Animal Physiology
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Module - 1
Lecture - 13

Welcome back to the NPTEL's lecture series on animal physiology. So, we are in the nervous system and we have covered 3 lectures. So, we have introduced about the neurons talked about the glia and we talked at about the neurotransmitters convergent, circuit divergent circuits and the synapse. So, now, what I will do in this lecture? Then the forth lecture of the section will move on to talk about some of the very simplest circuits which are very important in that process. Will talk about little bit about the muscle, because they are the things which are being controlled by the nervous system by the neurons.

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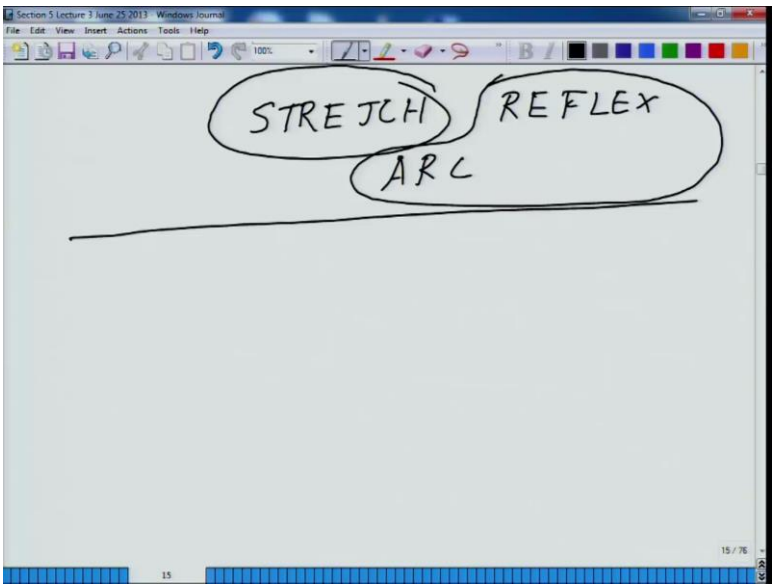

We will talk about these specific circuits, which are very primitive in nature. So, the first circuit what we are going to deal with is called stretch reflex arc, you all must have heard about this word time in again that so and so has very fast reflexes. So, and, so is has adapted to you know add very fast with some fast reflexes. So, reflexes something which is very reflex action has to be done very fast. So, what is a stretch reflex arc? So, this is a circuit by virtue of which the length of the muscle is being controlled. So, this the

technical term let me give an example. So, for example, so you see my hands I hit up on this muscles when I hit on these muscle.

So, have a look like I am hitting on this muscles right when I am hitting on these muscles. So, what is happening? The muscle is getting stretched. So, say for example, if the original length of muscle is l capital l after hitting on the muscles like this, this muscles become increase by some delta amount delta small l or something . So, now, this muscle cannot remain in that state it has to come back to its original length if that does not happen. Then with every push up and everything our size will go up, because the muscle will keep on stretching. So, that does not happen, so it has to come back to its original position. So, muscle, so how this is being done. So, the first what is that when I am hitting on something?

So, muscle is getting stretched. So, that is the first component in that stretch then the procedure by which the size the muscle length is being maintained is controlled by a reflex circuit which is and this sum total is called stretch reflex arc. So, in order to do, so you need 2 or 3 specific components. The first component is that your muscle should have a sensor, which could sense that there is a change in the length of muscle point 1. This is very, very important; second thing; what the muscle needs is that signal should be transmitted to the circuit and to the processing unit that is very important. So, there should be one set of neuron which will carry that information there is a change in length to the processing unit from the processing unit. There should be another set of neurons will come back and tell the muscle that you regain your original length.

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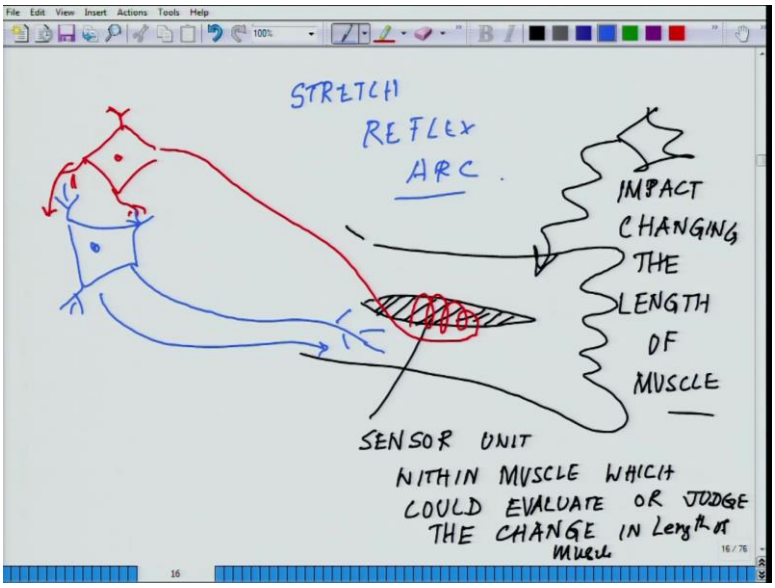

So, let me draw the circuit what I have let me kinds of enumerate the component what we are talking about. So, say for example, this is so this is your hand. So, these are the muscles what you see now I told you that there has to be a sensor which could sense the change in muscle. So, here is a impact which is following on it some kind of impact let us put it is the impact changing the length of muscle. So, now imagine this to be the within the muscle this let this be the sensor element which could sense the change. And will come to the technical terms afterward sensor unit within muscle which could evaluate which could evaluate or judge the change in length of muscle change in length of muscle. So, from here there should be some kind of system which could carry this information to the processing unit, so this processing unit. So, there has to be some sort of a neuron which could carry this piece of information to the, from this processing unit. It has to be transmitted to another set of neurons, which will do the computation.

And I will tell the muscles surrounding muscle that you have to come back to its original they may have a direct synapse between each other or there could be some connecting synapse or so and so forth. So, the information should come back like this which will say that this muscle has to come back to its original stretch once again stretch reflex arc it has to come back to its original position. So, why these are needed to be the reflex circuits, because these kind of actions say for example, someone is trying to hit on your eyes. And you have to do a reflex action or someone is hitting here. So, you have to immediately remove it. Or you are going towards flame you have to immediately retract

your finger these actions have to take place very, very fast exceptionally fast. And those kind of information's cannot be processed in the brain because that way information has to go.

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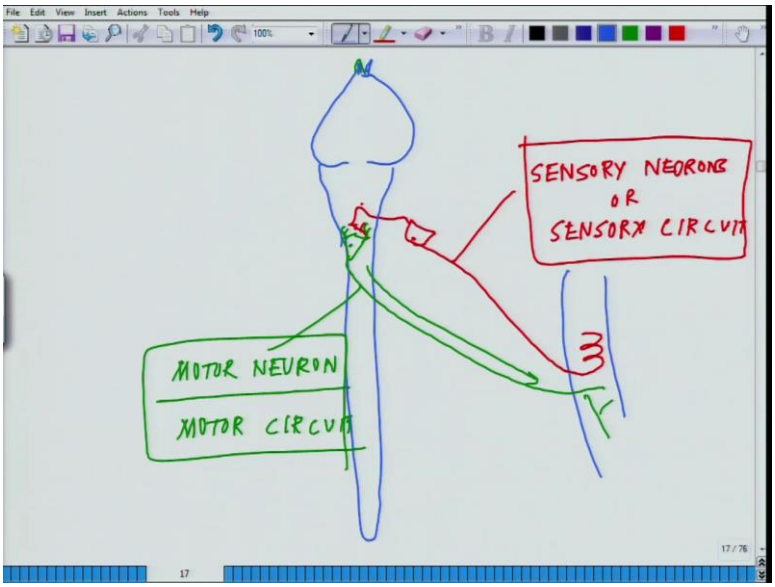

So, say for example, if this is the brain and this is the spinal cord likewise and here you have the muscle tissue from where the response has to come. So, say for example, this is the wrapping of the muscle on the on the sensor element which is coming here. Now, if this information has to go all the way to the brain it will take forever to brain to decode and comes back by that time you will get a bad amount of hit. So, nature does not do it like this. So, most of these processing's takes place at the level of spinal cord. So, all the most of the stretched or the reflex circuits are very narrow circuits which or small circuits which functions at this level.

And if you remember the signal which is being brought down from the spinal cord or the brain falls under the motor circuit or it is taken care by the motor neuron. Now, we are giving the technical term for it motor neuron or motor circuit the one which is sending signals to the brain falls under sensory neuron or sensory circuit sensory neurons or sensory circuit in between these 2. There may be a direct connectivity or there may be some form of specialized neurons called inter neurons which may be involved it. But that is like kind of adding up more complexity into it, now we have not talked about what are the components in the muscle.

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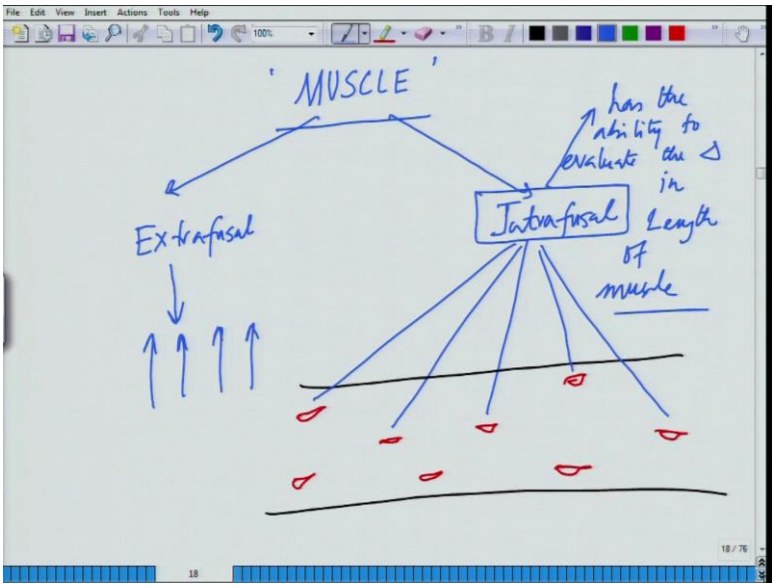

Now, what we will do? We will talk about two kinds of muscles now I am taking the detour of the muscle. Then I will again come back to the circuit without explaining the muscle nothing will make sense here. So, muscles can be broadly classified into two groups one is called extrafusal muscle. Now, another is called intrafusal muscle extrafusal muscle is all your, they are in highest number all over your body. All these muscles what you see out here these are all extrafusal muscle this is all extrafusal muscle all my hands chest and everything is an extrafusal muscle whereas, intrafusal muscle are very less in number. So, it is like this if this is a muscle tissue; this is all extrafusal muscles.

Now in between there are some small I am putting them in red small like this something like this small group of muscles they are in small small. These are called the intrafusal muscles and these intrafusal muscles are the muscle if I go back it is this one which sensor unit within the muscle which could evaluate or judge the change in length. These intrafusal muscle has the ability to evaluate the change in length of muscle. So, these are the intrafusal fiber, but how the muscles are formed and what determine the some of the muscle will be intrafusal? Or some of the muscle will be extrafusal, in order to understand that we have to take a slight detour to understand how the muscles exactly form in our body. And that will cover us for the part which you remember in the cardiac system as telling at some point come back to this skeletal muscle.

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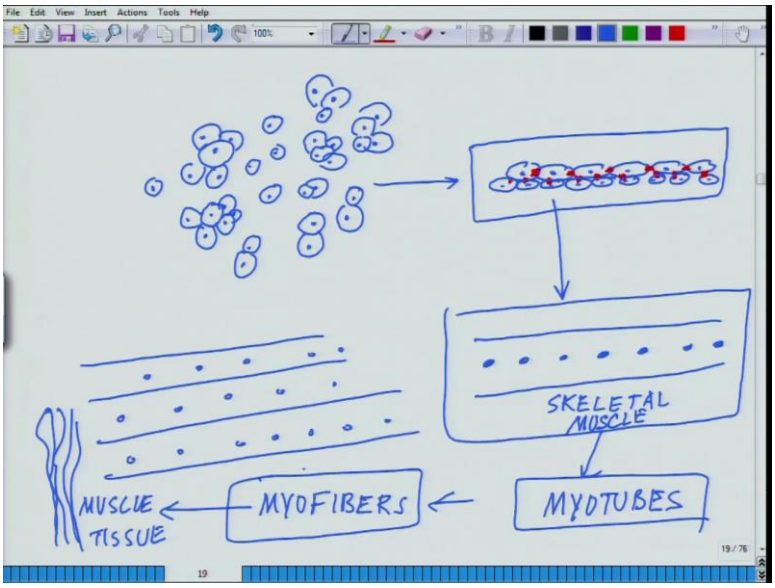

And I will talk about it. So, now, we will take up that tissue. So, initially while the while we are developing in the mother soon initially the muscle cells are single cells like this. They do not form what you see now all this continuous structure what you see this is not form in a day. So, there is a process, so initially what happen these muscle cells are like this single cells, individual cells with their nucleus likewise. Then the first thing during muscle development what happens is that these muscles come and align with each other likewise. So, in that process in that process 2 things which happens together they initially divide. Now this is the dividing phase they dividing multiple divisions takes place likewise now they dividing dividing they form dividing muscles. Then these dividing muscles align with other likewise, now this is what they do then after this what happens is this these individual cells losses their cellular identity a part of the membrane.

So, what happens is that now see they lose it here they lose it here they became continuous structure they lose it here they lose it here these are all the point contact what you see these are being lost. So, then what is left behind is something like this or if you want to want me to draw it horizontally. It will be like this a continuous structure continuous structure with these nucleus this is how skeletal muscle is being formed now if you compare this. So, this is what I am talking about the skeletal muscle if you compare this with the cardiac myocyte. In cardiac myocyte what happens in this kind of a structure? What you see where I am putting the red points those are the holes the gap junctions are being created.

It forms though the individual cells are there, but they are connected with each other using gap junctions. But here the individual cells losses their identity and what you see is a continuous tube light structure and the smallest unit of skeletal muscle is called myotubes. And will come to the in the next class will come to the final micro structural micro structural detour of this. So, now, these myotubes align with other like this then these myotubes form longer tube called myofibers. And then multiple myofibers wind up with each other likewise coiling and super coiling taking place they form the muscle tissue. So, this is how the skeletal muscle is being formed and in that process while the myofibers are forming and myotubes are forming.

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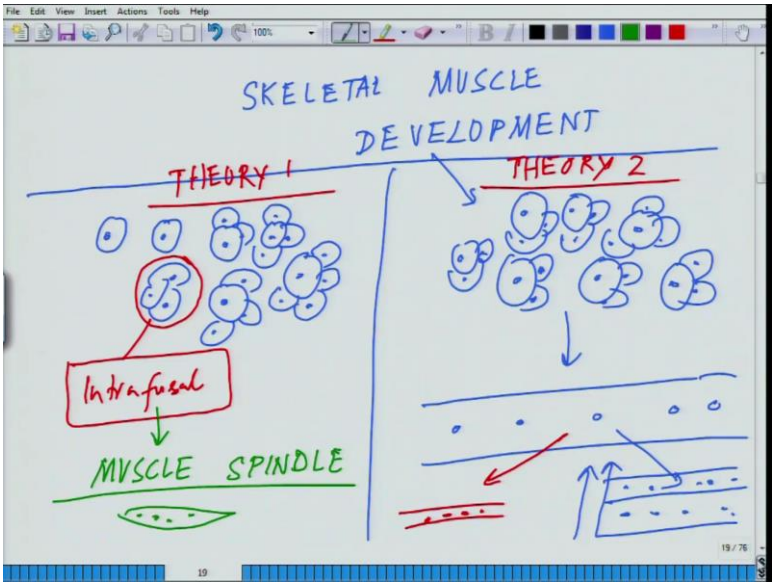

There are 2 theories. So, coming to skeletal muscle development there are two theories about the origin of interfusal fibers. I told you which are in smaller number, which are the length sensors it is one theory is this when the individual cells are dividing likewise. Now, they are entering the dividing phase you know at this phase some of the cells are destined to become interfusal fiber they are destines. So, I am saying the, this will become interfusal fiber this is one theory this is theory 1. So, there is another theory that phase slightly different that says initially all the cells none of the cells have any specific a that will become interfusal or extrafusal.

Then they start dividing after dividing they become tube light structure like this and once the form tube light structure then some of these tubes decides or by some x y z reason.

Because of the innovation or something some of them become intrafusal fiber where as the other become other larger chang become extrafusal fiber, which are in huge number. So, both these theories are being are currently they are and there is lot of studies which are going onto understand. How these theories, how these how these processes is being regulated in the developmental process?

But for us what is most important to note is that there are some myo-tubes or muscle structure which is the ability to sense the change in length. And that is most important for us rest is immaterial at this stage, but just for your knowledge I just highlighted that you might want that that how the sensor element is originated. So, these sensor element which are called intrafusal fiber are also terms. There is another term, which will come across that is a whole reason to make you understand this whole process is called muscle spindle.

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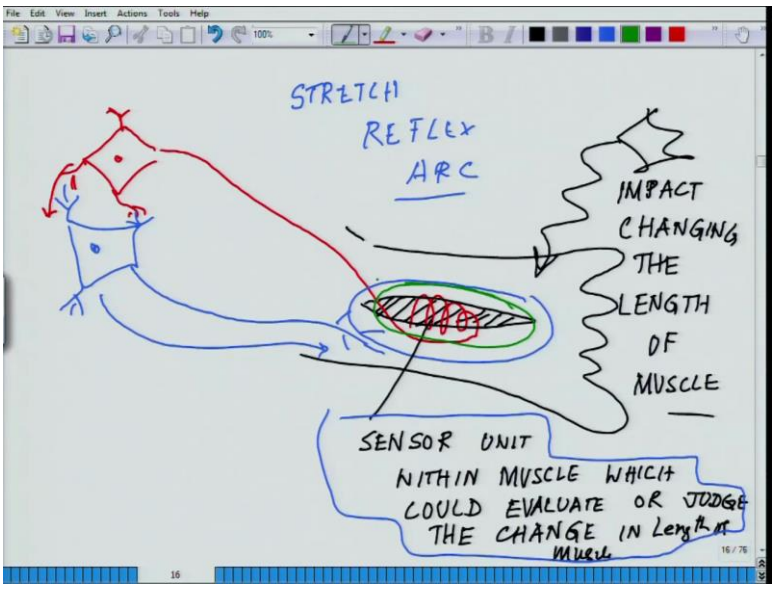

This is spindle shape structure now if you go back to the structure in a multiple see. Now, if you go back while I was drawing the structure I do it like this look at this structure muscle spindle.

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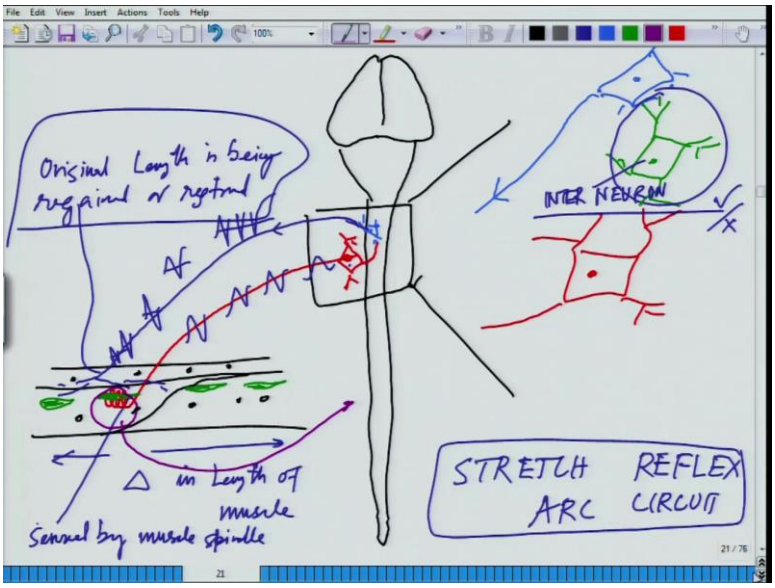

So, now I will redraw this structure for your understanding now in the light of this development of muscle what I taught you just now. So, now, the structure looks like this. So, here you have the spinal cord. So, let me see this is the brain and here is the spinal cord. So, here are the muscle sitting within the muscle, you have this sensory structure which are there present which are called muscle spindle or interfusal fibers. And these are the extrafusal fiber muscle these are the nucleus and likewise and so and so forth likewise. So, now, sensory neuron forms a wrapping around it and this sensory neuron cell body is sitting somewhere along the ganglia here. This process is goes in along the ascending path way if you remember I taught you about the ascending path way and the descending path way. These are the processing now it has 2 options either it form a connectivity with the motor neuron which are sitting along the central line along the ventral path way directly.

Or, so here is a motor neuron in or there may be a connecting neuron which if I have to like let me just kind of magnify this part what are the possibilities? So, one is this; this is the cell body of the sensory neuron it is coming. And there may be small connecting neuron called interneuron I have not talked about this. But they are these small neurons which act as which has very significant role to play as more and more. We are understanding the nervous system they help in a lot of communication process and here is a motor neuron. So, it either it may be through this through this one or without this one with this or without this the 2 options are open. So, now, the motor neuron what it does

motor neuron brings back the message out here telling this muscle to come back to its original position. So, whenever there is a shift change in length out here change I am denoting by delta change in length of muscle it is sensed by muscle spindle.

Then this signal there is electrical signal in the form of action putting shells a train of action potential travel all the way to the sensory neurons from sensory neuron. The signal is transmitted to the motor neurons either through inter neuron or directly then from this motor neuron. The signal, a train of signal is transmitted to the surrounding muscle ask them to contract and bring back, get back to their original length. So, then this signal comes original length is being regained or restored this is how it works. So, this small circuit is falls under stretch reflex now everything will make sense stretch reflex arc circuit. So, this is how this small circuit works and they are some salient features which I want to highlight. So, look at this structure at how many level the information are getting transferred let me us another color. So, this is the first information transfer.

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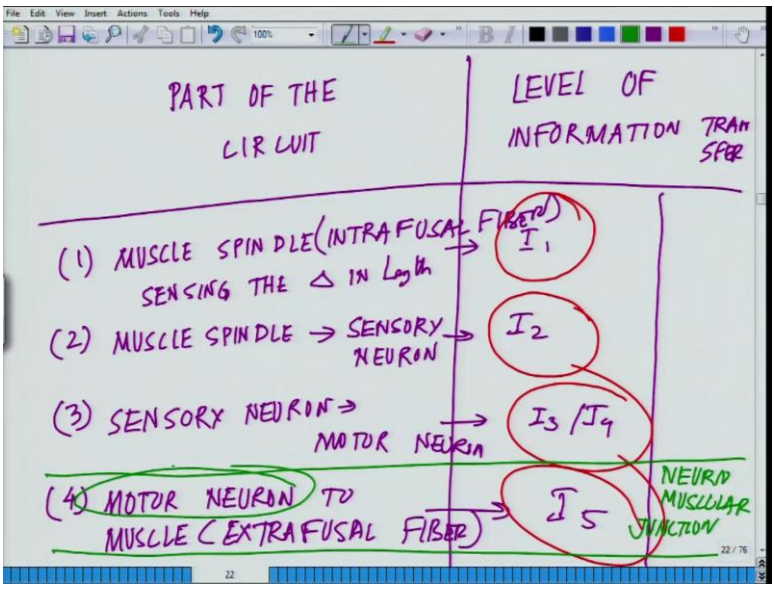

So, let me take another sheet part of the circuit and information transfer part of the circuit and level of information transfer level of information transfer. So, the first level is the muscle spindle sensing the change in length information one. So, first information transfer I denote it by I 1 second information transfer muscle spindle to sensory neuron I 2 second set of information, third information sensory neuron to motor neuron. Or there may be a not adding the complexity it could be through inter neuron from inter neuron to

motor neuron. Let us keep it simple I 3 now I just putting I 4 in case it is through motor neuron or through inter neuron. Then fourth motor neuron or let us put it like this muscle spindle or intrafusal fiber motor neuron to muscle or extra fusal fiber that is I 5.

So, if you look through this whole thing you will realize that information is being transferred. So, those who work on circuits at different level how the information is being transmitted, what is the feudality of the information, how much information how much signal is lost, how much is kind of you know traded off in this? So, they will appreciate that these kind of a information transfer characteristics. So, these falls under the transfer characterization information transfer characterization these are of profon importance. And this, these are the some of the circuits what people are trying to get into the neuro robotics.

They are trying to mix this circuits in a synthetic system in a silicon on a in silico system where if they know the algorithm how this circuits work they can introduce those algorithms into the robots. So, robots will have a much more you know robots should be able to walls they could move their hands are different degree of freedom and everything this is all taken care by circuit. So, if you look at the simple circuit for such one of the most fundamental circuit level 1 2 levels, level may be 2 levels here level here, but 5 level of information's are getting continuously added summative differentiate.

You put the all the mathematical operations out here everything is happening within few millisecond or a microsecond time. So, this is the beautiful look at this circuit this responds at an un fathermamily faster speed this is the beauty. And this is where lies a lot of our understanding to be learnt any has to come how these things work. So, coming back to it, so these are the level of transfer. So, this part the last part what you seen is falls under what you are going to deal with falls under neuromuscular junction. In the next class, we will be coming to that neuromuscular junction will talk in depth. So, because this is the zone where a motor neuron signal.

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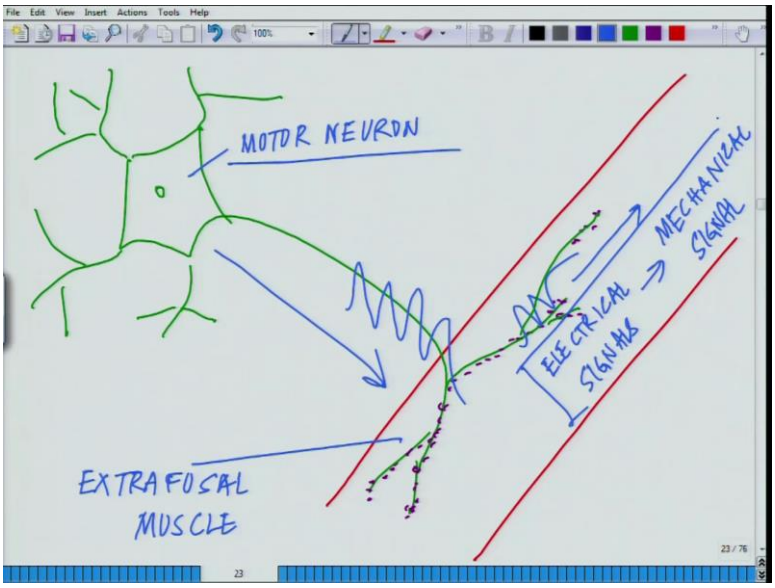

So, what is happening? Try to understand in breaking up situation now if this is a motor neuron and this is where the motor neuron is kind of forming the synapse with the muscle out here which is in red. And if these are the imaginary synapse which are all over the place and which I have already explained in the previous class how the synapses look like if these are the imaginary synapses. So, what is happening is that electrical signal which is coming the train of electrical impulse which is coming thus electrical impulse is being transmitted.

So, these are the electrical signals. So, it is coming in this direction electrical signals is translated into mechanical signal this is very very important will come to this. And there is a reverse situation which is going on which is if this is the last part you know it is let me if this is the motor neuron. This is the last information transfer in this circuit motor neuron and this is the extrafusal muscle extrafusal muscle. Then, so here what is happening the electrical signal is being transmitted into mechanical signal.

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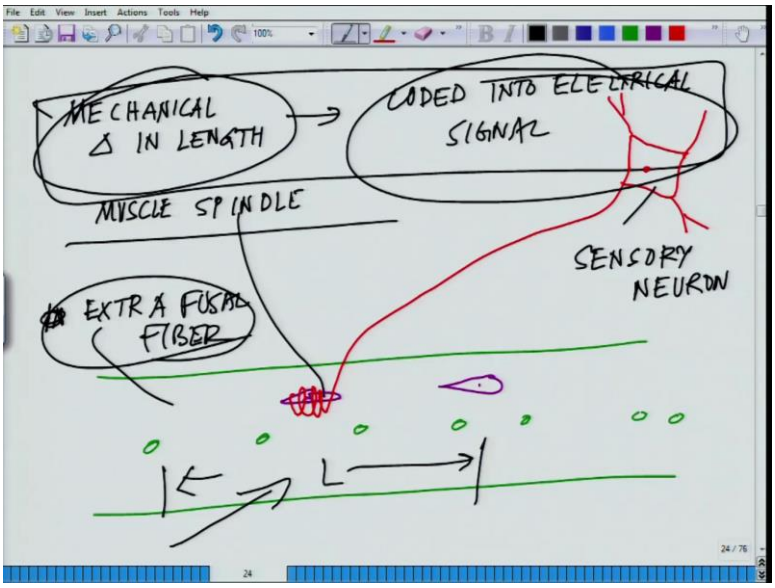

And in the beginning in the start of the circuit while here you have the, you have the muscle like this lying out here. And if this is the muscle and within the muscle you have these you have these muscle spindle sitting there and whenever there is a, so on top of that you have the sensory neurons wrapping. So, at this stage what is happening? Whenever there is an hit or something some kind of and there is a change in length. So, this change in length is happening this being sensed by this muscle spindle. In other word the mechanical change, what is changing taking place mechanical change in length is coded into electrical signal.

So, now if you compare this situation out here at the first part of the circuit where you have this one your sensory neuron and this one is your sorry extrafusal fiber. So, if you go back to the previous slide this is a zone where electrical signal is transmitted into mechanical signal. It has to come back to its original regional length, because the length has changed because of some impact, because of a stretch. And if you here here you look at it is a next slide very next slide here in the first part of the circuit the mechanical change in length is being coded into electrical signal.

So, this circuit why it is, so profoundly beautiful circuit is that there is an interchange of mechanical information to electrical information and electrical information to mechanical information. This is very important aspect to realize in such a simple circuit and these are the circuits which had been conserved for like you know for since the time

we are we have evolved these circuits have been conserved. So, how these circuits are. so profoundly functional this something really what looking at? So, this is the among the first circuits which I wish to discuss with you people.

So that you get a feel that the circuits, that what we are talking about and all these simple circuits. So, there are so many such circuit all over the place in our body which are continuously working in themselves apart from it you have you know you have these pin pricks I prick with some sharp object and immediately I react. So, there are specific receptor on the surface which immediately response help us to remove our hand from the pin prick. So, these are or say for example, I try to take my fingers towards some fire or something you know immediately remove my finger. So, these are some of those reflex circuits whose elements are the same the circuit may change, but there are h reflexes there are z reflexes series of such reflexes.

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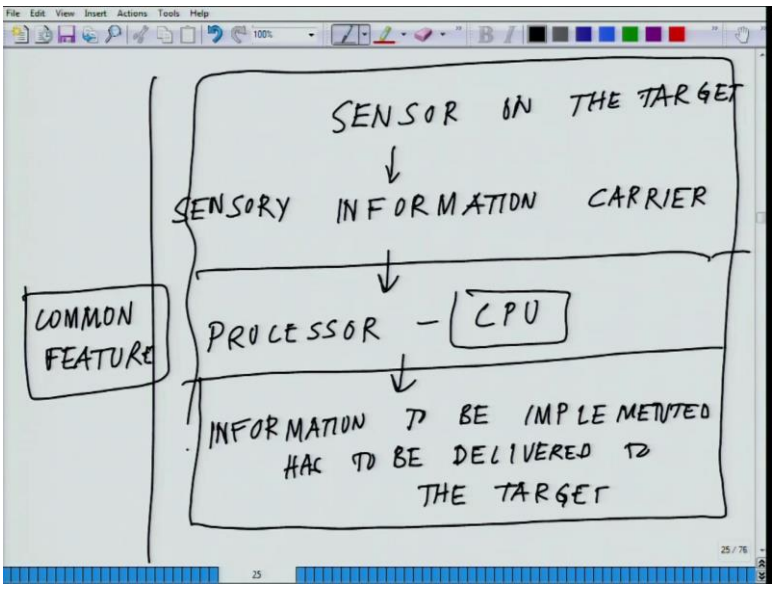

End of the day should have a sensory it should have a sensor. So, to summarize it should have a sensor first thing it should have a sensory information carrier sensory information carrier. It should have a processor which will process the information just like your central processing unit in the computer and then it should have a what to add. So, information to be implemented has to be delivered to the target and sensor on the target. So, these component are common is if I had to say what are the common features of all the reflex circuit. So, these are the common feature of the circuit and based on that you

have several names. You have different kind of sensor elements technician granule muscle spindle the series of such structures are there.

Then you have whole series of sensory neurons a from the peripheral nervous system which carries all those sensory inputs to the spinal cord or some of them goes all the way up to the brain. And then you have the brain and the spinal cord as the processor unit where you may have inter neurons a motor neurons and everything. And then that motor neuron path way which brings the information deliver it to the target that is your muscle and which falls under the neuromuscular junction. So, over all this is the geometry to summarize what we have covered in this lecture let us come back and let us because we just took bit of a detour today. So, I started with the stretch reflex arc circuit then we talked about the basic nature of the circuit how it looks like, why it is called arc it something like a structure like arc it is called basic stretch reflex arc.

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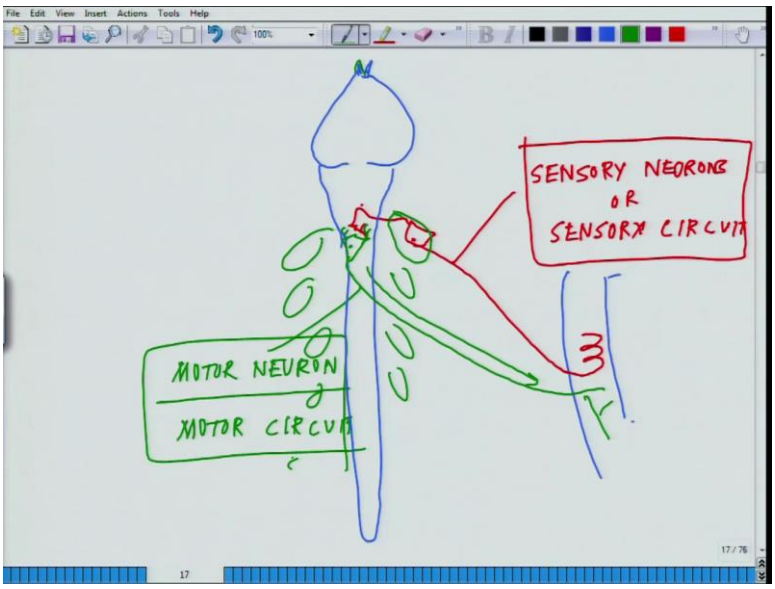

And from there we moved on to tell you the position of the motor neurons which are sitting in the spinal cord and sensory neuron whose cell bodies are outside the spinal cord into the ganglionic structure outside this spinal cord. And then we moved on to talked about the muscle development where we talked about the muscle could broadly divided into 2 groups extrafusal which is the highest in number huge number. And we have intrafusal which are very few and interfusal fiber has the ability to evaluate the change in length of the muscle these interfusal fiber further. So, they are formed, so we talked

about the development of the muscle. So, basically initially the muscles divide and after division they lose their individual cell walls what we showed you.

And I told you the difference between cardiac muscle and skeletal muscle difference between cardiac versus skeletal this I want you people to really look carefully for the structure. And then we talked about the myotubes then we talked about the individual myotubes coming closer together to form integration of this forming the myofibers. And these integration of these myofibers form muscle tissues, what you see in your hands legs and all over the body then we talked about the 2 theories of muscle development. We talked about the theory 1 and theory 2; the theory one talks about that there are certain cells while in the development which are destine to become interfusal fiber. So, that you could see here some of the cells which are destine and then we they are very few in number. And there is another theory which says that all of them become myotubes.

And then some of the myotube, because of some form of in a ration or something become interfusal and some become extrafusal. But there is lot of debates and lot of studies which are currently under way to understand this. And then from there we talked about again revisited the whole circuit in the light of intrafusal and extrafusal fiber. And we talked about then about the level of information transfer at this levels second level third level and the fourth level four different levels for such a simple circuit. And then we talked about that where the electrical signal is getting transformed into mechanical signal and whereas, where mechanical length changes orient to electrical signal. So, this is where we finished our first circuit a very, very primitive and a very important circuit which will help us to develop the story for next of the series of circuits. So, in the next class, what we will do? Will talk about the, this part how this mechanical how this electrical signal is transmitted mechanical signal?

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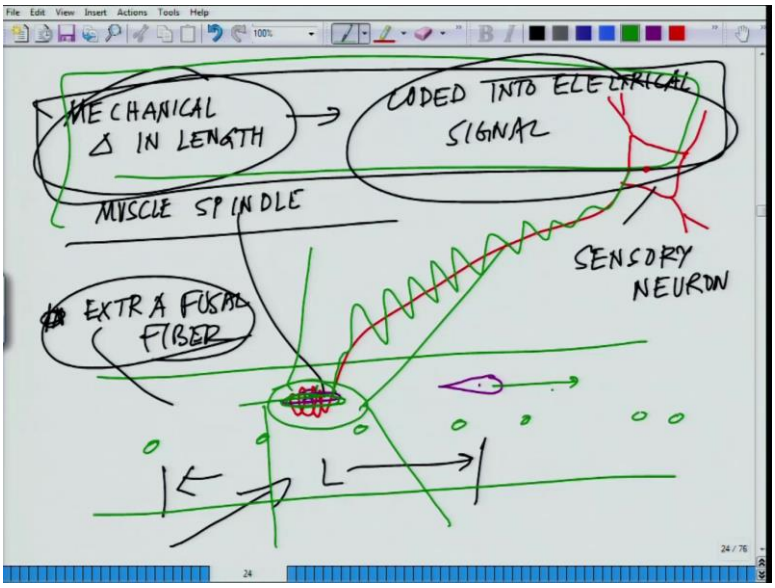

Before we go finished this lecture I will tell you something how, what is happening here? This is not very clear to anyone of us in the world what exactly happens it is believed that while the there are this muscle spindle. It is a structure which when it senses a the change in length it some way or other opens up sodium channels out into the sensory neurons. And thereby, because and thereby this information or action potentials are been generated here. But still now nobody is really very clear that how from the muscle spindle information's. In other word if I go back to information how this first of all how this is being sensed is under intense study and how this muscle spindles and this signal to sensory neuron is another unsolved mysteries?

These are some of the not fully understood we know certain things, but again we do not know many things about these 2 circuit. These two circuits are what we know a lot is about this one we know a lot we know partly about this. But this one we knows the best, but this is the part which is still under lot of intense studies currently across the globe. Those who are interested in this kind of area and specially in the neuro robotics and everything, because they want to understand this kind of algorithms, what decides that the change in length could be decided and all these things. So, with this finishing this circuit I will closing with this lecture.

Thanks for your attention, and next we will move on to the neuromuscular junction.