Biomechanics
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Lecture – 20
Force Length Relationship: Skeletal Muscles

Welcome to this video on Biomechanics. We have been looking at Skeletal Muscles.

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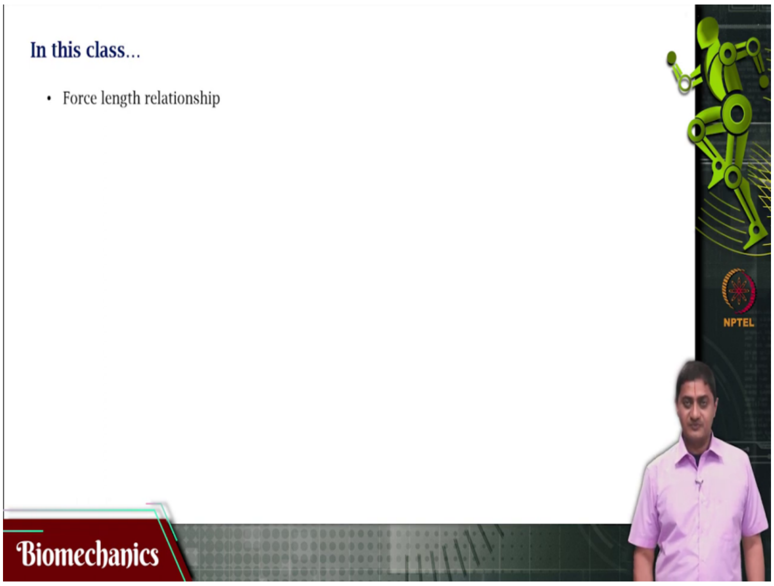

In the previous video, we saw how forces developed in a sarcomere or the sliding filament theory or the cross bridge theory? We explained how force is developed in the smallest functional unit of the muscle. The smallest functional unit of the muscle is sarcomere. And we said that cross bridges between the thick myosin fibers and the thin actin filaments are formed in the presence of calcium and ATP.

And the myosin then undergoes a conformation change and pulls the actin. I saw that reminding you on one more time. In this video, we will be looking at Force Length Relationship. The relationship between length, not of the sarcomere. In this case, we are interested in length of a muscle and force developed by a muscle.

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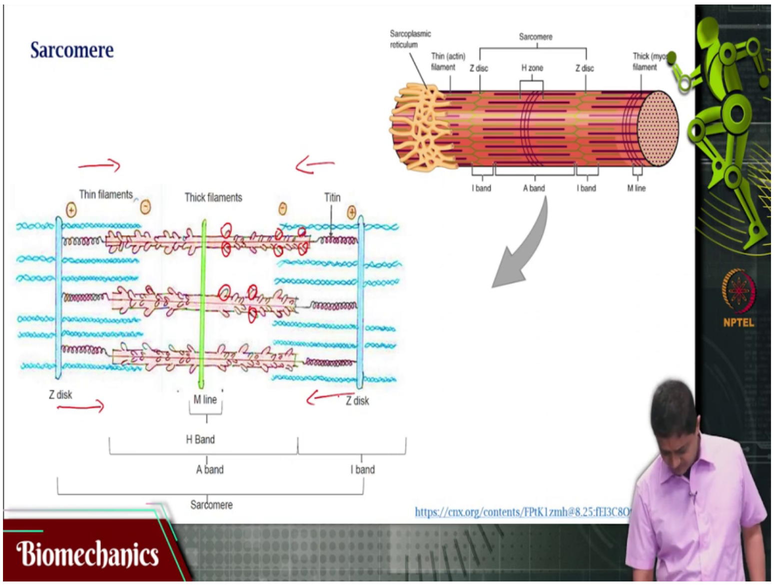

So, in the previous videos we have seen this. This is the sarcomere. There are this myosin heads that are marked by these red circles that I am marking by these red circles. These are attaching to the actin sides or the binding sites on actin. And then they undergo a conformational change and pull on the actin filament, thus causing a minuscule amount of contraction.

The 2 Z disk move closer to each other in that direction. Eventually, reducing the distance between the 2 Z disk are causing a contraction. This is what we saw in this.

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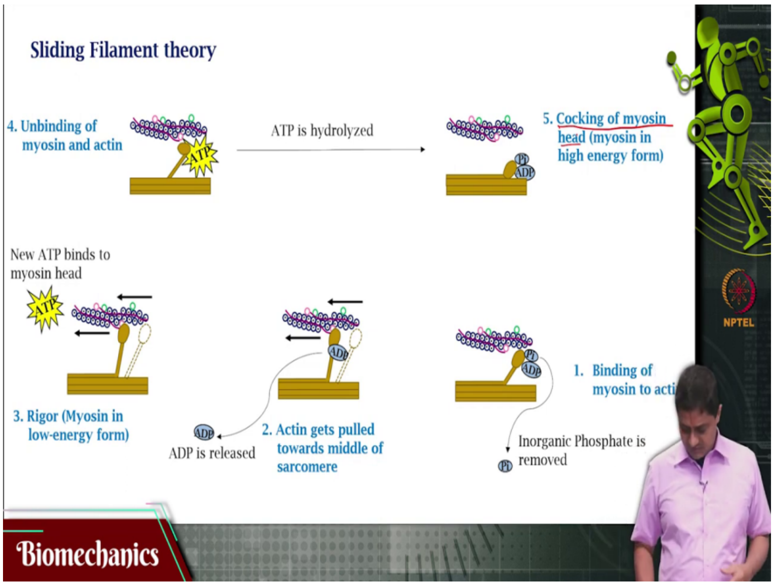

How this is happening? Because myosin attaches to actin and then the third phosphate bond of ATP is broken. And this energy is then utilized by myosin to undergo a conformational change and pull on the actin filament, causing this contraction. We said that immediately after it cannot undergo another pull because of that. Initially, it is in a low energy state and then it unbinds.

And then ATP is then hydrolyzed and then myosin goes back to a high energy state called cocking of the myosin head. Then again, the next cycle begins. This is how it happens. And because of this reason we said that in each sarcomere there will be a small amount of contraction that will be developed. And a small amount of force that will be produced.

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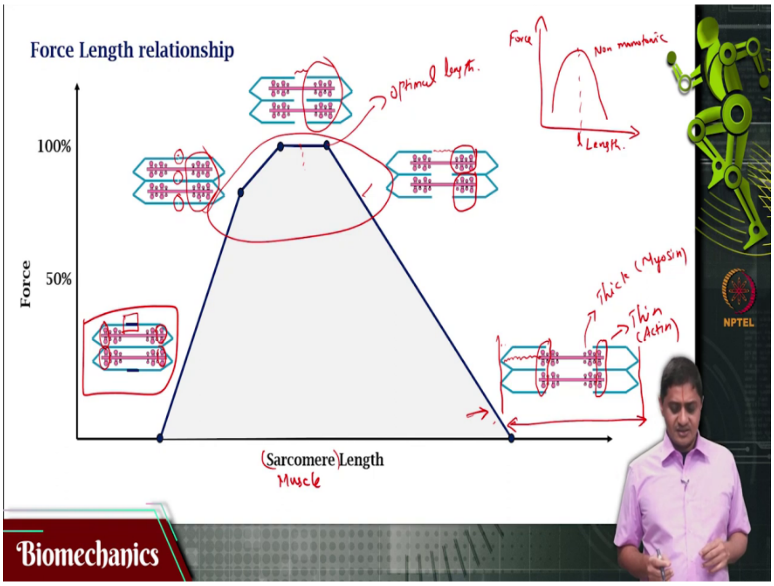

Now, a question is for the whole muscle itself, what is the relationship between force developed and muscle length? Because by this logic, if I would like to, by the logic where we discussed previously, if I wanted to develop more force that means I will have to keep on shortening the muscle or in other words there is a monotonic relationship between muscle length and force, not necessarily positively correlated.

Or in other words my expectation based on the previous discussion of the sarcomere if the sarcomere contracts force is developed. So that means as the length of the sarcomere are muscle is essentially composed of a lot of sarcomere. So, as the length of the sarcomere keeps on reducing force keeps on increasing something like this. I can expect something like this, not necessarily linear fine, something like this. This is what you can expect.

That is this is force, this is length but this is not observed in practice this is not observed in reality. What is observed in reality is something like this? As shown in this plot. That means it seems like there is an optimal length at which I am going to have maximum force that is that length. At that length I am going to have maximum force produced. At length above this length force is going to be reduced.

At length below this length force is going to be reduced. How is this happening? Let us try and understand this mechanism by which force and length are related. Now, let us start by analyzing what happens at the highest length when the sarcomere is at it is longest. What happens is? Here, the blue lines show the actin filaments or the thin filaments. The pink lines show the thick or the myosin filaments.

When the muscle is stretched, when the muscle length is great, when the muscle length is very high, what happens is that? The distance between the 2 Z disk. This is from the Z disk. So, the state of the sarcomere in each of this in some of these discrete points on this plot are shown in these diagrams. So, the distance between these 2 Z disk is so high that that is very little overlap between myosin heads and actin binding sites.

Because actin is suspended from the Z disc whereas myosin is suspended through titin from the Z disk. And because already the Z disk is far apart that is a very small number of myosin heads that can attach to actin. Whatever number of myosin heads that can attach to actin attaches and then they pull and because of this reason at very high lengths because that is very little or a very small amount of overlap between the myosin heads and actin.

The force developed is relatively small that is this point. Force is very small at very high lengths that make sense. Then what happens? If you reduce the length, the length is slightly reduced then the overlap between the myosin heads and the actin is relatively high. Because of this reason, what you see? Is that at this point all these myosin heads will be in a position to attach to actin binding sites and pull?

This is the reason you have high forces same reason here, same reason here. You are going to have relatively high forces in these regions because there is maximum overlap like I am having these two points and if I have to connect here. There is very little overlap but between these two hands there is a great amount of overlap that you see. This overlap is what leads to a situation in which the myosin heads are all are a maximum number of myosin heads can attach to actin bind.

This causes a very high amount of force or the maximum force that is produced. This lengths at which this happens is the so called optimal length for the muscle that is the optimal length. This is the length at which the force is maximum. So, essentially in summary, as the amount of overlap between the myosin heads and the actin binding sites increases. The forces produce increases that make sense.

So, as this amount of overlap reduces are, as the muscle length keeps on increasing, there is very little overlap between myosin heads and actin binding sites. So, force will be small. However, the question is why is the force small in this point? Here, there is still a large amount of overlap between the myosin heads and actin binding sites. Why is the force small? Because it turns out as you can see, actin keeps coming closer and closer as the muscle length reduces.

At this point, the two actin filaments suspended on the two Z disk are almost touching each other. At this point, what happens? Is actin filaments are overlapping with each other that a large number of cross bridges cannot be formed because actin filaments start overlapping with each other. So, only a finite number of myosin heads can attach and these myosin heads will not be in a position to attach.

It is because of this reason, the forces developed is relatively small at very low lengths. This is the reason you are going to have this non monotonic force length relationship. This is the active force that is produced. What is the difference? Active force is that force that is produced by the muscle through a neural command. Whenever a neuron gives the command the force produced in the muscle is the active force that is developed. This is the non-monotonic relationship between force and length for the active muscle.

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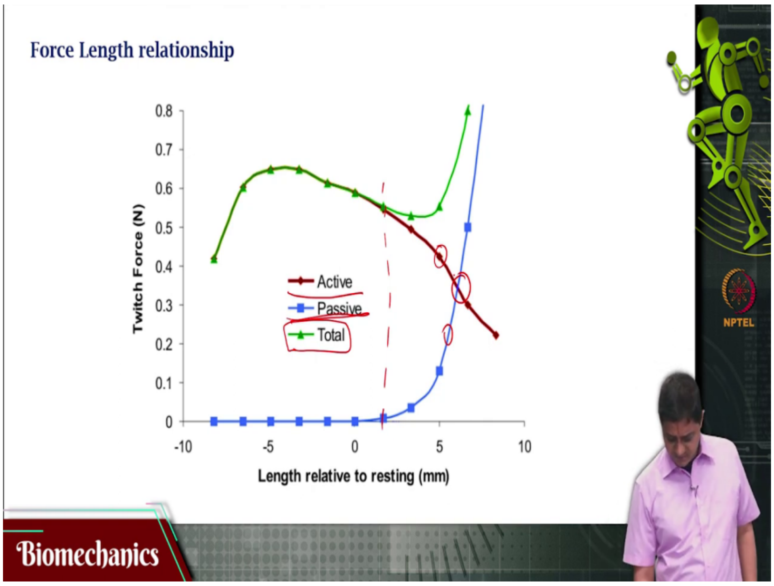

But then what you also have is the passive property of the muscle? Note that the muscle also has contractile materials like this rubber band. You are having this rubber band and I am stretching this rubber band. When I am stretching, I am applying a force. When the length so this rubber band has a resting length. As I keep stretching, the rubber band starts resisting the stretch with the force.

And we know that this force is perhaps proportional to the length. Something similar is what you see here. The blue line is the passive response. So, as the length increases after some point, the muscle starts resisting stretch. This is due to passive properties are contracting properties that the muscle has. The net force that is developed is the sum of the active force and the passive force.

That is the sum of the brown curve and the blue curve. So, at each point, when these two are added, you get the total force that is developed. So, at any point in time, when we measure what you are measuring is the total force. But of course, at relatively low lengths, the passive force does not play a major role. At relatively low length it is active force that is dominating the total force.

Whereas, as the length increases; the passive force starts increasing. In fact, at some point it even crosses at this point. For example, it crosses the active force.

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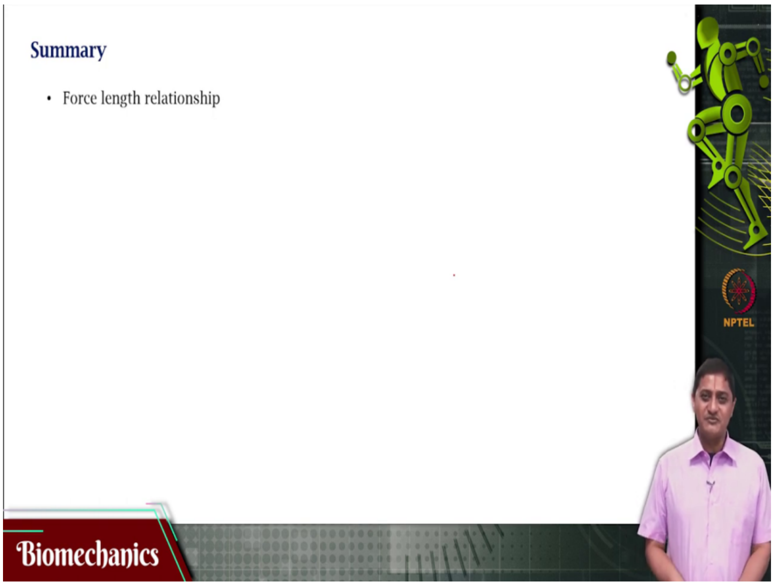

So, with this we come to the end of this video. In this video, we saw the relationship between force and length. Critically important to remember that at low lengths of the sarcomere forces are low because the thin filaments act in filaments start overlapping with each other. Everything else follows logic but this particular point where at low sarcomere lengths, why is the force small? Because the actin filaments are overlapping with each other remember this. Thank you very much for your attention.