Biomechanics
Prof. Varadhan SKM
Department of Applied Mechanics
Indian Institute of Technology – Madras

Lecture – 19
Sliding Filament Theory: Skeletal Muscles

Welcome to this video on Biomechanics. We have been discussing about Skeletal Muscles.

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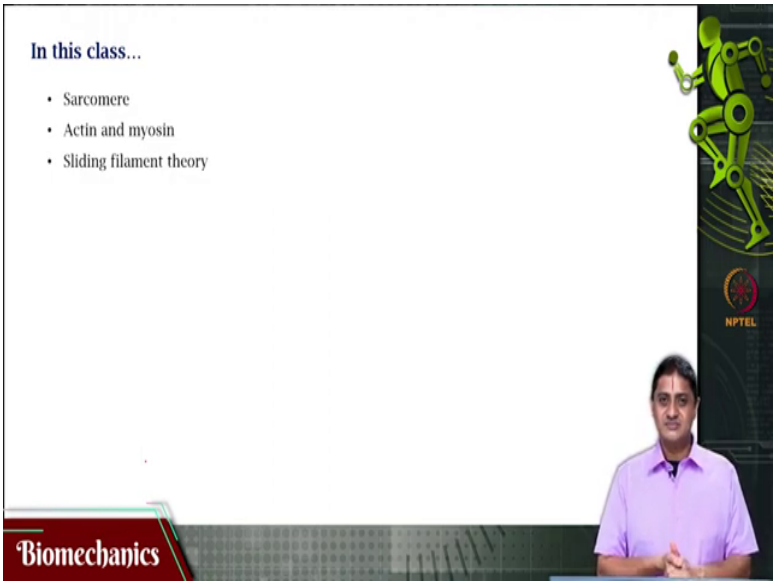

In this video, we will be focusing on sarcomere something that we discussed in one of the previous videos. And the thick contained filaments which is myosin and actin respectively. And how the interaction between the thick and thin filaments? Are myosin and actin produce force or the sliding of these two filaments with respect to each other contributes to the build up of force or contraction tension within the muscle.

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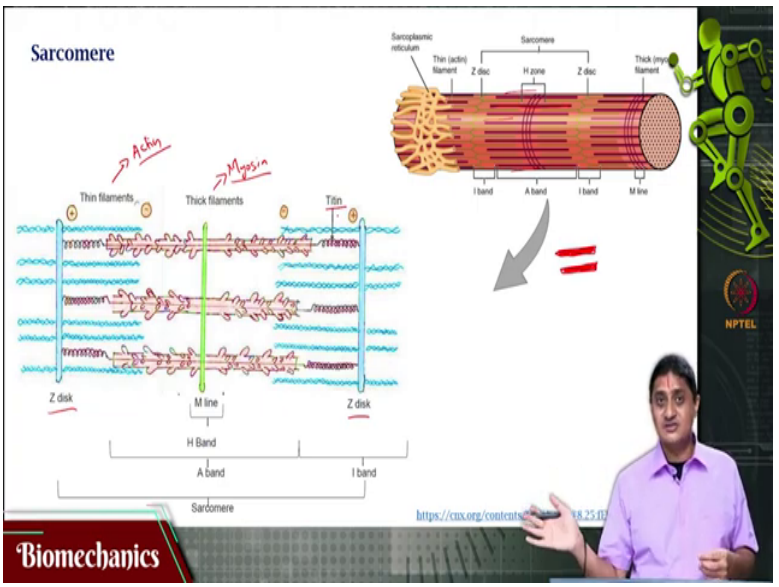

So, let us get started, we saw this in one of the previous videos that there are this thick filaments which is myosin and then the thin filaments which is actin. Under consecutive Z disk where this actin and myosin are suspended are called Z disk or the distance or the set of all components that you find between 2 Z disk together put together is called as a sarcomere.

This is the smallest functional unit of a muscle. So, how does this produce force? That is of interest for us. So, let us zoom in further. So, initially you have this myofibril which I zoom in I am finding this thick lines, followed by thin lines. So, giving this striped appearance. We saw this characteristic a unique characteristic of the striated muscles. I zoom in and I find this thick filaments which are myosin and the thin filaments which are actin.

The thick filaments are attached to Z disk through thin. The thin filaments are directly attached to the Z disk. I want to zoom in further and understand how this works?

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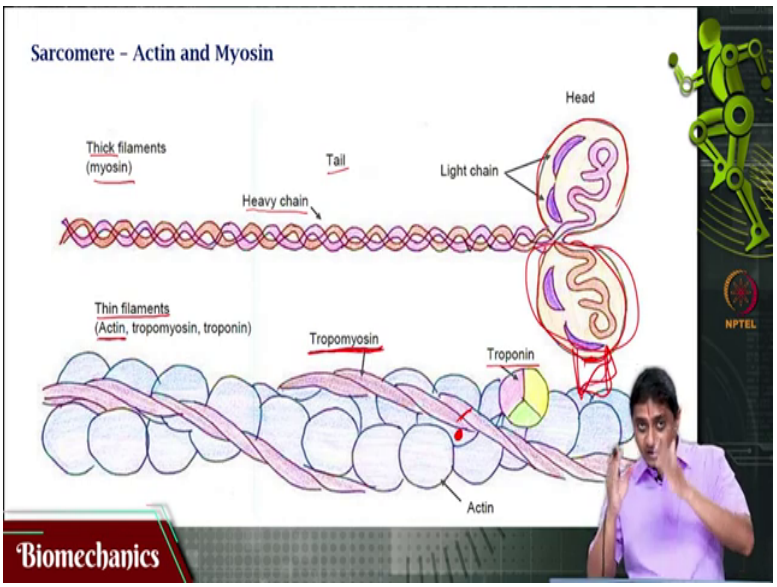

Let us zoom in further. Zoom in further, what I find is that? This is the thick filament showing only two heads. That is one head here and there is one head here only two heads I am showing. In previous slide, I see there are many heads 1, 2, 3, 4, 5 6 hundreds of these. For convenience in this slide, I have only two heads that I am drawing. So that we can discuss without cluttering the slide.

But there are many more such heads that are not shown in this picture. Only two heads are shown. So, the thick filament has many of these heads within which there are this light chain proteins. And the filament itself is the heavy chain protein which there are this head that is attached to this long chain called the tail of this protein, myosin. The thin filament is not a single filament as it appears.

As I zoom in, what I see is that? There are many other things that are there in the thin filament. The thin filament is composed of the thin filament itself which is actin. And this thin filament is surrounded by a thread which is called tropomyosin. So, imagine this pen is the thin filament. And this thread is the tropomyosin. It is like this I have surrounded the thin filament which is the pen with the thread which is tropomyosin.

And the nature of this tropomyosin is such that it hides at rest. It hides very important points. There are some very important regions within the thin filament actin which have the capability to attach to this head of the thick filament. The head of the thick filament can attach only to specific regions in the thin filament. And these are hidden at rest. These are hidden by the thread that is surrounding like this.

So, imagine just below this thread. That is the active region. That is the binding site where the thick filament can attach. But it is not visible. Why is it not visible? Because this thread is hiding it this thread is intentionally hiding it. Then how is force produced? It turns out that to this thread another protein is attached like this. Let us say another protein is attached at this point. That protein is called troponin terminology.

The thick filament is called myosin. The thin filament actin is surrounded by this thread like protein called tropomyosin which has this tendency to hide the binding sites on the thin filament are actin. And on this tropomyosin is troponin one more protein that is attached. The nature of this troponin is such that when it detects the presence of calcium. Whenever, there is calcium it undergoes a conformational change.

A structural change that just slightly moves this thread, thus exposing the binding sites. Exposing the important crucial regions where this myosin head can attach. The myosin head is always present. The binding site on the actin or the thin filament is also always present, just that it is hidden. It is like this. Now, unless I move this thread away, I have to just slightly move this thread away from the binding side to expose it.

So that myosin head can attach to the binding site. Note that myosin head cannot attach anywhere on that inside. It cannot attach anywhere on the actin filament. It can attach only to specific regions. So, this region, where it can attach is called as the active region or the binding site on actin which is hidden by this rope like or thread like tropomyosin protein which is moved by another protein called troponin. And why will troponin move it?

Then calcium is detected by troponin. It undergoes a structural change or a conformational change. Or, it goes to one more of it is stable states such that tropomyosin is slightly moved exposing the actin binding site. Thus, the myosin head can attach to that binding site very crucial to understand this part of this lecture. So, myosin head can attach only to the actin binding site.

And actin binding site is hidden by the presence of this tropomyosin or the rope or thread like tropomyosin which is further attached to troponin which detects the presence of calcium. And then moves the tropomyosin exposing the actin binding site. Immediately, it is possible for

the myosin head to attach to the thin filament binding site. Now, we understand the special crucial role of calcium.

If there was no calcium then it is impossible for this binding site to ever be exposed. In one of the previous videos, we discussed why calcium spark? Are the build up of a huge amount of calcium within the muscle cell is absolutely critical for the production of muscle force. This is where it comes into play that calcium build up that. You see that we discussed in the previous video is what leads to the movement of troponin or the structural change of troponin?

Conformational change troponin, thus slightly moving the tropomyosin exposing the actin binding site such that the myosin head can attach to the actin binding site.

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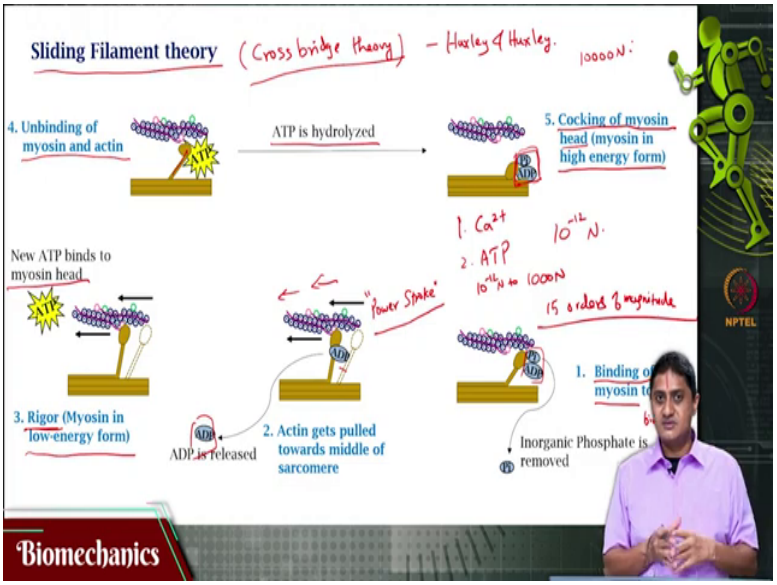

How is this happening? This is believed to be happening through the so, called is explained by the so, called sliding filament theory. Also, sometimes called as the cross bridge theory, why this name cross bridge? Come to the data bit attributed to Huxley and Huxley. The work of Huxley and Huxley for the first time demonstrated. It was theorized first by Huxley and Huxley that this is perhaps, how it works very popular?

Perhaps the most dominant view of how muscle force is developed? Is a cycle through which this happens. You could start anywhere in this explanation and stop anywhere because it is a cycle. It continues through the muscle force production cycle. But we will start with the point at which the myosin head attaches to the actin not anywhere on the actin, actin binding site.

For this to happen, it turns out that myosin will need energy, energy that is found as ATP is previously hydrolyzed and converted into ADP + P. When the third phosphate bond in the adenosine triphosphate is broken usually that is the high energy bond. When that is broken, energy is released. So, energy is available in the form of ATP which is hydrolyzed and present as ADP and P.

And the third phosphate bond is then broken when it is broken ADP is released, energy is also released. That energy is what leads to a conformational change in the myosin? So, myosin are the head of the myosin is already attached to the binding site. When that energy is released by the breaking of the third bond or when ADP is released, energy is also released.

Leading to a conformational change in myosin such that it pulls the attached actin or the thin filament in a particular direction, in this direction. This stage or this step in which the pulling of the thin filament are actin by the head of the thick filament. The myosin head happens is called power stroke. This is of course, this is not just one head that is pulling right. We have hundreds of these heads, all of which are simultaneously attached.

All of which require ATP, all of which take energy and then pull in the same direction. All this force adds up and appears as muscle force. But here we are talking about what happens at the molecular level? So, this situation, in which one myosin head is attached to a binding site and is pulling the actin filament because that attachment is so strong. And because it is having the energy to pull where is energy coming from?

From ATP of course because it is having that energy to pull it is pulling in that particular direction that is called as power stroke. That movement is then completed after which myosin goes into a relatively low energy form. It is still attached to the actin. But it cannot now pull it has to release itself from the actin and again, cock again attach and again you know hydrolyze one more ATP and then pull.

Right now, it is present in a relatively low energy form. This low energy form is called as rigor. Now, new ATP binds to the myosin head once new ATP is binding to the myosin head, myosin releases itself from the actin binding site. Unbinding of myosin and actin happens. Then ATP is then hydrolyzed to ADP + P. Once ATP is hydrolyzed is present into ADP and P.

The myosin is ready for the next cycle of attaching to the actin. This situation in which the myosin head is present or myosin is present in high energy form is called cocking of myosin head. Exactly the opposite of rigor. When the myosin is in rigor, it is in a low energy state. Although, it is attached to actin, it cannot pull. But when it is in cocking, when it is cocked, it is ready to pull. But it is not yet attached to the actin binding site.

And then the binding happens, binding of myosin to actin happens. Once that happens by the way this can happen only when the binding sides are exposed. Remember that this can happen only when the binding sites are exposed. So that binding happens once that binding happens because ATP has already been hydrolyzed. That ADP is pulled away that energy from the third phosphate bond is released.

Leading to a conformational change in which it is pulling this thin filament in a particular direction. Power stroke this cycle repeats itself. Is it not? This is how sarcomere are one actin binding with myosin or one actin myosin bridge produces a small, a minuscule, an extremely small amount of force. So, the amount of force that we are discussing is sub pico-Newtons one actin and one myosin.

When they attach the amount of force that is produced is less than 10 power –12 Newton. So, very, very small amount of force is produced by this. And this cycle is repeating crucial for this to happen. There are two things that are absolutely crucial for this to happen. One, of course, our hero calcium you must have calcium for this to happen. Why? In the absence of calcium, the tropomyosin will cover the actin binding site.

No matter how much energy is available? Myosin cannot attach. Where will you attach? You can only attach not. You cannot attach anywhere on the actin. You can only attach to the binding site in the absence of calcium tropomyosin will cover the binding sites. You have to expose the binding sites. For you to expose the binding sites troponin must detect the presence of calcium.

Whenever, troponin detects the presence of calcium it will move tropomyosin, thus exposing the actin binding sites. So, calcium is absolutely crucial for this to happen. Second is, of course you need energy. This is an energy consuming process. Of course, you need ATP if

you do not have ATP, it is not possible to do this. So, you need both of this. You need calcium and you need ATP for the production of force by the muscle.

This is how force is produced within one actin, myosin bridge. Because this bridge is formed between myosin in head and an actin binding site. And it is an cross bridge right because these two are sliding with respect to each other. And so, there are two lines and there is a line that is attaching these two. There is a bridge that is formed between the thin filament and the thick filament.

So, if you see here, there is a bridge that is formed here through this attachment. This bridge because it is formed across it is called as a cross bridge. Which is where this whole theory is also called as the cross bridge theory of force production. When this happens in the hundreds of myosin heads and the actin binding site found within a sarcomere. A small amount of force will be produced.

That force is also very small that will be of the order of 10 power –12 Newton's. An extremely small amount of force but then in real life we find thousands of Newton's of muscle force being produced. For example, as I am standing the force produced by my muscles that are responsible for posture maintenance will be several hundreds of Newton's. May even cross thousand Newton's.

So, you are talking about thousand Newton to rather, you are talking about 10 power –12 Newton to thousand Newton or 10 power –12 Newton to 10 power +3 Newton's. You are talking about 15 orders of magnitude. Remember when you are jumping or performing some explosive spots. Jumping up and down sometimes the muscles that are responsible for jumping may even produce ten thousand Newton's are very close to that.

Depending on the weight it may be ten thousand yes pretty close to eight, nine thousand Newton's. You are talking about 15 or 16 orders of magnitude in which force is produced and controlled within the human body. That is a huge scale in which you can operate. Imagine an engineering system in which you could operate across such a large scale just imagine this. So, such is the wonder of the human musculoskeletal system.

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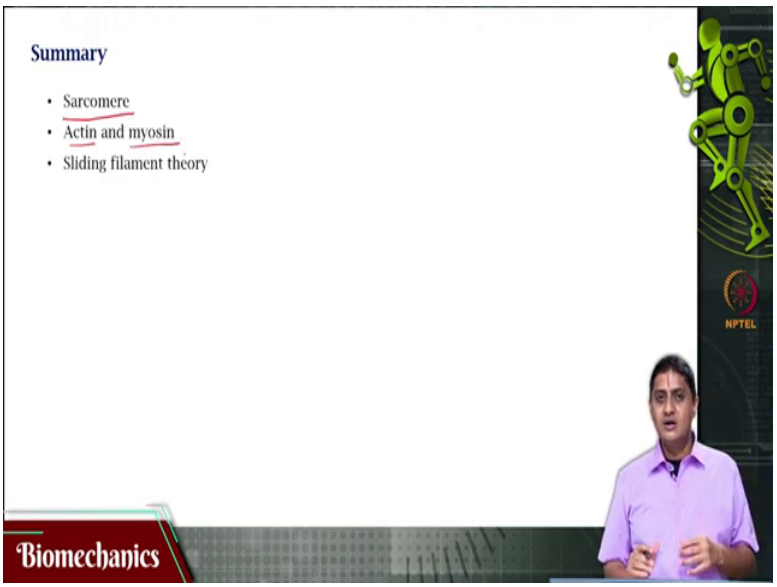

With this we come to the end of this video. In this video, we continued our discussion on sarcomere. They saw what is a thin filament or actin and the thick filament are using. And how cross bridges are formed between these two filaments? Are these two filaments slide with respect to each other producing force? And this is not why calcium and ATP are crucial to this function of muscle force production. Thank you very much for your attention.