showed this basic plan of the hindbrain here. And now I want to talk about what happens-- why, in the adult, especially the human, but it's true for other primates especially, it's very hard to recognize that in a cross-section, especially in the rostral part, the hindbrain. Because that basic embryonic organization becomes very distorted.

Remember other species that have different kinds of distortions. We saw the picture of the freshwater Buffalo fish with a huge beta lobe. Similarly, the catfish with vagal and facial lobes, which we expanded. We know that the cerebellum in electric fish is enormous. It's very specialized for it has a role in the electroreception.

Well, in mammals, especially in humans, the cerebellum is also very large because of its role in motor coordination, especially the coordination of the most distal muscles, control of our hands and feet. In addition to the cerebellum itself, there are cell groups that provide input to the cerebellum. We call them the precerebellar cell groups. For example, the so-called pontine gray.

So let's just take a look at one of these, at a cross-section of the human hindbrain. This is from the rosral hindbrain. Now, a caudal hindbrain would not look so different from my diagrams. But if we saw this entire section here, here would be the ventricle. It would be about this big. They've cut it there so you can see the core of the hindbrain.

Now, what I've been diagramming is basically here, below the ventricle. This is the huge structure that's appeared with the development of this enormous cerebellum in humans. So we can think of that as a distortion. It's much smaller in other mammals, so it's easier to recognize the hindbrain organization in the adult.

Even in human, if you look very early in development, you see the plan that I was outlining very clearly. Because the cerebellum then develops late and distorts it.

So here's the ventricle. This would be the alar plate region. And there are secondary sensory cell groups in here. There are motor neurons here. In fact, here you see some myelinated axons, one of-- some of those motor neurons.

But then what has happened here is that you have movement of cells from the alar plate region that have migrated down. And these are cells that receive connections from various parts of the brain, but especially from the neocortex. And they send their axon up to the cerebellum.

In addition, you have huge bundles of axons passing through that region. These are the corticospinal axons, which, in human, are very, very numerous. Just caudal to this, they form the pyramidal tract at the base of the hindbrain.

OK, if we look at this picture, this is where the cerebellum-- oh, my. I drew it in the wrong place. Sorry. I must have been under the influence of that champagne for Rutledge's thesis defense. OK, (CHUCKLING) sorry about that. I can see it immediately here. Just take your pen and move them right down there. I put them in the midbrain. They go in the rostral part of the hindbrain. Sorry. I will change that after the class.

OK, you see, I've drawn this without the cerebellum so that you can see the basic plan more readily. I just want you to know that, in the rostral part of the hindbrain, in the alar plate region, there you have this enormous proliferation of cells in development. They migrate up to the roof plate and form the cerebellum.

They migrate, also, down and from the pontine gray and also other cell groups. I'm not going to name them all. It gets too confusing, at this point. And it distorts the basic organization. But once you know, and if you follow it in early development, it doesn't become-- you can see this basic plan.

The more caudal part of the hindbrain remains pretty similar to this, except you have huge numbers of pyramidal tract fibers, like corticospinal tract fibers, at the base there, which will distort that somewhat. But it's much easier to see the basic organization.

And, of course, the spinal cord that looks like this early on. It changes too because the walls in the neural tube get thicker and thicker, and it basically balloons out like this, OK. So you end up with the little ventricle in the middle with a big spinal cord around it. But it's a little easier to understand than what happens in the hindbrain.

I know. We're almost through. I just introduced here at the midbrain. I want you to go look at those pictures. I know when you first get this kind of anatomy, it can be very confusing. And the only way to rescue yourself is basically go over it a number of times. I will go over it in class, in different ways, when we talk about different functions. And it sort of grows on you until, finally, you don't have so much trouble with it.

The midbrain will be a little easier to deal with. Again, we have the ventricle. Again, we have thickened walls of the neural tube. But the way it develops is quite different. It's an important area of correlation centers, especially the colliculi that get auditory and visual inputs.

There's also particular long axon output systems that originate there. I'm going to just show a couple of those and show you what happens in different species to change the whole shape of the midbrain. And just like we had for the hindbrain, we have to deal with these long tracts passing through.

This is just summarizing these so-called correlation centers, the colliculus, which we'll refer to at various times in the course. In the class, it's best known for its visual inputs that come into the surface layers. But it also gets auditory and somatosensory input.

It's important in these functions of orientation and anti-predator responses. And it gets major modulating inputs from the forebrain as well, as well as from some of the more diffusely projecting accents.

Inferior colliculus is similar. It's more related to the auditory system. Both of these structures send axons forward into the thalamus. It's a major relay for sensory information to the thalamus, for both visual and auditory, even though both of those systems also have more direct axons that bypass the midbrain on their way into the thalamus.

And then we'll talk more about these, the multimodal regions, the more primitive parts of the midbrain reticular formation in central gray. And then this output system for sensory motor control of the limbs.

This is the one we'll end with. I'm just showing this basic outline of the midbrain in an adult rodent. The human would be similar, except the axons here would be much, much larger. It would be mainly a quantitative differences in species. I'm showing here where the fibers are coming in from the retina. Here's an auditory pathway coming from the more caudally located part of the midbrain.

And here we see our axons coming through the medial lemniscus fibers and spinothalamic tract. They form a band coming through the midbrain and the spinothalamic tract fibers, some of them terminate right in the deeper parts of the tectum there.

On the output side, we have two major pathways that originate in the midbrain. One is in the tectum, controlling head and eye movements, where large neurons in the deeper part of that structure send axons, as most systems do, across the midline. And then they descend to the hindbrain, primarily, and also the upper spinal cord.

But there's also neurons-- this is controlling head and eye movements. They're also neurons here concerned with limb control. This is the so-called red nucleus because of the red pigment there in a human brain. Again, the axons are sent across the midline, where they then descend in a more lateral position than the tectospinal fibers.

Notice, I've only underlined those two for you on this. I want that to begin to stick in your mind. I know you won't memorize it right away, but we'll talk about that later when we talk about motor control, two motor output pathways that originate in the tectum.

All right, so that's where we'll start next time.