Microsensors, Implantable Devices and Rodent Surgeries for Biomedical Applications
Course Instructor: Dr. Shabari Girishan
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore
Week - 08
Lecture - 29

Welcome back to the module on Rodent Neurosurgery. The last session was about Spinal Neuroanatomy. So, this entire module is aimed at covering spinal surgeries for various experimental spinal procedures. The objectives will be to study the spinal cord structure or to probe the various centres or pathways that will be useful for various translational neural engineering work. Last time, we covered extensively the central nervous system, spinal skeletal system, and spinal cord vertebrae relation. To have a brief recap, we saw how the spinal cord forms a very important conduit to convey information starting from the brain towards the end organs like muscles, glands, heart, and various other organs. We also saw how the spinal skeletal system envelops the spinal cord and protects it, and how to approach the layers that need to be excised or revealed. More importantly, we discussed the spinal cord-vertebrae relation and how each spinal cord segment relates to the different vertebrae.

So, with that, we have covered the majority of the skeletal system. Today, we will deal with the actual spinal cord, its vascularity, and how to take care of the vascularity before we approach it. We will also briefly cover cross-sectional anatomy and the actual spinal cord structure, including grey matter, white matter, and the circuits involved. This knowledge is crucial before you begin your experiment. If you have your research questions ready, relating them to spinal anatomy is very important for a good experimental outcome.

With that brief introduction, I will now show the layers and how many layers need to be dissected before reaching the actual central core of the spinal canal, which is the spinal cord. On the left-hand side, I have shown the rat to orient you again to what is dorsal and ventral. What has been exposed here is the glabrous part; after shaving the hair, you will see the outline of the spinous process. I hope you all remember what the spinous process is: the neural process, which is the dorsal-most portion of the vertebra. As shown last time, each spinal vertebra surrounds the spinal cord like this.

This is the part that we are trying to expose by making an incision here. If you remember the anatomy, it starts from the cranium where the spinal vertebra begins and ends in the tail bones. The spinal cord runs right in the centre of the spinal canal. To expose it, you need to go in that direction. Each layer in this slide is from above downwards, meaning we will expose the skin first, then the muscular layer, followed by the bone, dura mater, arachnoid, and finally the spinal cord.

These are the layers you will see in each subsequent slide to approach the spinal cord. Rostral is towards the tail; this is how the dissection will progress. Before making a skin incision, once you make the skin incision, the first layer is the muscle. As mentioned, if you remember the three-dimensional anatomy and the various muscle groups explained last time, the subcutaneous tissue will be along with the skin.

The subcutaneous tissue is fortunately quite thin over the dorsum, over the spinous process. However, there is this body habitat we will discuss when dealing with animal handling and animal selection sessions. You need to remember that if the vertebral body is very prominent and seen right on the surface, it indicates that the rat is emaciated. This means that the subcutaneous fat is lost, and you can see the spinous process. This implies that the rat's nutritional status is poor and may not withstand the surgery. There is a thin layer of subcutaneous fat that may be visible, as shown here.

Once you reflect the skin, there is a thin layer of subcutaneous fat which usually moves out. There are various techniques to hold it back with multiple retractors, which we will discuss in the spinal surgery section. What you are seeing here is the outline of the spinal vertebra, and these are the erector spinal muscles, which maintain the posture of the rodent when it moves. The spinal skeletal system needs stability on both sides for the purposeful movement of the rodent. There are various paraspinal muscles shown last time, which are important for maintaining posture. For example, if this part of the muscle is weak, then this part of the muscle, which is active, will pull the spine towards its side, resulting in scoliosis deformity.

If there is a malformation in the front, known as ventral, you will get what is called kyphosis, or hunchback. This is how the spinal skeletal system will bend, which is called kyphosis. Spinal bending is known as scoliosis; together, it is known as kyphoscoliosis. All these are important to remember because if your experiment involves catheter injection into the epidural space or if you plan to tap the spinal canal by way of injections, which we will discuss in the spinal surgery topics, then the anatomy of the spinal canal should be normal. Only then will you be able to pass the needle blindly between the spinous processes in a sagittal plane? This is how it will look, and that is the spinal canal.

If you are trying to take a CSF sample, you might be familiar with a procedure called lumbar puncture. Lumbar puncture or CSF tapping involves taking cerebrospinal fluid from the arachnoid space for various research purposes or instilling drugs into the spinal cord or spinal subarachnoid space. This anatomy is very important. There should not be any bends in the spinal canal, like scoliosis or kyphosis, because the anatomy will be different, and you will not be able to tap the CSF canal. Thus, the rat should not be selected for the experiment if it involves such a delicate procedure where you have to go through the spinous process blindly without image guidance. You need to ensure there are no skeletal deformities.

So, that is one thing you need to remember at this point. What you are seeing here is the spinous process. The muscle has been split; there are various techniques to split the muscle, which we will discuss in the spinal surgery section. In anatomy, I want you to appreciate that once the muscle is cut along the sides of the spinous process, the actual spinous process comes into view. So, that is rostral, and this is caudal again.

The spinous process comes into view, and as you dissect further, the technique involves sticking to the bone to prevent injury to the spinal cord, which will be partly exposed between the bones. For example, if this is one bone and this is another bone, you will see the spinal cord somewhere in between. If you are not careful, using a bovie cautery or bipolar or monopolar cautery, there could be heat-induced damage. So, the idea is to use blunt dissection, using dissecting tools right on top of these bony processes, and keep pushing the muscle away from the bony structure to go deeper. Once you do that, the vertebral anatomy will be appreciated.

What you see here is the T13, the 13th thoracic vertebra, and this is the spinous process of the L1 vertebra. It is important to keep this in mind. Once these landmarks are exposed, the actual drilling or removal of the lamina, a process called laminectomy, will follow. I am sure all of you are familiar with what laminectomy is by now. Then, what you see right underneath is the dura covering the spinal cord.

And you are trying to take the CSF sample. I do not know how many of you are familiar with a procedure called lumbar puncture. Lumbar puncture, or any level of CSF tapping, involves taking cerebrospinal fluid from the arachnoid space for various research purposes or instilling drugs into the spinal cord or the spinal subarachnoid space. In such cases, the anatomy is very important. There should not be any bend in the spinal canal, such as scoliosis or kyphosis, because the anatomy is different, and you will not be able to tap the CSF canal. Therefore, that rat should not be selected for the experiment. If your experiment involves such a delicate procedure where you have to go through the spinous process blindly without any image guidance, you need to ensure that there are no skeletal deformities.

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The spinous process comes into view, and if you dissect it a little further, the technique is to stick to the bone to prevent injury to the spinal cord, which will be partly exposed between bones. For example, if this is one bone and this is another, you will see the spinal cord somewhere there. If you are not careful, if you are using a bovie cautery or bipolar or monopolar cautery, especially, there will be heat-induced damage. The idea is to use blunt dissection, using a dissector right on top of these bony processes, and keep pushing the muscle away from the bony structure to go deeper. Once you do that, the vertebral anatomy will be appreciated.

What you are seeing here is the T13, the 13th thoracic vertebra, and this is the spinous process of the L1 vertebra. That is very important to keep in mind. Once these landmarks are exposed, the actual drilling or removal of the lamina, a process called laminectomy, comes next. I am sure all of you must be familiar by now with what laminectomy is. Once you remove the lower part of the lamina, you will see the dura covering the spinal cord.

This is a very thin layer of dura covering the spinal cord. To keep your orientation, that was the spinous process you exposed last in the previous slide. After removing the lower part of the lamina, the dura will come into view. If you remember sequentially, the structures are: first, the skin, then the subcutaneous tissue, and then the muscle plane. Once you dissect the muscle plane, you will see the spinous process. When you deepen it, all these vertebral structures come into view, and then comes the dura mater covering the spinal cord. These are the structures you need to dissect or remove before approaching the spinal cord.

It is a demanding microsurgical step with a significant learning curve. If you are not careful in any of these steps, the delicate spinal cord will be injured. Moreover, here, by mistake, it is shown as an artery; most of the time, it is a vein that you encounter first. It may be the dorsal spinal artery, but most of the time it is the dorsal spinal vein you see here, that will be injured, affecting the entire cord. If it is the contusion model of spinal cord injury, then fine, but you are supposed to do a controlled contusion, not injure the spinal cord while performing the surgery. Even if your experiment involves the contusion of a specific segment, you need to be careful before you bring in the impactor and cause the contusion.

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This is a very thin layer of dura here, which is covering the spinal cord. Just to keep your orientation, that was the spinous process you exposed last in the previous slide, and then you removed the lower part of the lamina, and the dura will come into view. If you remember sequentially, the structures are: first, the skin, then the subcutaneous tissue, then the muscle plane. Once you dissect the muscle plane, you will see the spinous process. When you deepen it, all these structures of the vertebra come into view, and then comes the dura mater covering the spinal cord. These are the structures that you need to dissect or remove before approaching the spinal cord.

It is a pretty demanding microsurgical step with a significant learning curve. If you are not careful in any of these steps, the delicate spinal cord will be injured. Moreover, here, by mistake, it has been shown as an artery; most of the time, it is a vein that you encounter first. It may be the dorsal spinal artery, but most of the time, it is the dorsal spinal vein that you see here, and that will be injured, affecting the entire cord. If it is the contusion model of spinal cord injury, then fine, but you are supposed to do a controlled contusion, not injure the spinal cord while performing the surgery. Even if your experiment involves the contusion of a specific segment, you need to be careful before you bring in the impactor and cause the contusion.

It should not be that your surgical instrument causes the injury because that will be unpredictable. You will not know the depth of injury, and it might affect the behavioural outcome of the experiment. Once the dura mater is exposed, and after you remove the dura and arachnoid, what you see here is the dorsal surface of the spinal cord. You are seeing small vessels, which we will discuss. This is how the spinal cord will be visible, and what you will see along the side are the rootlets, which we discussed in the previous session, and this is how the spinal cord segments will be named. For example, if this is the T13 cord segment—I mean, if this was the T13 vertebra, if you remember from the previous lecture, we need to add at least plus 4—then this would be what segment? This would be around the L3 segment of the spinal cord because this is under the T13 vertebra, which will house maybe the L2 or L3 segment of the spinal cord, and this is how the rootlets go. That will be the L4 segment of the spinal cord, and that would be the L5 segment.

Each rootlet corresponds to one cord segment here. So, that is how to look at the length of the spinal cord and how smaller it is, and as it goes closer to the cauda equina, which is the end of the spinal cord, the segments become shorter and shorter. That is how each vertebra will house at least 4 to 5 cord segments toward the end of the spinal cord. So, I hope you understand the relationship. Each segment of the spinal cord will have the rootlets, which will have a dorsal rootlet and a ventral rootlet—this is the dorsum—below this, there is another root that goes right underneath, and toward the foramen, there is ganglion formation, which is a dorsal root ganglion. Then, the peripheral nerve starts, which is the interface between the PNS and CNS—CNS being the spinal cord and PNS being the nerve—and that is the interface, and that is where usually the tumour arises. It is called the Obersteiner-Redlich zone (ORZ), where the oligodendrocyte stops, and then the Schwann cells begin. That is the area where a lot of cell division activity happens, and it is a very different zone. So, this transition zone is where the Schwannomas arise—just some added knowledge of applied anatomy at this juncture.

So, as a result of showing you a little bit more details of how the dorsal root ganglion is seen, and here at this level, I mean even the spinal anatomy is pretty complex, all right, because the entire spinal cord is three-dimensional. The cord is just exiting laterally, that is sideways, whereas you are exposing the spinal canal straight down from the top of the animal, that is, skin, subcutaneous tissue, muscle, and bone. So, when that comes, this is the orientation. For example, if that is the mouth of the rodent, this is the body with the spinal canal on top, and that will be the tail, just to give an orientation as to how this skeletal system is aligned. That will be the hip bone of the rodent from where the hind paw comes, that is, the hind limb, and that is where, for example, if this was the cervical vertebra, what is being shown is the zoomed-in view of the lumbosacral, that is, lumbar vertebra and sacral vertebra. If you remember the 5th to 8th vertebra, this is the tail, this particular vertebra will be somewhere here, only in this region. So, that has been zoomed in and shown, but just to give you orientation, this is how the rat is lying here, all right. So, you are approaching from the top.

So, once you get the orientation, I will just erase this. So, when you expose the spinal canal, as I said if you continue your exposure sideways, these are the laminas, all right, from the back, and if you take a cross-section here when you cut it perpendicularly to this line, this is how it looks like—this is the axial section. If you all remember the plane that we just discussed, this would be coronal, and this will be axial because it is perpendicular to the midline, all right. So, it takes slices like that, and this will be axial. So, that is where the ganglion would be, and that ganglion in coronal orientation, this is where it is. That is the idea of this particular slide—to show you how the dorsal root ganglion appears, and this is a very important landmark for various research that involves the sensory system.

The dorsal root ganglion is the major junction for all the sensory inputs that come from the peripheral, you know, hind limbs or forelimbs, or from the periphery, and for that matter, even the trunk sends the sensory inputs. All the sensory inputs go through the dorsal root ganglion from the peripheral nerve. So, this is the nerve that I was talking about; this is the spinal cord, that is the spinal rootlet, for example, the dorsal rootlet. Then it combines, then it fuses with the ventral rootlet and forms the dorsal root ganglion—that is what is being shown here, all right. Then the peripheral nerves continue along, for example, if there is a limb, it goes and supplies the limb there—that is how the entire peripheral nerve system starts, all right. So, to expose this, what they have done is, you need to remove the lamina. So, this has been removed only after the removal of the lamina, then you extend a little more laterally, you know, all this has been removed to expose the dorsal root ganglion.

For example, you compare the bony landmarks on top and below, then you know what has been removed to expose the dorsal root ganglion. We removed one half of the lamina, all right—that is the outline of the removed lamina there. Once you remove the lamina and part of the facet, then this nerve will come into view, or the dorsal root ganglion. So, suppose your surgery or your experiment involves the dorsal root ganglion. In that case, this is how the exposure should be done, and these are the layers that you would have to dissect before exposing those dorsal root ganglions. So, when you are using bony instruments in this area, you need to be very careful to prevent injury to those nerves or neural structures that you are trying to expose and study in the first place.

That is why the anatomical orientation, anatomical planes, and all the structures are so important to understand before you begin your surgical experiments. So then, now let us go one more layer deeper. This is where we were, all right. We removed the bony structure, and this is when the spinal cord, which is the major neural conduit structure comes from the brain with all the information. So, any cut here will leave the person paraplegic—he or she will not be able to move the limbs, and in rodents, both hind limbs will become paralyzed, all right. So, that is a major injury, and all the spinal cord injury models will target this particular area to induce injury by using what is known as an impactor, which we will, you know, go through in detail when we discuss spinal surgery.

So, now, just to understand, this is the side view, you know, or anatomically lateral view. All the bony structures have been removed to expose the spinal cord, and this particular slide is mainly to expose the rootlets that we just discussed. So, this is how the roots would look; this is the outline of the root, and you can see various arteries coursing around—those are the vascularity of the root as well as the spinal cord blood supply, all right. So, these roots exit through what is known as the intervertebral foramen and then become the peripheral nerve here. So, this peripheral nerve divides further and supplies the muscle belly.

So, this is the muscle belly of the forelimb or the forepaw, and you can see it is supplying the flexors of the elbow. That would be the shoulder region. One of the major nerves supplying this is probably the musculocutaneous nerve, supplying the biceps brachii muscle. So, we will deal with peripheral nerves and skeletal muscles in a different section, but this is how the peripheral nervous system continues, starting from the rootlet, all right. So, I hope you all remember every layer we just discussed to expose the peripheral nerve to the muscle. This is how the neural structures are going to course, starting from the brain. So, imagine if there is a motor cortex, a neuron, and this is how the brain is, then the spinal cord, which we dealt with just now, the rootlets come in, then it goes and supplies the muscle, which is shown here.

So, we finish with the brain, we come through the spinal cord, then the rootlets, then the nerve through the foramen, and then it continues this way to form the peripheral nerve. So, until here, we call it the central nervous system. From the rootlets onwards, we call it the peripheral nervous system. So, that is what, in a nutshell, the entire nervous system would look like, and that is how the various neural signals will be conveyed from the brain to the end organs. But how does the transition from the brain to and spinal cord look? So, just to recapitulate, if you remember, this is the cerebellum, all right.

So, the hidden part of that ventral to this is the dorsum, ventral, rostrum, and caudal—that is the orientation, all right. So, when you orient, this would be the head of the rodent, this is the back portion of the brain, and that would be the lambda, and then the occipital, interparietal bone, and the occipital bone which is covering it. So, that has been removed. This entire part has been removed—all the skull bones are removed. This is the otic area, that is the ear canal, and this would be the brainstem. Just let me clear it out. This is the cerebellum, that is the brainstem from the medulla oblongata. You can see that the spinal cord starts and then goes down, and you can see these tiny rootlets that are coming out.

So, these are the cervical spinal cord. So, this would be C1, C2, C3, C4, and C5, and so forth. So, these are cervical roots from the cervical cord. The Latin "cervix" or "cervical" refers to the neck region. So, this would be the neck region of the rodent, and this is how it's a little bit complex because you need to deal with the posterior part of the head to expose the cervical cord. So, it is a little bit if you need to expose up to the C4 segment, you need to follow all the stereotactic techniques of head fixation, and exposure of the posterior part of the skull, then only will you be able to expose the atlas and the axis.

So, it is very important to understand the orientation of the cervical spinal cord along with the posterior fossa structure or, for that matter, the cerebellum. So, you need to sort of understand what length of the incision needs to be made because it will be tailor-made for your experiment. There are no standards; for example, in brain surgeries, all the incisions are standard. Whereas, in spinal cord or spinal canal exposure, you need to understand which part of the segment you need to expose. If you want to expose up until C5, you need to start the incision from there and then go down; only then will you be able to expose the upper cervical cord. You need to expose the cerebellum and the occipital bone to safeguard those structures to expose the upper cervical cord, that is, up to C3, all right.

So, it is very important to understand the relation with the brain before you begin exposure to the upper cervical cord. That was the whole idea of this particular slide, all right. So, now briefly before I wind up about the spinal anatomy, you need to understand the spinal cord arterial supply, which is very, very important. One is that it might directly deal with your experiment if you are trying to study various stroke models of spinal cord arterial compromise or arterial malformations, and so on. If you need to study the arterial anatomy of the spinal cord and if your experiment deals with it, then you need to know. And of course, when it involves any sort of surgical implants, then you need to know how to safeguard those vessels to make sure that the cord is alive, OK? So, as I said, this is the dorsum, this is the ventral, and this is the cross-section, OK.

So, the cross-section is taken that way, and then you have the vascularity shown here. So, when it is ventral, there is a midline artery known as the anterior or ventral spinal artery, all right. So, that is a major vessel that comes in the centre; you can see it here in the cross-section, which supplies the majority of the spinal cord—almost up to the anterior two-thirds of it is supplied by the anterior spinal artery. On the dorsal surface, if you all remember, there were roots, multiple roots on the sides of the spinal cord, and one of the blood vessels entered and then supplied the spinal cord that way, all right. So, that is how the dorsal part of the spinal cord is taken care of.

So, any damage to any of these vessels leads to ischemia or stroke, which results in deficits in those specific areas of the spinal cord. It is crucial to remember that this is how the spinal cord arterial supply functions. If you're wondering where it originates from, it all comes from the vertebral artery at the top. This is the vertebral artery, which travels through the spinal canal. One of the arteries joins with the opposite side and then continues as the anterior spinal artery. Multiple intercostal arteries, which are the arteries between the ribs, approach the spinal cord and supply all these rootlets as well as the substance of the spinal cord on the dorsal surface. On the ventral surface, this artery continues as the ventral spinal artery.

It might be overwhelming to take all this in at once, but reviewing these videos and reading more about the topic will make it easier to remember. Since we're mostly dealing with spinal surgery, I am focusing primarily on applied spinal anatomy and applied cranial anatomy. If you delve deeper into these structures, it will be easier to understand and orient yourself to various anatomical structures. Now, let's look at the spinal cord venous drainage. I hope you all remember that venous drainage removes blood from the organ, while arterial supply delivers oxygen and various nutrients to the brain or neural structure.

What we saw earlier was arterial supply; this is venous drainage. You can see here that an artificial dye was injected into the vein, although it doesn't naturally appear this blue. This is blue latex infused after the rodent's death, and you can see the dorsal spinal vein. As I mentioned earlier, that is the major vein present there, and it drains all the blood supplied by the ventral spinal artery. This is the artery, and there is also the ventral spinal vein, which is very thin. What you need to remember is that the vein is very prominent on the dorsum, while the artery is very prominent on the ventral side. A large artery runs along the midline ventrally, and dorsally, there is a large dorsal spinal vein that drains blood from the spinal cord towards the heart.

The orientation, supply, and drainage are more or less similar. If you safeguard all those structures during surgery, you will be protecting both the artery and the vein. This image gives you a good three-dimensional orientation of what is an artery and what is a vein. The left-hand side provides a nice orientation of these structures, which we just discussed, and the entire neuroanatomy. I emphasize the importance of this three-dimensional orientation because neuroanatomy, like any organ in the human body, must be understood with a three-dimensional orientation and its relationship with other structures. In neuroanatomy, most of the time, you will be exposing only a part of the nervous system, not the entire system, because the nervous system is surrounded by a very strong skeletal system, unlike other organs. For example, when exposing an abdominal organ, a single incision in the centre can reveal the entire abdominal organ, making it easier to handle.

However, in neuroanatomy, you need to plan, understand, and make a very small opening to that particular area, deal with it, and then quickly close it. If you're not sure about the anatomical aspect, you might miss the structure or open it at the wrong level. That's the biggest problem, and that's why these sessions are dedicated to anatomical and applied anatomical details. This will give you a good orientation before you even start reading in detail about it. Looking at the spinal cord, this is a three-dimensional view where the spinal cord continues in that direction. Imagine this is a rat's body, with the mouth here and the tail there. To orient you, this is the dorsal part of the spinal cord.

So, that would be dorsal, and ventral is ventral. There is a dorsal horn and a ventral horn. I will discuss the inner part of it, but this slide is mainly to help you understand how the vascularity is oriented. Once you've understood this, you can see the posterior spinal vein on the dorsal or back side of the cord. There is a prominent vein running there, and on the ventral side, a large vessel runs along the midline, which is ventral. This vessel surrounds the spinal cord and supplies the substance of the spinal cord. It also takes away the blood through the veins, which are called capillaries here.

When the artery becomes smaller and smaller as it reaches the end organ, it forms what are known as capillaries. These are some basic anatomical concepts that I recommend you all learn and familiarize yourselves with so that these anatomical details can be understood. The arterial system, venous system, and capillary system are all critical. The capillary system is where most of the oxygenation and nutrients diffuse into the surrounding nervous tissue. The venules then form, leading to veins that carry the blood back to the heart.

So, that is how, and this is the angiographic 3D modelling of the arterial and venous structures on the right-hand side, all right. So, you see how the artery divides within the substance of the cord and supplies it, and these are the multiple vessels that go around from the same anterior spinal artery. This is the posterior spinal arteries which come from the rootlets and then supply all around, and the entire cord substance is covered with the arterial arcade. So, if you want to make any sort of surgical approach, these arteries should be avoided at any cost. Whatever surgery or experiment you are planning to do, you need to safeguard and choose a relatively avascular zone. As we discussed in stereotactic brain surgeries, you need to avoid these arteries; only then can you approach the cord substance, all right.

So, how does the inside of the spinal cord look, and what is it composed of? So, as I said in the beginning, it is a nice little bundle of electrical wires. If I need to give an analogy to the cables, this is how it looks like you know, there is this earthing wire, and then there is a positive and a negative wire.

So, there are wires that connect the brain with the end organ, taking the impulses from the brain to the muscles, and there are cables or the axonal bundles or the white fibre tracts that carry the impulses from the muscle to the brain, all right. Just like the artery and vein, there is the motor system and the sensory system. Similarly, there are motor tracts and sensory tracts; "tracts" means fibre bundles, all right. Tracts refer to fibre bundles, which are nothing but white fibres. White fibres are formed by multiple axons, okay? If this is the nerve bundle, then there are multiple smaller bundles within it. So, that is exactly the reason why I said it is like fused cable wires, which have multiple small white fibres, which are formed by the axons at the cellular level, which is seen nicely here where this is the grey matter. I hope you know the basics that the entire nervous system is formed by gray matter, which will have the neurons, and then the white matter, which will have the axons.

Just to give a brief recap about the basic structural unit of the nervous system: the structural unit is the neuron, which will have dendrites, and this is the axon. Then it forms the synapse with the dendrite of the other neuron, and then it continues as axons and dendrites, and so on. So, if you see, there are multiple neurons within this gray matter which will house the cell bodies. You can see nicely those axons coming out of those multiple neural cells, and this is how the rootlets form. So, rootlets have thousands, tens of thousands, and millions of these axonal bundles fused to form the rootlet, and then the rootlet will form the dorsal root ganglion. Then it continues as the peripheral nerve, which we just saw in the previous class and previous sessions.

So, this is how it is; this is grey matter, and this is white matter. So, and that is in the form of an H, maybe we will have it, yeah. Here you can see this is the actual outline of the grey matter, all right. So, you can see that it is in the form of the letter H, and here you have what is known as the dorsal horn and ventral horn. That is the central canal, which will have spinal fluid inside it, which is continuous with the ventricles of the brain, and then you will have the spinal subarachnoid space around it, where there is the arachnoid membrane, and then you have the dura mater. That is when you have a spinal vertebra around it, all right. So, that is the structure of the spinal cord, where you can see there are multiple nuclei within the ventral horn. These are the anterior horn cells. I am sure all of you must know Stephen Hawking, who had motor neuron disease, multiple sclerosis, and other neurological illnesses where celebrities have these problems.

So, this is where the problem begins. Now, they have these anterior horn cells being affected, where the cells start to die, and they will have what is known as lower motor neuron paralysis, you know. So, this is where the problem starts, where there is grey matter and the cells start dying, and then, obviously, the axonal bundle distal to it starts degenerating. What is outside the H is the white matter zone, where you have fibre bundles. These are the dorsal funiculi, which will carry the touch sensation and the vibration sensation. On the lateral side, you have the lateral spinothalamic tract, which will carry the pain sensation. So, outside this H are the multiple white fibre bundles. Inside the H is the grey matter, whereas in the dorsal horn, you have this laminar architecture. If you see, the neural bodies are organized in a laminar architecture, whereas the nerve impulses that come will terminate in a very specific layer, which is in a mathematical order, all right. So, the sensation from the thumb goes to a very specific cord segment and synapses with the very specific laminar architecture. For layers 1 to 7 or 8, these entire layers are dealing with sensation, all right.

This entire section deals with the motor system, which will have multiple interneurons. The impulses come from one axon, synapse with the interneuron, and then the axons, again, there are multiple neural cells, and then it goes down. So, this will be dealt with when we discuss the circuitry, but to know that there is grey matter, white matter, and there are various white fibre tracts suffices at this moment, all right. So, that is how the laminar architecture is arranged. You can see there are various descending tracts and ascending tracts. Ascending tracts take the sensation from the periphery to the brain; descending tracts send the signal from the brain to the end organs. That is very important to understand.

So, these tracts are only in the white matter. This is the grey matter zone, which has cell bodies where it synapses, and from the second-order neuron, it climbs up. Then there is one more synapse relay junction, and then the third-order neuron goes to the brain, all right. So, if your study involves a specific pathway, then you need to know where the first-order neuron is, where the second-order neuron is, and where the third-order neuron is. The first-order neuron, then the second-order neuron, and the third-order neuron go to the sensory system. If we are dealing with a touch pathway, it ascends for a while, then crosses over, and then the second-order neuron climbs, and then the third-order goes to the brain.

Here will be the thalamus. This is the major relay station; then it goes to the brain. So, we are not dealing with the actual nervous system structure, which is an entirely different session. So, grossly, this is how the spinal cord is organized. In a very organized structure, we can target very specific zones, and it produces very, very specific focal deficits in your rat behaviour, all right. So, briefly, I will introduce the spinal cord circuitry that will come at the end of today's session.

So, this is also very important, and as I said, it is like classical electronic circuitry, you know. So, this is the dorsal root ganglia. I hope you all remember the gross anatomy of it. When you dissect it, this is how the neurons are organized. These are what are known as pseudo-unipolar neurons, where one end of it is in the skin of, let’s say, the forearm.

It carries the impulses and then releases them. With this process information, it goes to the specific neuron in layer 3 of the dorsal horn, then it synapses with the interneuron, then it sends the neurons right on top until the thalamus, all right. From the thalamus, it then goes to the brain, which is the third order that forms the second order; this is the first-order neuron. So, that is the entire circuitry for touch sensation, if I were to say. So, similarly, multiple neurons come from the top. For example, if this is a motor cortex neuron, it directly descends to the interneuron in the spinal grey matter, and then it ends up in the alpha motor neuron, then it goes directly to the muscle belly, all right.

So, this is the alpha; this is the interneuron; this is the descending corticospinal tract, which is known as the pyramidal neuron. So, that is how the entire spinal cord circuitry works, and this circuitry exists not only for motor and sensory, but there is also what is known as the autonomic nervous system, and then there is the vestibulospinal tract, then there is the reticulospinal tract, which all deal with autonomic function, balancing function, and various other functions. So, there are several tracts and several circuitry, but this is the basic idea behind the basic structure of those simple circuits, to begin with. Just to sensitize you as to how these circuits are organized and how to target each of these structures to take your experiment forward. So, ultimately, your surgical experiment depends on what objective you are trying to address and what the research question you are trying to answer is.

Once that is formulated, you need to decide which section of the spinal cord you are trying to deal with, and then your surgical protocol starts getting designed. But then, in the next session, we will try and look at various surgical protocols that form the foundation for various surgical experiments. Whatever spinal surgery you are planning, you have to go through those basic steps with a little bit of improvisation here and there and modification and customization as per your experiments. So, that covers the entire spinal anatomy and the anatomy of the spinal cord. In the next session, I will take you through the various steps that are needed for the exposure of the spinal cord and then a brief introduction to various spinal experiments that were done in the recent past and also the potential for future research projects that we can discuss. Thank you all.