GERALD SCHNEIDER: OK, we started class 12 last time, and we're going to go back over what we covered at the end of the last hour. We're looking at spinal cord structure in a little more detail and then the autonomic nervous system. You can also read quite a bit about these things in your textbook. My way of presenting it is a little bit different from the textbook. I'll point out just a few differences.

So these are the topics for today. So we'll look again at the formation of the neural tube from the embryonic ectoderm, the surface layer of the embryo, define what we mean by alar and basal plates, also the roof plate and the floor plate, the developing neural tube. And then we'll talk about neural crest cells as well.

OK, so if we just take a section, a cross section, through the back of the developing embryo-- this would be true for all of the chordates, that the surface ectoderm above a structure called the notochord, which is just cartilage at this stage, begins to thicken. And those are the cells that will become the central nervous system.

The thickening of the ectoderm is called the neural plate. This is the neural plate stage, the beginning of neurulation. And then neurulation continues with an invagination of that neural plate. That continues until a tube forms, leaving out some cells that become peripheral nervous system. Those are the neural crest cells.

And these are sections depicting the human embryo at a couple of specified stages. And you should be able to relate these pictures, which are in your textbook, to the pictures I'm showing you. You can see that this is happening pretty early in development.

Now, exactly when it happens in various animals will vary a lot. In the Syrian hamster that I used for my research, the neural tube is closing in only eight days after conception. But, then again, they're born at 16 days after conception.

OK, so we're going to look again at these. Let's look at here. Let's look what happens to the cells. This is a section right through the neural plate. You can see here begins to invaginate. There's the notochord.

And now, already before the neural tube is closing, you see neural crest cells that are outside the developing neural tube, and they're beginning to migrate. They're migrating dorsally into the skin and ventrally, where they're going to form the ganglia of the peripheral nervous system.

These are the somites. They're going to form the bone of the-- you see the formation of the vertebrae. These are bone and muscle.

And now you see the neural crest cells that migrated ventrally are in a couple of groups here. These will form the dorsal root ganglia, and these will form the paravertebral ganglia. Others continued further down ventrally to form prevertebral ganglia of the sympathetic nervous system. We'll look at that again in a minute.

OK, we might as well look at this again, too. The closure of the neural tube here happens very rapidly. So I just note when it's open and when it closes. It zips up very quickly in this film.

And you can look at a different one like this one here, a good picture of that closure of the neural tube. It closes first at the rostral end, and then it closes at the caudal end.

In some cases, there are defects in the cellular mechanisms controlling these things, or there might be trauma in the womb to disturb it. And if the neural tube fails to close at the rostral end, you get the condition called anencephaly. Because the CNS is exposed, it doesn't develop properly. So a child will be born with basically little brain and won't live very long, or live very briefly, showing some reflex actions, and that's all.

If it fails to close it the caudal end, you'll get a spina bifida. And that is correctable. It's a defect that varies a little bit in degree, but it's generally correctable surgically.

OK, this I took off the web, as I mentioned last time. Carol Moran in the UK has a website. She does research on neural crest cells. She summarized what happens to the neural crest cells at various levels. She points out that, in the most caudal region, lumbosacral region, cells migrate to form the enteric nervous system.

Now, you don't know what that is yet, but these are basically cells all along our gut. They sort of form a nervous system of their own because they interconnect with each other. And they will function even without connections with the CNS. So we'll define that.

Also, in the trunk region, they form melanocytes in the skin. And they form the sensory and sympathetic ganglia, as we already pointed out. They're also forming the Schwann cells, the cells that make myelin in the peripheral nervous system. They form the cells of the adrenal gland, particularly the adrenal medulla, the cells that, of the endocrine system, that secrete epinephrine or adrenaline.

More rostrally here, the hindbrain region, neural crest, you get migration of cells all the way down into the thorax and abdomen. It's part of the enteric nervous system, whereas those in the head form the equivalent of the dorsal root ganglia in the head region, sensory ganglia of the cranial nerves.

They also form the autonomic ganglia of the head region. It's like the ciliary ganglion. It controls the iris behind the eye. And they also contributed to the formation of connective tissue and skeletal elements.

But now, just focusing on the spinal cord, what we're most interested in this class is how the axons form and what kind of connections they form. So after that migration has occurred-- and I placed the ganglion perhaps a little too far dorsally here. It's probably down here.

But these cells become bipolar, and axons appear on either side. And these grow and extend little growth cones at the tip. We'll see pictures of those a little later. I'll show you some video clips of growth cones. These are the cells that will become unipolar later. But when they first develop, they're sending an axon out in either direction.

And, meanwhile, within the cord, in the lower part here, which we call the basal plate region, there are neurons that are sending axons out very early. And so we know that those are the motor neurons.

OK, let's look at the adult cord a little more and look at the different levels, talk about the sensory channels of just a few descending pathways that will come up again in the class. And we'll define this term, propriospinal.

OK, what kind of stain is this? What are we staining there? White matter, we're staining it black. What actually is being stained? Do you know? The myelin. There are other axon stains, but this one is from myelin.

And you see that most of the axons are outside this central butterfly shaped region, which is the gray matter where most of the cells are. Of course, there are bundles of axons in the gray matter as well.

That little tiny spot in the center there is what's happened to the ventricle, the central canal of the neural tube. So the walls of the neural tube have become very, very thick. It started like that, the embryonic neural tube.

So what's happened now? It's gotten thicker and thicker and thicker. You can imagine it progressively getting thicker. But, in fact, it doesn't thicken up so much in the floor plate and roof plate. So, basically, if that's the ventricle, the roof plate, and the floor plate, it's going like that, basically ballooning out.

OK, now, who remembers what's happening here? Why is the white matter so much thicker here than it is here? Two reasons-- yes?

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: OK, you said the nerves. We don't call them nerves in the CNS, axonal tracts. The axons that are coming down the corridor, they're leaving those bundles, and they're going into the gray matter and terminating. Whereas the ones going up, more and more are being added as we go up.

So, for example, the dorsal column here is small, down on the sacral cord. And then, as you pass each spinal nerve, axons are entering. Primary sensory axons are joining the dorsal column, actually branches of those axons. Another branch actually goes into the gray matter. And so that becomes thicker and thicker.

And this would be, the cervical level here-- see two at the very top of the spinal cord. This would be just caudal to the dorsal root ganglions. The dorsal column nucleus, two of them there, nucleus gracilis gets the more medial part here from the legs. Nucleus cuneatus gets the axons from the lateral part here from the upper part of the body.

OK, and the other thing is to note that the spinal cord is thicker here in the lower cervical region and in the lumbar region because of the innervation of the limbs. You'll note how much wider the ventral horn is because there are many more motor neurons there because there are many more muscles to innervate.

Not only there are more muscles to innervate, but there's a greater amount of innervation of the muscles where we have greater dexterity. And, similarly, there's more sensory fibers coming in where we have greater acuity, which would be especially in our fingers.

OK, I just talked about all these things, except the last one, the presence of the lateral horn and the thoracic and upper lumbar cord. That's that little lateral protuberance. So we talk about-- if you look at this level first here-- a dorsal horn and ventral horn, the upper and lower wing of the butterfly.

And then, in the thoracic region and upper lumbar, there's an extra little horn there, a little lateral protuberance. Those are part of the sympathetic nervous system, and we'll define that in a few minutes.

OK, so now let's look at those sensory channels and a cross section of the cord, local reflex, cerebellar channel, and the meniscal channels. So here's the cross section of the cord. This would be the lower lumbar region.

How do I know it's lower lumbar and not sacral, just by looking at the cross section? That, the lateral horn, it's only present in thoracic and upper lumbar.

And so we have dorsal root fibers coming in from the spinal nerve. The spinal nerve would be way out here. It contains fibers of the ventral roots, like this axon, and fibers of the dorsal roots, like all these axons I'm depicting here. And I just depict them of varying sizes.

Many of them, but not all of them, have branches into the dorsal column. So that's the origin of the dorsal column medial and meniscus pathway that we traced out in the previous class.

Others are terminating directly in the dorsal horn. And that includes some cells that give rise to the spinothalamic tract, which is made up of axons that are decussating right away, entering a position about here in the anterolateral cord in the lateral columns. And then they ascend.

I show a reflex here. I'm showing it being made by-- its input is from an axon that also goes to the spinothalamic tract. But it connects to interneurons in the intermediate layers of the cord here, and then it connects to motor neurons by way of that interneuron and goes out. So that would be a local reflex. That's the local reflex channel of conduction.

What about the cerebellar pathways? While I don't show them here, there is a crossed spinocerebellar pathway, the ventral spinocerebellar tract, that looks very much like the spinothalamic tract.

There's another one that terminates in this region, the ventral part of the medial dorsal horn. And those fibers descend on the same side, so the dorsal spinocerebellar tract.

I'm not asking you to memorize so many details. I know this is going to seem like too many details to you. And I've put a lot of these things into the text file now of that program you have, the [? flash ?] [? key ?] program. And I'm going to post that on the web. And if you want I can also send it as an attached file by email as well. I'll try to do that today.

And it's all divided up into separate lessons. There will be a few things in there that might seem too much detail to you, but they're all things that I'm mentioning in class. So I'm making it up completely from the class.

So let's now talk about some of these descending pathways, the major ones, just a few of them. There's a huge number of them, of course, but these are major ones which we talk about later in the class.

The corticospinal axons, they're out here in the lateral columns. One reason the lateral column is thick in humans is because we have a very large corticospinal pathway.

Now, there are some mammals where that pathway is not in the lateral column at all. In some species, it's right here in the ventral part of the dorsal columns. That's where the pyramidal tract axons, or corticospinal tract axons, are in rodents, for example. But we have them in the lateral columns.

There was once a big controversy about the Malayan tree shrew. People said it's the most primitive of the primates. And everybody wanted to study this little animal because it seemed to be very much like the ancestral animals that led to primates, the beginning of the primates. I actually studied them for a while here at MIT. I found out that they were very stupid, so they fit the role of an ancestral animal.

And then people began looking at the anatomy, and they discovered that the pyramidal tract ended up, the corticospinal axons ended up here, just like in a rodent. And then people thought it might be an insectivore, but it didn't have all the characteristics of an insectivore.

So it ended up in its own order just because, well, because of many characteristics. But the clincher that it wasn't a primate was that all the primates have corticospinal axons out here in the lateral columns.

OK, now, rubrospinal, that's a pathway coming from the nucleus ruber of the midbrain. We've not shown the cross sections of the midbrain yet, but we're going to. It's a major pathway controlling limbs. And before there's a corticospinal tract, or if we're missing a corticospinal tract, then that pathway is very important.

This function is totally overwritten in higher primates by the corticospinal connections. But all those axons at various levels connect into the gray matter. In the case of the rubrospinal, it's mainly at the enlargements because they're concerned with the movements. Corticospinal also because it has so much innervation of distal muscle control elements. It will also give rise to many more axons in the enlargements.

Corticospinal goes to all parts of the gray matter of the cord. And then here in the ventral columns, I'm showing-- well, there's a little bit of corticospinal there, axons that never crossed. That varies a lot in different people. It's probably a function of your genetics. How many of those do you have? There are some people that don't have it at all.

But these are pathways. We'll be talking about their function later. They come from many different places. They're always concerned with coordination of balance and posture. They come from reticular formation. They come from the vestibular nuclei. They come from the cerebellum.

That funny name, fastigiospinal, totally foreign to you at the moment, I suppose-- it is because one nucleus of the cerebellum that gives rise to output of the cerebellum is called nucleus fastigious. It's the most medial one. So that's really a cerebellospinal.

Also, the optic tectum has a pathway. It only goes to the cervical cord because it's concerned with orienting movements of the head and eyes.

And there's other pathways there, too, that I'm not naming. I don't expect you just to memorize a figure like this, but you'll keep encountering these things. And if you read it, try to understand what it's talking about, and some of it will grow on you. But it might not seem that way right now.

Autonomic nervous system-- let's talk first about the functions of the autonomic nervous system, and then I'll give you a schematic overview of the structure of this system. Very important for controlling the stability of our internal environment.

We're going to look at this table enlarged in a minute. And we're going to look at this cross section and look at this dorsal view of the embryonic nervous system, in which I depict the chain of ganglion, or the sympathetic nervous system.

Those are those ones that ended up in front when we saw the migrating neural crest cells. They're actually on both sides. I'm showing them only on one side here. And this ganglion here is really in front.

The sympathetic preganglionic fibers all come from the thoracic and upper lumbar levels here. The ones coming from the head here, the hindbrain and midbrain, and from the sacral cord, we call parasympathetic. Those are the two divisions. And they have a different pattern of innervation and different kinds of functions.

You have this kind of thing in your book, too. This will be a little hard for you to read here. But some of this, you know, let's just take a few organs like the iris. What does the iris do in your eye if the sympathetic nervous system is activated?

Now, to remember this, think of sympathetic nervous system as the system that gets activated for fight or flight. That's the way it's usually summarized, and it's pretty accurate. Fight or flight-- that will include when you're angry or when you're very scared.

When your heart is pounding, your heart accelerates in blood volume and rate. What is that due to? It's due to two things, secretion of adrenaline by the adrenal medulla. But before that, it comes from direct innervation of the sympathetic nervous system and secretion of the neurotransmitter for that system, noradrenaline or norepinephrine.

But let's take the iris, here. What do the eyes do when you're angry or when you're frightened? Get big. The iris dilates. It dilates the pupil.

Parasympathetic does the opposite. If you shine a light in the eye or it's brighter outside, your pupils get very small. That's due to parasympathetic nervous system.

Now, in general, if the sympathetic nervous system is causing dilation of the pupil, the sympathetic nervous system is doing things to the rest of your body, too. Almost all of these things are happening.

That's a general difference in these two systems. Sympathetic, the whole thing tends to be activated. That chain of ganglia has many interconnections up and down. So part of it gets activated, the whole thing tends to get activated. So not only is your heart speeding up, but you will have all these other things happening, too.

So, for example, the bronchi of the lungs, the lumen in the lungs dilates, take in more oxygen. They'll be constricted by the parasympathetic. Salivary glands, to reduce the sympathetic, the parasympathetic causes secretion.

Urinary bladder-- well, if you want to run or you're angry, you don't want to take a leak. So, in fact, it constricts the sphincters. It's the parasympathetic that allows your bladder to empty. It relaxes those sphincters.

There are exceptions to that. If we're very, very frightened, a fixed action pattern can override that function of adrenaline. And you can violently defecate, which is something that can save a woman's skin if she's being raped.

You see it in monkeys when they're very frightened. If you frighten them, come in the room, and there a monkey's just come and he doesn't know you and he gets very frightened of you, that he will sometimes defecate.

It's very well known in rats, in the laboratory rats. In fact, they count fecal boluses as an index, a quantitative index, of how frightened they are.

In the case of sex organs, it's much more complex because both systems are involved. The vasodilation that occurs in sexual arousal is parasympathetic. But there are also sympathetic actions, particularly in the muscle contractions of orgasm. OK, so you can study these, and they're also in your book.

Let's talk about how this thing develops, just introduced with that film. Here's my pictures again, and I'm showing in red here the neural crest. What's happened to the neural crest cells?

They've become the dorsal root ganglion. They've become the paravertebral ganglia, which are a chain of ganglion next to the spinal cord, and the prevertebral ganglia. There's a few of those, also, where the cells come together and form similar ganglia out in front of the CNS.

I'm showing the notochord here because I'm showing a very embryonic nervous system. But remember that, as this develops, that becomes buried in like vertebrae, the spinal vertebrae. So these ganglia are just outside the vertebrae. They're in front and lateral to the bones of our spinal cord. Or up the spine, I should say.

OK, so now let's look at what happens to those axons. The system is called thoracolumbar because it's present at the thoracic and upper lumbar levels that I pointed out. Neurons that innervate those ganglia are here in the lateral horn. So if you look here in the cross section, we call these preganglionic motor neurons. So that's here.

Preganglionic, sometimes I'm writing here and then I'll see if I already have it written down, preganglionic motor neurons. They're motor neurons because they send an axon out of the cord. And all the cells that do that, we call motor neurons.

But they don't actually innervate the muscle or gland cells themselves. Instead, they connect with cells that do. They connect with one of these cells that migrated from the neural crest, forming a paravertebral or a prevertebral ganglion.

If they're in the paravertebral ganglion here, the postganglionic cell, the actual motor neuron of this sympathetic nervous system, its axon rejoins the ventral root and goes out the spinal nerve to the periphery. And it would innervate, for example, smooth muscle. Or it's in heart muscle, also.

It could innervate the muscles that cause the erection of the hairs in our skin for temperature regulation. It doesn't help us very much for temperature regulation, but it does for many animals. It also innervates the sweat glands.

The prevertebral ganglia have a very similar pattern. Their axons go out to the smooth muscle of the gut. The ciliary ganglion is a particularly large one. It's in a plexus out in front of the cord. We call it the solar plexus.

You know how you feel if you get hit very hard right in the belly because it can-- just like touching your elbow can activate the axons of the arm, so you can activate those cells and cause the gut to be somewhat upset if you get hit hard that way.

Now, if we deal with the heart, I'm showing here cells in that lateral horn that are leaving the CNS. A number of the ones that are going to affect the heart innervate a series of ganglia, not just one. So some of those axons have to go up a ways up the chain.

And then the postganglionic cell, the sympathetic motor neuron, goes to the heart muscle and releases what? It releases norepinephrine, abbreviated NE. Or noradrenaline, it's often called, noradrenaline. The term adrenaline is actually a trade name, but it's based on these scientific names.

Well, the heart is also innervated by the parasympathetic system. And that comes from up here. So here's a neuron up here, the parasympathetic that's going to reach the heart. And here I show an axon of what we call the vagus nerve. And there are some of those axons go right to the wall of the heart.

They don't innervate the heart muscle. They terminate on cells of the cardiac ganglion, which is right next to the heart. And the axons of the cardiac ganglion, then, innervate the heart muscle and release acetylcholine. The vagusstoff, remember, of Otto Loewi.

That's a characteristic difference between the way the sympathetic and parasympathetic systems innervate their targets. The parasympathetic is long axons that leave either the brain-- and I'm showing their locations here midbrain and a number of them in the hindbrain-- or in the sacral cord. And they innervate ganglia that are near the organ being innervated. Whereas the sympathetic system, those preganglionic cells are not always near the organ. They're in that chain of ganglia or in the preganglionic groups.

OK, now this is from your text. And it just, in a single diagram, it tries to summarize the anatomy. It doesn't really show the chain, that these are a chain of ganglia here, so that can be a little confusing. But it does show the various functions of the sympathetic. And the parasympathetic, that's the one I was showing here with the green.

And this would be an axon of the so-called vagus nerve, which innervates the gut, innervates the heart, innervates the various organs of the abdominal cavity and chest. Vagus nerve is very important part of the parasympathetic nervous system.

But there are other parts, too. There are neurons just like it here in the sacral region that innervate ganglia in the pelvic region and innervate the various organs of the pelvic region. Whereas those up in the cranium, what other things would it be doing besides affecting the guts and heart?

Well, the iris-- and I show that originating from part of the third nerve nucleus, the oculomotor nerve. And axons go out to the ciliary ganglion. This is the ciliary. And the postganglionic cell then goes to the iris, whereas those sympathetic fibers from the iris come from the uppermost or superior cervical ganglion.

So there would be the preganglionic. Here's the postganglionic axon, goes right through the ganglion without stopping and goes all the way to the iris. So just about every organ, gland tissue, and smooth muscle is innervated in this dual fashion.

This is the textbook picture of the parasympathetic. I don't like it too much because it gives you the idea that these ganglia are placed similarly to the sympathetic, which isn't true.

The ganglia are very close to the organs being innervated. These cells that innervate the stomach and intestinal tract are actually found right along the wall of the intestinal tract. They form the enteric nervous system. This is just to remind you of Otto Loewi's discovery in 1921. And this just summarizes the enteric nervous system.

Initially, we thought the guts were innervated by the sympathetic and parasympathetic in the way I described, and they are. But what's been discovered more recently is that there's actually a network of neurons that are interconnected with each other, and they even have their own reflexes. They control things like peristalsis without help from the CNS.

And those neurons we divide into these different-- a plexus is usually a tangle of fibers, but in this case, it also contains neurons. And it's divided into these regions. It is innervated by the vagus nerve. But sensory input from the gut reaches those neurons, also. It doesn't all go into the CNS, although much of it does.

For example, we can feel pain from the gut. And that's due to an activation of small fibers, sensory fibers, that go in through the dorsal roots and into the spinal cord coming from sensory organs that detect changes, especially stretch of the abdominal viscera. But they also connect directly to cells in these plexuses. And those cells, some of them are motor neurons and innervate the smooth muscle.

Similarly, the cardiac ganglion functions as a kind of little brain in the heart, but it's under major control of mainly the parasympathetic nervous system. The sympathetic nervous system has innervation, but not through those neurons in the heart, not through the cardiac ganglion. It connects directly to the cardiac muscles.

OK, we've got five minutes left. You can either ask me questions, or I'll introduce the next topic. Yes.

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: Reticular formation, that's a good question. It was called reticular formation by anatomists because when they divided up the brain into different cell groups using cell stains and fiber stains, when they had named every cell group they could clearly outline, everything else just look like a mixture of cells and fibers. And they called it reticular formation. And there's a lot of it in the core of the hindbrain and in the midbrain. It can be divided somewhat.

We talk about the medial magnocellular reticular formation of the hindbrain. We know it has major control of whole body movements and axial muscles. When we talk about motor control, we'll see some studies of that. And then there's a lateral part, too, that we know less about.

And then the reticular formation in the midbrain, we know also has diffuse connections even to the forebrain that plays a role. It's sometimes been called the reticular activating system because it seems to wake up the brain.

That was discovered when they had animals that were sleeping because of a brain lesion. And they put electrodes in the midbrain reticular formation and stimulated, and the animal would wake up. So it became known as the reticular activating system.

But, in general, they're incredibly important neurons that are primitive in function. They contain a lot of the inherited circuitry that control fixed action patterns at the level of the hindbrain and midbrain. Sorry to give such a long answer. You wanted a much simpler definition, I'll bet.

A mixture of fibers and cells that-- where it's hard to draw clear borders. Although anatomists every year draw borders that they couldn't draw before because now we have better methods. We can define the chemical transmitters. We find that they do differ, and they allow us to subdivide the reticular formation a little better than we used to be able to do.

So let's just introduce this. They are difficult lectures for people that have trouble with spatial things and neuroanatomy. But, believe me, no matter how good you are at spatial things, when you first encounter a lot of these things, it's going to be a little hard. There's a lot of words so far, and I've simplified it vastly, believe me.

We're going to go through hindbrain, midbrain, and forebrain, all these major divisions. I want you to know the English and the Greek names. There's a few Latin names I've also put in the program. And the reason I did that is because you encounter them in textbooks all the time. So, for example, the hindbrain, we call the rhombencephalon because of the rhombic shape of the ventricle when we look at it from the top.

But many of you hear medulla oblongata. Well, what does that mean? Well, medulla, or medulla, is a term that means the marrow, like the bone marrow. It's the marrow of the spinal cord. You see, it's the soft stuff in the middle. And before they knew what it did, that's what it was because it happens to be the spinal cord.

So that was originally called, in Latin, the medulla spinalis. We usually don't use that term anymore, but we do use the continuation, the oblongation, the elongation of the medulla in the brain. That's the medulla oblongata. That's the caudal part of the hindbrain.

I told you this was a, unlike the shrew brain, is a more realistic view of a top view of the developing nervous system, central nervous system. And I've shown you cross sections here. This is a cross section of the spinal cord. Here's a cross section of the hindbrain.

And you'll note that they're pretty similar, except the rift plate is stretched out in the hindbrain. And, in fact, it's basically organized like a fancy spinal cord, so I call it a glamorized spinal cord. We'll go through the basic functions, the cell grouping, the sensory channels, and how it gets distorted. But the basic organization is the same.

And this will be the last slide today. Here's the spinal cord. If we divide here, the embryonic cord has a ventricle in the middle, and the walls are just starting to thicken. The top part is alar plate. The ventral part is basal plate. And these are the cells of the floor plate and roof plate.

The hindbrain is very similar, except the roof plate gets stretched out. And we have the alar and basal plates are still there, where you get the secondary sensory and motor neurons forming. OK? That's enough for today.