Bioelectricity

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Lecture – 17

Welcome back to the bioelectricity lecture, series. So, in the last class we talked about the ultra structure of the skeletal muscle, and I just introduce the sliding filament theory. So, today what we will do, first of all I will introduce two terms, here the excitation contraction coupling apparatus., and in that context we will talk about how the excitation reaches, and how the contraction in the muscle takes place.

So, these are some of the example, just before I go ahead with a details of how the electrical pulses are been transmitted across the muscle, and how it leads to the contraction. These are some of the very simple inspiration for developing micro electromechanical system or which is commonly known, as mem-systems where several items are being made to develop bio-inspired machines which functions by the transformation of electrical to mechanical energy from mechanical to electrical energy, so on and so forth.

So, let us start first of all based on what we have done in our lecture sixteen. So, we are on the lecture, let us start with the sliding filament theory after sliding filament, we will talk about the excitation contraction coupling apparatus, and some of the inspiration which could be arrived out of it.

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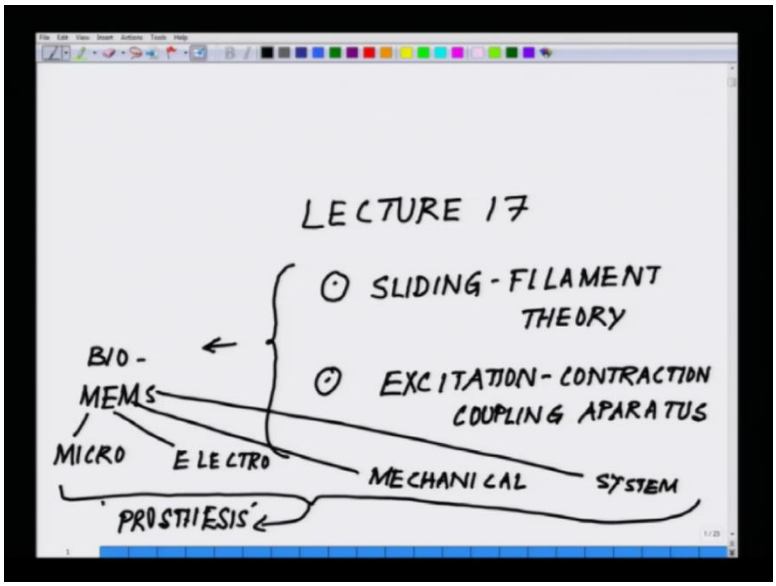

So, so here we are into lecture seventeen, and these are what we are going to cover we're going to cover sliding filament theory and then will be talking about excitation contraction coupling apparatus and how these things, inspired bio-mems, which is essentially micro electro mechanical systems, and how such things could be utilized for prosthesis, this is essentially what we are going to cover in this lecture, and in this section. So, coming back to the sliding filament theory. So, in the sliding filament theory we have talked about the cross bridges of the actine, and myosin filament we have talked about tripponine, and trippo-myosin proteins which are present there.

So, a just a small recap. So, what essentially happens is this when the nerve impulse comes on the muscle surface it leads to the transfer of the impulse, and which leads to the contraction of the muscle that is what essentially is happening. So, in other word the excitations, when you talk about the excitation contraction coupling excitation. So, if we if we break down the word excitation is excitation which is arriving from the electrical impulse electrical excitation, and contraction is the movement of the muscle, and in this whole process one of the key ion which place a vital role is calcium.

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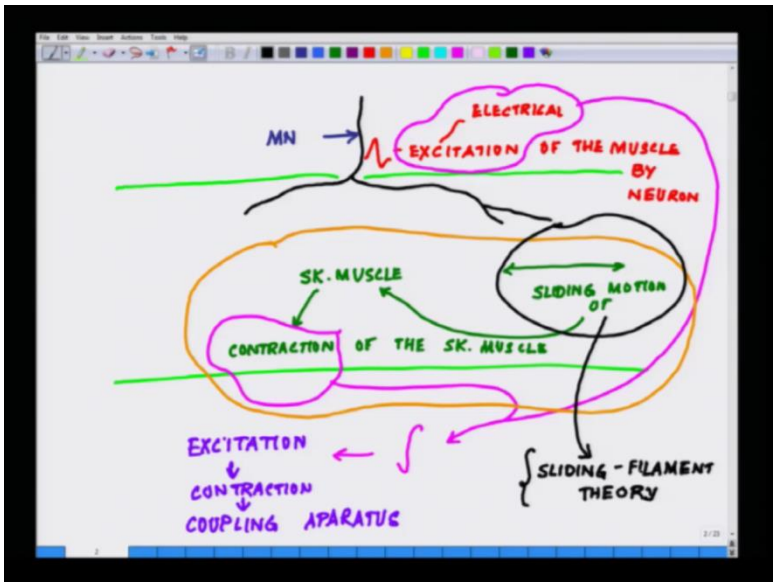

So, if I have to just draw it is something like this here say for example, you have the neuronal cell body, and which is forming a synaptic contact on top of the muscle . So, here you have the electrical impulse coming, which is leading to the excitation of the muscle or which is essentially, and electrical excitation of the muscle by neuron where this is your motor neuron which is showing by m n, and here you have the skeletal muscle s k denoting as skeletal muscle. So, here you are having the electrical excitation reaching, and what is ever sliding movement, which is taking place within the muscle sliding motion of skeletal muscle is essentially the contraction of the muscle.

And this excitation contraction of the skeletal muscle, and essentially this electrical excitation, and this contraction these two are integrated to form the excitation contraction coupling apparatus. So, this is what we meant by say in the first slide when I was telling you excitation contraction coupling apparatus. So, this is what it essentially means as excitation contraction coupling apparatus. So, what will be talking first is the contraction process the process by which the sliding movement once the sliding motion of the muscle takes place.

So, essentially we will be talking about, coming back to the slide first of all will be talking what this part this part of the story will be talking about, and then will come back to the upper part well the well the electrical excitation how it reaches. So, in that context

we will be talking first about the sliding motion of muscle, which is also governed by sliding filament theory.

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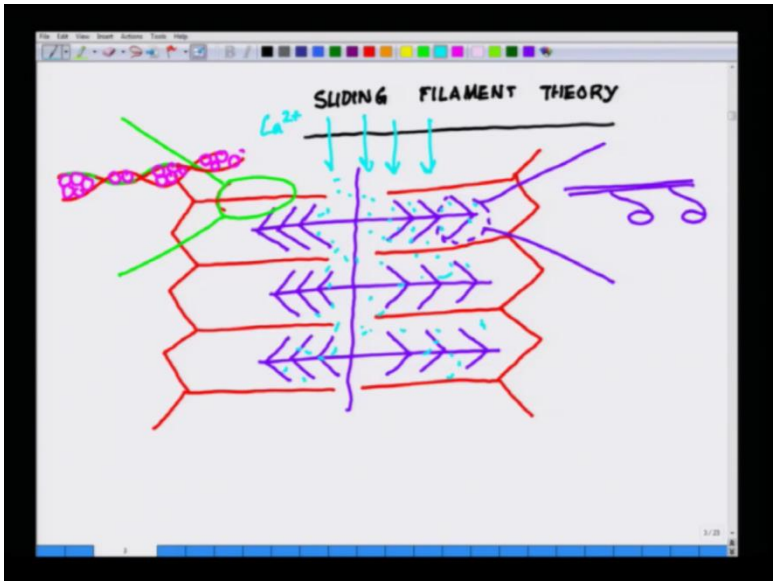

So, now, let us move on to the sliding filament theory. So, part of the sliding filament theory we have already discussed today will be discussing the final details in order to recapitulate back what we have done in our last class. I'll have to again draw the cross section of the muscle what I have drawn in the previous class if you remember when I was drawing this cross section. So, this was essentially what I have drawn previous class like this, and lines the lines are slightly off. So, do not worry straight, and in between you have the like this. So, this was the arrangement what I have already discussed this has been discussed now, if you if we kind of looked at it very carefully out here. So, for example, along these along this part let me pickup another color if you look at it very carefully on this part. So, it looks like something like this.

So, this will be more or less like, let me pickup another color, and on this you are having the triponent, and trippomyos in proteins like, this we have already discussed this part is already done on this side if I pick this up this one looks more like this you have the myosin heads likewise fine. So, the processes what happens is this whenever out here there is a movement of calcium ions say for example, I represent these dots as calcium ions all of a sudden there is an exposure of calcium ions which are coming here. So,

entry of the calcium ions essentially what it does is let us move on to the next page there are two three things happen?

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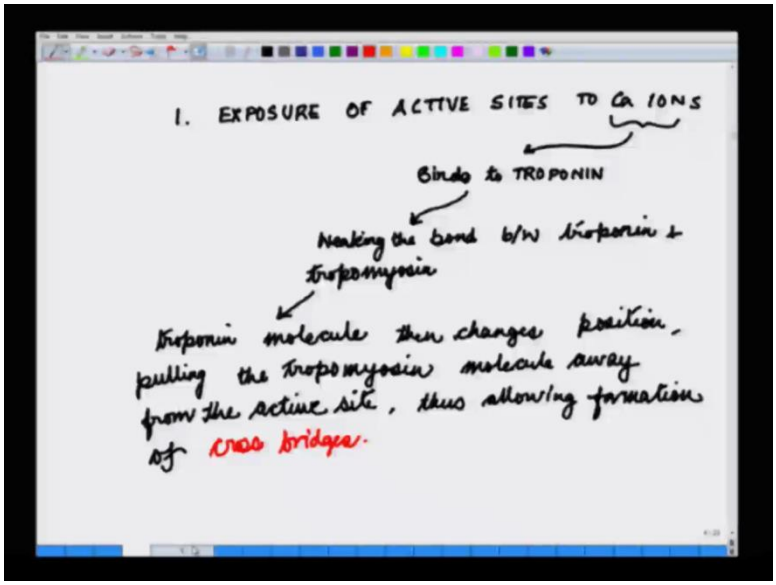

First of all step one of the sliding filament is exposure of the active sites to calcium ions exposure of active sites to calcium ions, and calcium ions essentially after entering the sarco plasm by extraponent, and this calcium ions after entering binds to troponin once it binds to troponin binding to troponin. This weakeness the bond of between troponin, and tropomyosa weakening the bond between troponent, and tropomyosin.

This weakening of the bond between troponent, and tropomyosin leads to the troponent molecule changes position pulling the tropomyosin away from the active site. So, the next step is the troponent molecule, then changes position, and thereby pulling the tropomyosin molecule away from the active site thus allowing formation of cross bridges formation of cross bridges. So, this is step one. So, step one let summarize what is happening calcium molecules are getting into that whole cross bridges or or in the in that in among those sliding structures.

And it removes the troponent, and tropo basically it weakness the bond between troponent, and tropomyosin, and thereby removing the bond, and thereby, because the active sites are actually prevented or they are not exposed, because on top of the active sites if the troponent, and tropomyosin sitting like this as soon as the calcium comes say for example, if this is the as soon as the calcium comes, it weakness the bond, and it

separates out, and thereby exposing the active site and then this active site is the binding site which will be our step two let us move on to the slides again. Now, we are on step one second yeah.

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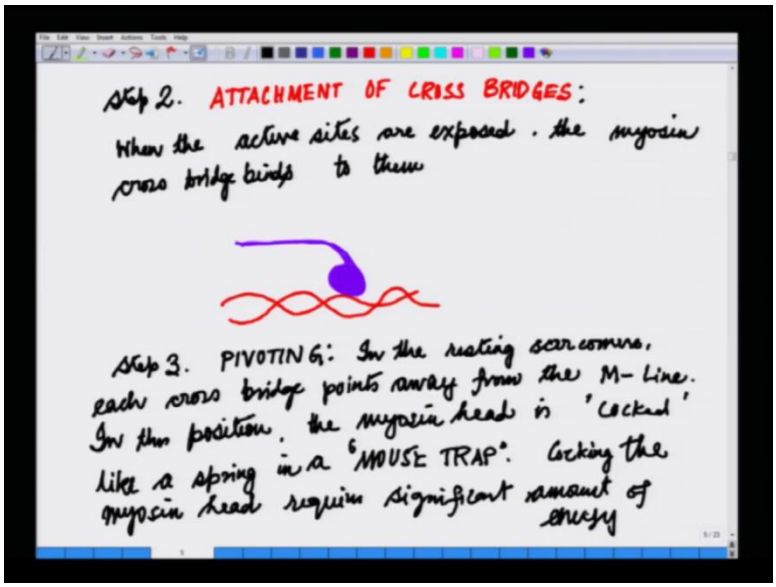

Now, we are in step two step two is basically step two is essentially attachment of cross cross bridges attachment of cross bridges, because now, the basically the inhibitory or or the molecules, which are not allowing to exposed is being removed the troponent tropomyosin is gone. So, now, the cross bridges can form. So, the active site is all exposed. So, coming back to the slides. So, attachment of cross bridges basically this step essentially means when the active site are active sites are exposed the myosin cross bridge bind to them binds to them.

Binds to them. So, this is essentially would is happening is now, myosin cross bridge which is say if I represent it like this is. So, this is in contact with. So, now, after this will move on to step three step three is essentially something called pivoting pivoting what is pivoting pivoting is essentially in the resting sarrcomere each cross, bridge points away from the m line if you if you realize here. So, basically this is the m line.

So, they are pointing away from the m lines, if you look at look at these m lines. So, if you look at the structure very essentially very carefully, and you will see most of at most of the time they are facing away from the m line. So, this is where you are having the m line fine. So, at the resting there are facing away from the m line. So, coming back

pivoting in the resting sarrcomere each, cross bridge points away from the m line in this position the myosin head is a term which is used cocked like this spring in a mouse trap. This cocking the cocking the myosin head requests significant amount of energy. So, essentially this is a energy driven process, and out here energy is supplied by the a t p molecule.

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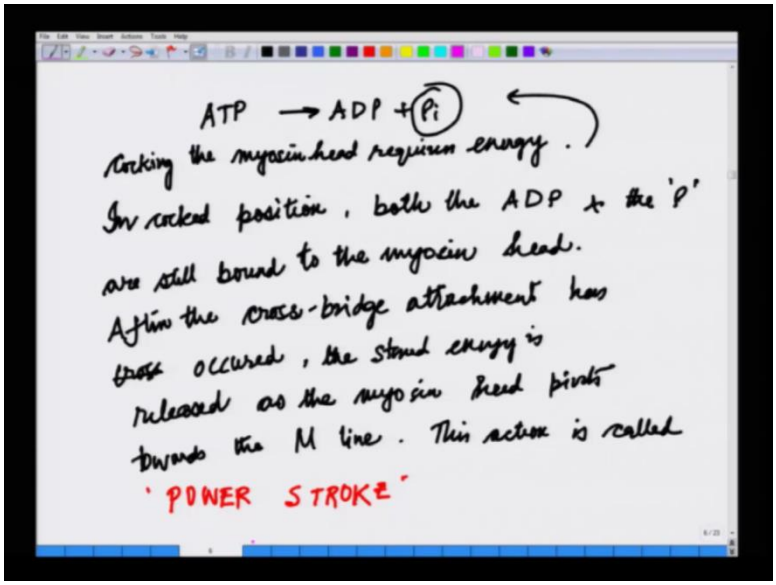

So, this essentially what happens energies, obtained by this time energies obtained by a t p's broken down into a d p this phosphate, and this is the phosphate generation which leads to the energy, and this leads to the formation of the. So, after the cross bridge at attachment has occurred the stored energy is realized as the myosin head prevents towards the m line.

So, this is where basically what happens? If I go back this energy what is present there. So, this is what is leading to this motion see, there is a preventing motion which takes place this being promoted by. So, essentially the motion is like this whenever it has to you know pull pull them. So, so the motion towards this direction. So, in other word this these two arrow what I am drawing now, if you follow this motion is being promoted by the a t p which is releasing a d p, and phosphate, and this energy which is generated out here this energy actually goes here, and leads to that something eventually what is being called is the power stroke.

So, this is essentially, what is happening here coming back out here. So, coming back from where I was talking about cocking cocking the myosin heads requires energy, and this energy is obtained by as I have already mention from the a t p in cocked position both the a d p, and the phosphate. Which is shown here a d p, and the phosphate are still bound to the myosin after the cross bridge attachment has occurred. So, this is called cross bridge one second as occurred the stirred energy is released as the myosin head piverts towards the m line this action is called the power stroke is called power stroke.

Coming back, so essentially what is happening, if you try to look at it, it is basically the heads are like this, they are unexposed. As soon as calcium comes, they bind, once it is bind, they make it move like this, and this whole motion of the myosin head like this from this to this, this to this from both sides. If you look back to the picture again, coming back this is a conceptual thing. You need to understand; these head this whole motion out here, if you look at it out here. This motion what I am showing you in pink color now, this motion.

This motion is critical for the power stroke to take place. Essentially it is sitting like this, and here you have the myosin head, which is making it move like this, and this whole power stroke is a function of energy. It has to be significant in one of energy ATP has to go there bind there, and has to release its energy, and thereby allowing that this power motion. So, this is what we call has a power stroke, and this is what leads the sliding filament motion sliding filament theory. So, there are few other therapies on this before we move on to the excitation part of this. So, coming back.

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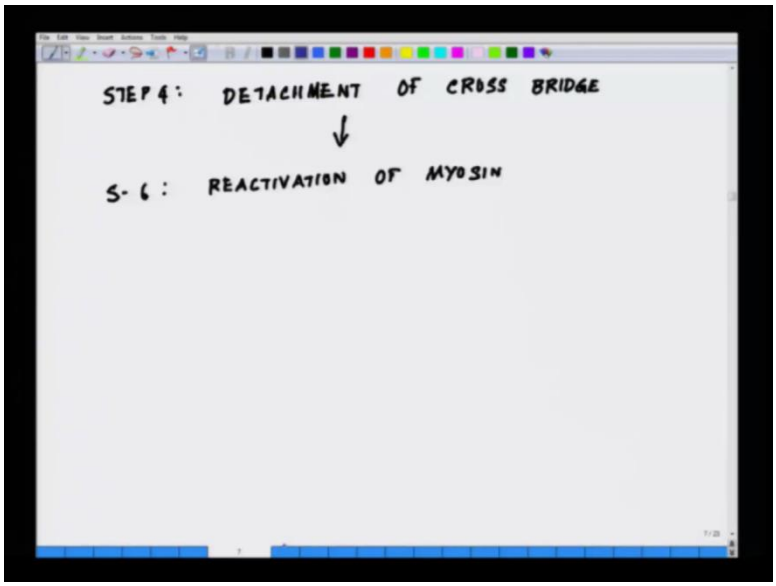

So, the next step it is have to in is step 4 step 4 is essentially detachment of cross bridge next is the, because this process is a dynamic process detachment of cross bridge followed by step six which is reactivation of myosin . So, this is what is essentially is happening this whole process is being governed by the presence of calcium. So, coming back to the slide, where I was showing the excitation contraction. So, electrical impulse reaches transmitted from the neuron to the muscle surface within the muscle surface it has to reach all the way along the three dimensional architecture of the muscle.

So, now, what we will be talking about how that excitation is being transmitted to the muscle, and the end goal a of that excitation is that there is a contraction which takes place, and that contraction is initiated by by the release of calcium. So, coming back to the slides. So, this is where we started the electrical excitation reaching, and leading to the motion of the muscle. Now, the question is where we started this whole thing is how it reaches all the way down on several occasions we have kind of kind of try to highlight this part how this is happening. So, for that we have to one second let me yeah.

So, for that we have to understand the muscle architecture, because this is where, because of this electrical excitation there is a release of calcium, but how that is actually regulated is very essential to understand how that calcium release is being regulated that point of time, because that calcium release is the cause of the power stroke what we have just learned. So, now, let us see the architecture in another finite details. Which will let

us know exactly what is happening. So, coming back to power stroke reactivation of myosin now, we will be talking about.

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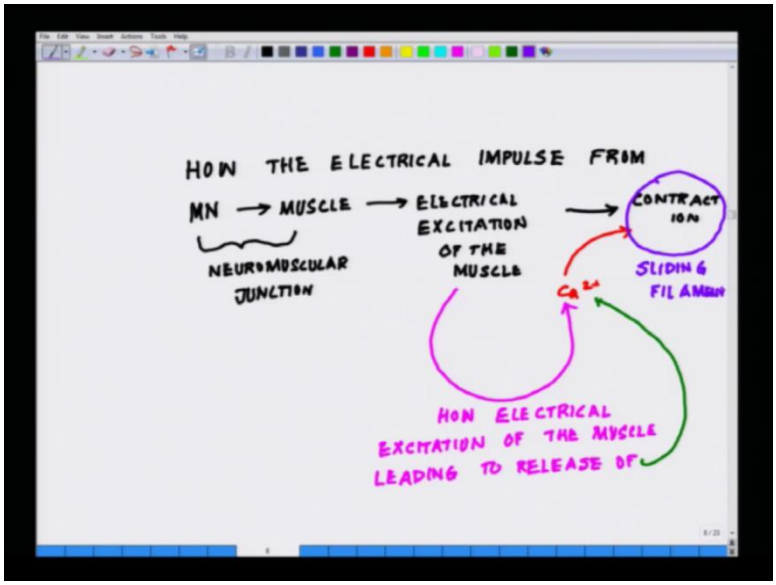

So, the question we are asking now, how the electrical impulse from motor neuron m n motor neuron is transmitted to the muscle of course, this is happening at the neuro muscular junction, and the followed by that how this electrical excitation of the muscle leading to contraction, and we have seen in that process one of the major role is being played by calcium. So, essentially what we have to understand now, how this electrical excitation leads to the calcium release how electrical excitation of the muscle leading to release of calcium this is what is essential for us to understand.

Because we talked already talked about this part the contraction which is governed by sliding filament, and the power stroke, and everything part of it in order to understand this part we have to look at the muscle geometry again to revisit the whole muscle geometry. So, muscle structure is that continues cylinder of all these muscles what you see, there are gorge like structure in this there are kind of know we draw the structure they look more like this one second. So, the muscle structure is something like this.

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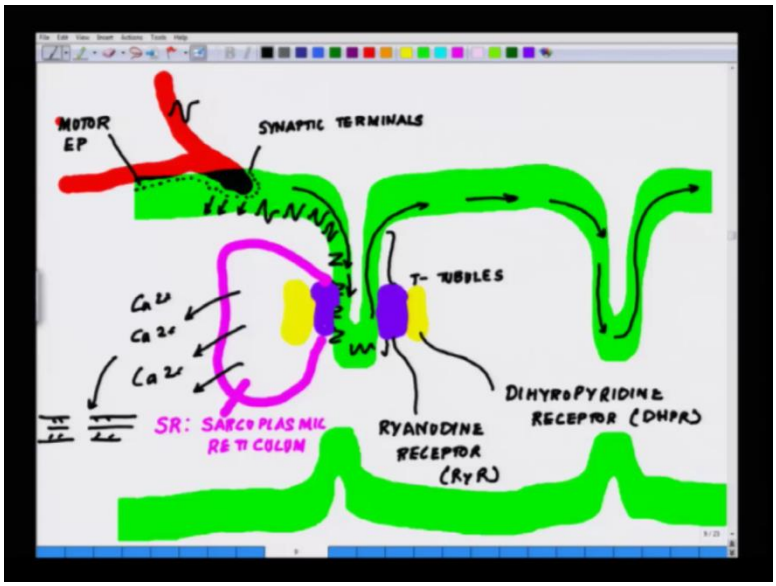

This is only one side am showing that side also had, and the way the neuro muscular junction is functioning is something like this. So, the motor end plate are sitting like this. So, these are the motor end plate. So, now, So, whenever. So, let me put it like this. So, this is the motor e p stands for end plate, and these are the synaptic terminals out here these dot like dotted dotted structure. What I am drawing now, synaptic now, there these kind of structures what you see this gorge like structure these are called t tubule's.

So, whenever the electrical excitation is. So, these are when the neuro transmitter are being released. So, the electrical impulse coming from muscle is transmitted to the electrical impulse sorry electrical impulse coming from motor neuron is transmitted to the muscle. So, within the muscle these electrical impulse are now, travelling. So, they will travel like this likewise likewise, and they will move on like this which-so-ever direction they move. So, if you follow my arrow this is how the electrical impulses are moving. So, well the electrical impulses are moving along these t tubule's within the t tubule there are some very specialized structure there are two unique gates which are sitting there, and these are voltage gated channels.

They are sitting out here like this they are sitting here like, this a two individual gates one I have shown in violet the other one I am showing as yellow like this on both side on could be on any side like it does not matter, but these small gates which are present there these voltage gated channels what I have shown you now, in violet, and yellow colors

these voltage gated channels sense the electrical impulse within the muscle, and what they essentially do is they are attached to another structure here called a part of a structure called s r or one second s r. Which is called sarco plasmic reticulum sarco plasmic reticulum is an interesting structure this is the structure which regulates calcium one has to realize though calcium plays a very vital role.

But the calcium has to be continuously regulated excess of calcium could be some excited toxic. So, how to regulate the calcium within our individuals cells of as body there are certain sponge like organals called sarco plasmic reticulum they have a very tightly regulated mechanism by which they release calcium, and they pull it back, and this sponge action or this releasing, and pulling them back as if your squeezing it water comes out from a sponge, and again you leave it it pulls out pulls the water back. So, as if there is a force, which coming pushing it water comes out, and push it back same way. You push u there is some force which comes which throws over the calcium, and pulls it back as soon as you release remove the force.

So, in this kind of a structures of sarco plasmic reticulum the way it functions is that it is completely, and thoroughly regulated by the voltage gated calcium channels, and those two channels what i've drawn represent their these channels essentially regulates calcium. So, these two have very specific names one is called ryanodine receptor the other, one is called dihydr pyridine receptor which is called d h p r, and this is also called r y r. So, essentially what happens is that as soon as either one of them it is not really clear which one senses, what it is still at the molecular details not clear clearly wrote.

So, one of them senses the electrical depolarization, and the depolarization is this these are the depolarization waves, which are moving within the muscle the as soon as this depolarization waves are sensed by the voltage gated calcium channels one of the voltage gated calcium channel either the ryano dine or the di hydro pyridine, and by the way. these names they have got, because of the different compounds which are bound to them. So, ryano dine bounds to one of the calcium channel. So, it got. So, name ryano dine di hydro pyridine bindes to another. So, it got. So, name di hydro pyridine receptor as soon as it binds it as if they are coupled with each other.

It something like the hydro pyridine ryanodine say for example, such them ryanodine sense it once it senses it tells this one you open up once it opens up the calcium goes out.

So, essentially the end result what do you see is this calcium from sarco plasmic reticulum is being clust into the with inside the cell, and is this calcium what you essentially see goes to your that finer structure of which promotes, your sliding filament motion. So, essentially if I have to kind of you know put them in perspective.

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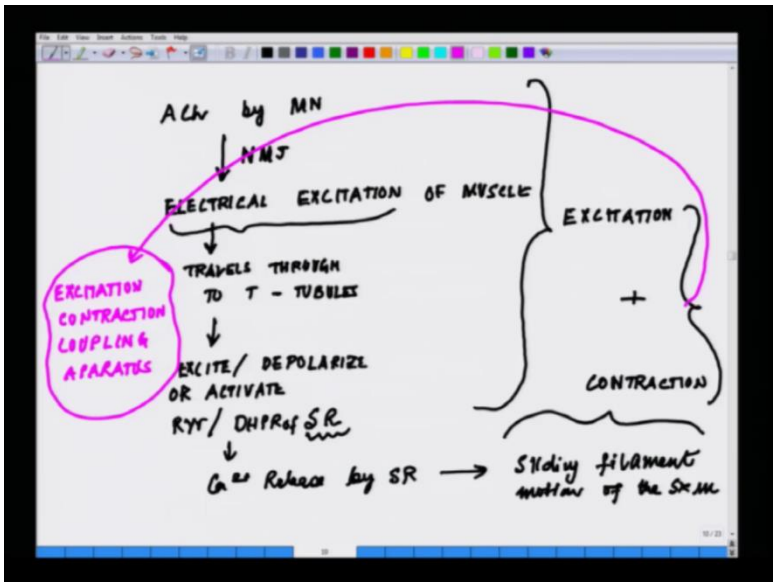

So, what is happening is acetin colin release by motor neuron through neuro muscular junction, it leads to electrical excitation of muscle electrical excitation, then travels to travels through to t tubule's within the t tubule's they excite or depolarize or actually essentially acts activate ryanodine, and dihydropyridine receptors or the sarco plasmic of s r sarco plasmic reticulum. Its leads to the calcium release by sarco plasmic reticulum, and this leads to the sliding filament motion of the skeleton muscle. So, this part of the study was excitation, and this part of the study is contraction, and when you add both of them together rather this becomes excitation contraction coupling apparatus.

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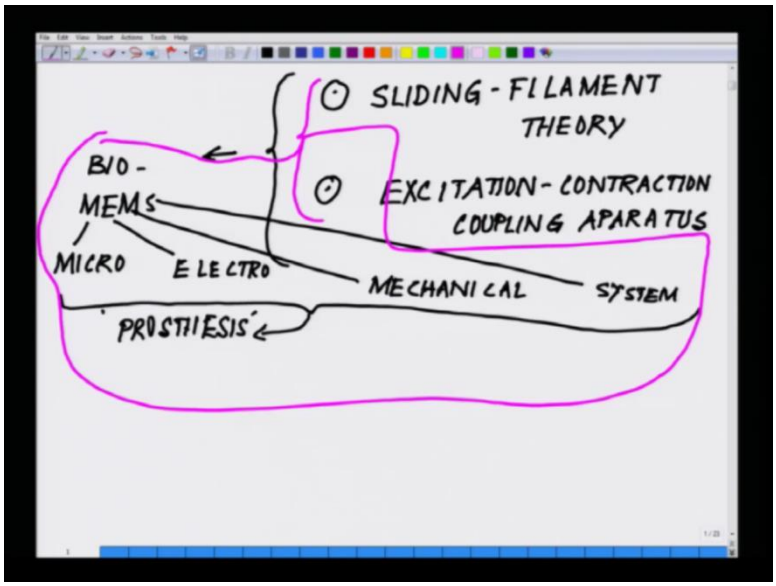

So, this is essentially is inspiration to understand how electrical signal leading to a mechanical signal, and could we make this. So, if you go back to the first slide while I was telling you. So, if you look at it well I was trying to come back. So, this is what I was trying to tell you sliding filaments excitation contraction, and could this be used as an inspiration for developing micro electro mechanical systems. So, this these are some of the approaches which are currently underway across the world by several people who are working in these kind of areas that could be understand the structure memecate, and kind of develop biological machines out of it, and one has to realize one of the key component in all these games are the voltage gated channels.

If you realize, because when the neuro muscular junction. There is is released of acetyl coline acetyl coline release leads to the well on upon binding on the muscle surface leads to the opening of the cat-ion channels that leads to then depolarization, and that depolarization of the muscle eventually get transmitted leads to activation activation of the calcium channels voltage gated calcium channels in the form of ryanodine receptors, and dihydro pyridine receptors leads to the opening of the calcium pores on the sarco plasmic reticulum, and these pores essentially leads to the release of calcium, and this calcium plays a vital role in removing the connectivity between the myosin head, and the active filaments by binding to the triponin, and removing weakening the bond between triponin, and tripomyosin.

Thereby exposing the active site, and upon binding on the active site it leads to in the presence of of course, adenosine triphosphate the energy molecule it leads to the power stroke like this which leads to the sliding. So, it is a very tightly regulated, and and as soon as soon as that happens the calcium is pulled back by the sarco plasmic reticulum it has to be regulated it has to be very time bound very nicely regulated phenomena. So, if you look at it very carefully you will realize that, there is enormous amount of involvement of electrical, and mechanical forces interconnection which is beats to such processes.

This is always inspired since the time, we have lot of fairly good understanding of this whole process in last 20 years there is lot of inspiration could we develop such machines could we integrate to machines. Which could function exactly the way the biological system functions. So, I will closen here for this lecture, and we will learn more about in the coming lectures next two three lectures will talk more about the retinal prosthesis cocked layer prosthesis.

So, essentially what will be doing in the coming lectures, will talk about the structure of the eye, and what are the retinal prosthesis cocked layer what are the structure of the ear, and then will be talking about electrophysiology of the cardiac systems. So, I will closing here thank you for your attention.