# Biomechanics
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## Lecture - 16
## Muscle Fibers – Pennation Angle

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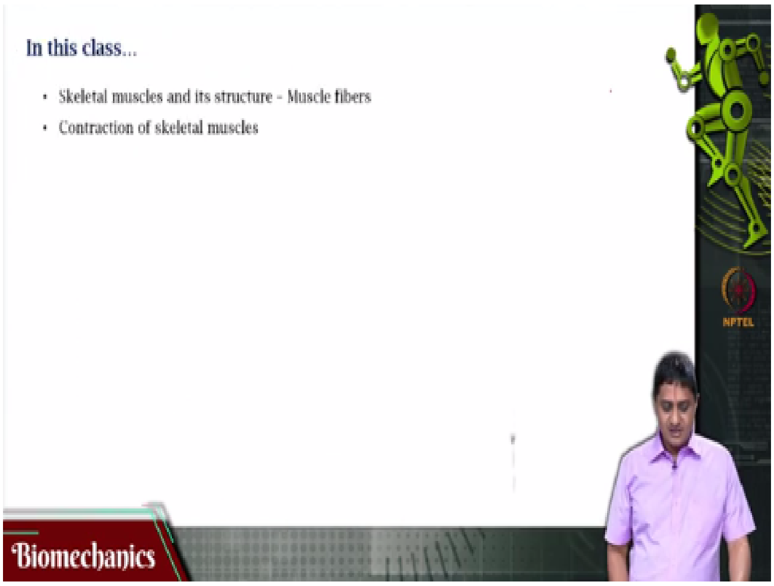


Welcome, to this video on biomechanics. We have been looking at skeletal muscles. So, in this video, we will be looking at structure of skeletal muscles, muscle fibres and how they are arranged. And how based on contraction, we can classify different types of contractions that happen within skeletal muscles.

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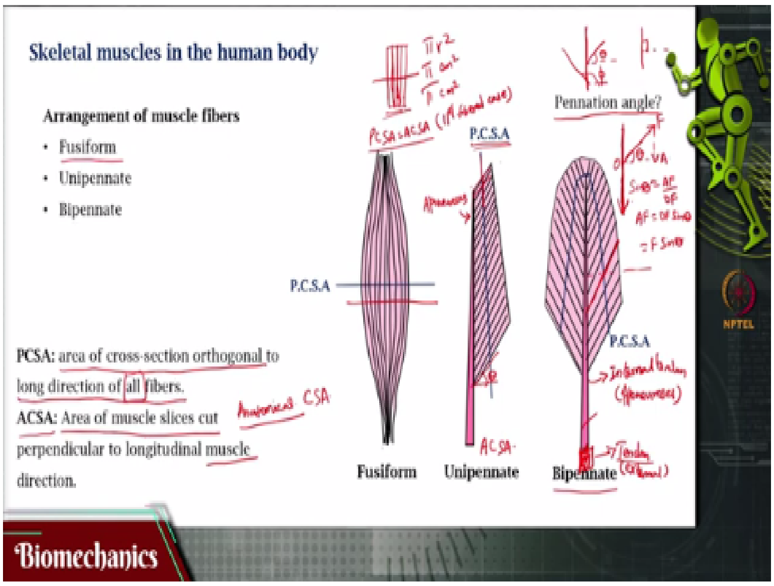

We already started having this conversation about different types of muscles based on the arrangement of fascicles or fibres within the muscle. We said that if, muscle is having the spindle shape they said that if in that case the fibre in the middle will have a length that is smaller than the fibre at the end. And that makes sense. It does not require much thought to agree or understand this.

Why is that? Because this is having a curvature and this is not having a curvature. So, obviously, this one let us call this fibre one, and let us call this fibre two. F 2 when it is elongated will actually be that long, for example, it could be so. It is slightly longer. So, that means, depending on the arrangement of the fibre, depending on where the particular fibre is located its length may vary.

But note that its attachment to the bones; happen through tendons here and here. There are only two tendons. So, all the force is transmitted through these tendons, serially. So, this is the case of the spindle shaped muscle or the fusiform muscle. And this is what is shown typically, when someone tries to explain a muscle. Some lay person is trying to model or trying to draw a muscle, this is what they would draw.

And that makes sense, because the most common muscles that they would come across would be of this type. But we are going to be experts in this. So, we would like to understand more. What are the other types of muscles? We named some of the other types. We said that, that is parallel fibre muscles, we said that there are pennate muscles, and we said there are convergent muscles, and then there are these circular muscles, we said all those things.

But here we only restrict our attention to pennate muscles. Two types of pennate muscles, unipennate muscle and bipennate muscle. But before we do that, let us define some terminology. An important measure of the force that is produced by a muscle, and are an important determinant of the force that is produced by a muscle is its, cross-sectional area. But when you say cross-sectional area, it is not clear what is cross-sectional area.

Which cross-sectional area are you talking about, is the question that comes many times. Why is that? Because there are two types of cross-sectional area that can be there, depending on the type of muscle. Let us look at what this is in a bit more detail. Now let us assume in this case there is this spindle shaped muscle and I am interested in finding the cross-sectional area. In general, when you say a cross-sectional area of a muscle, what you would say, what you would do is that you would take the muscle and make a section.

So, this is the muscle, and I take a section and I look at that section. Let us say that, this is the muscle, and I make a section, and I look at that section and find its area. That is a cross-sectional area. This is the cross-sectional area that is taken for the muscle as a whole but not the fibres or their orientation. Immediately you are asking, can the orientation of the fibres be different within the muscle? Yes, of course, that is what constitutes the pennate muscles.

So, if you are looking at fusiform muscles, or more precisely if you are looking at parallel fibre muscles, the cross-sectional area of the fibres, or cross-sectional area that is found perpendicular to the direction of the fibres and the cross-sectional area that you would find when you section the muscle itself will be the same. Because, fibres are not oriented in a direction that is different from the direction, or the way the muscle itself proceeds.

Suppose I have a parallel fibre muscle, let us say that distance is something, some let us say you know 2 centimetres. This can be modelled as a cylinder with diameter 2 centimetre, then the radius is 1 centimetre. Then, I could find, let us assume that this is a uniform cylinder. This is almost always never true, but we will assume this. If it is a uniform cylinder, then I can find the area of this muscle as pi r square, is it not? r is 1 centimetre so that is actually pi centimetre square.

That is the area of this muscle that we are discussing. Now, I would like to find the area that is perpendicular, through the direction of the muscle fibres itself. So, the muscle fibres are travelling in this direction and I am making a section that is perpendicular to it. And if you look, that will also be pi centimetre squared. Why is that? Because the fibres are all aligned parallel to each other, and parallel to the direction of this muscle itself.

Because of this reason, the muscle fibre related area will not be different from the muscle related area. They will both be equal. Now, let us attach some names to this. Now, if I find the area of the muscle slices cut perpendicular to the direction of the muscle itself, muscle as a whole that is called as anatomical cross-sectional area, ACSA means anatomical cross-sectional area.

Important distinction between anatomy and physiology. Anatomical cross-section area means, purely dependent on structure. Anatomy means, purely we are interested in geometry, morphology, structure. Now, this does not necessarily include about how the muscle would function. We are not worried about function here. Here, I am taking a muscle, and I am sectioning it in a direction that is perpendicular to the whole muscle.

Muscle as a whole, without considering how the fibres are running within the muscle. This section is called as anatomical cross-sectional area, purely dependent on structure. Now if I take a cross section that is such, that it is orthogonal to the long direction of all the fibres. All the fibres, the key word is all, of all the fibres. Then that means, I will have to find how each of the fibre are any sets of fibres are going, and find a cross sectional area, and some.

This would not be different in the case of the parallel fibre muscle as we have seen because, the section that you are making for the muscle as a whole, is the same as the section that you would be making for the set of fibres. It would not be different; it would be the same. So, physiological cross-sectional area would be equal to the anatomical cross-sectional area in parallel fibre muscle. This is a special case. Please remember this, this is a special case.

This is not general; this is not the most general case. In the special case of the parallel fibre muscle, you will have the physiological cross-sectional area, which is the area that is found. Orthogonal to the direction of all the muscle fibres, and the area that is found by slicing the whole, muscle as a whole will be equal. This is the special case of the parallel fibre muscle. But if you take the case of the pennate muscles, you will have this situation.

Now this is the muscle. That is the muscle I am asked to find the area. I will make a slice like this here. Actually of course, depending on where you are slicing the area will change. I mean for example, this area I have drawn it as if it is a perfect cylinder, it is not, it is more like a cone. Many muscles are more like a cone, because they are convergent. We will assume that this is a cylinder.

Then what I would find is that, this is the diameter of the cylinder, and I would find area using this. This area that is found, based on the diameter of the muscle as a whole is the ACSA, is it not? That is the anatomical cross section area but because, the fibres themselves are not parallel to the muscle itself. In this case, I am having an internal tendon. This is the internal tendon or the aponeurosis.

The support neurosis, is where the individual fibres are attaching. And if I would like to find how the muscle fibre force is acting, we are talking about a functional aspect. Functions means physiology, structure means anatomy. In biomechanics, we are interested in studying structure and function relationships. We have said this previously, just reminding you one more time.

We are interested in studying structure function relationships at multiple scales, this is biomechanics for you. So, I am interested in finding, an area orthogonal to the long direction of all the fibres like this. This is the fibre, and I am dropping a perpendicular to all these fibres. Now I will find an area. This area is called as the physiological cross-sectional area. And then I have a bipennate muscle like this.

I have 2 PCSAs, I have one physiological cross section area for this orientation, and I have one more physiological cross section area for that orientation. But the anatomical cross section area would be that, would be the area that I would find by slicing using that horizontal line. This is the area that I would find. Is it not? This is the difference between anatomical and physiological cross-section area.

Now importantly in the case of the pennate muscles, a question comes which one would be greater? With some thinking variable to immediately understand that the physiological cross-sectional area, especially in bipennate and multi-pennate muscles are likely to be greater than the anatomical cross-section area. Why is that? Because I can pack large amount of fibres that are oriented at different angles in a multi-pennate muscle.

But they may all form a single muscle. So, if I am making a section of the muscle itself, the area might appear smaller. But because for each orientation I will have to find separate cross section area, all these areas will keep adding up. So, the physiological or functional cross-sectional area will be much greater than the anatomical or the structural cross-section area. Now, how much greater? That is the question.

Sometimes in multipennate muscles it turns out that the physiological cross-sectional area, can be as high as eight times the anatomical cross section area. That is a very large number, take a few seconds and meditate on this. The area of the fibres depending on various orientations can be as high as eight times more than the structure based or the anatomical cross section area. So, now we get a sense of why do we have pennation itself.

Because, we are interested in packing a large number of fibres in a given volume. If all our muscles were required to be parallel then we will be huge. And because we do not have the luxury of space, we have pennation. Because there is a need to pack a large number of fibres in a given volume, we have pennation. But with this arrangement, there is this inefficiency that, I am not able to convert all the muscle fibre force into the tendon force.

Because I am always operating at an angle, we have seen this because in this case this is an angle. Let us assume that there are exactly two orientations in which these fibres are attaching to this bipennate muscle. One is this orientation, and the other is this orientation. And within each of these orientations all the other fibres are parallel. This is an idealization; this is not always true.

I am idealizing that there are only two orientations in this case, and I can find the theta, that is the horizontal I can find that theta. Actually, there can be two thetas obviously. So, I can now I can draw this. Let me draw one fibre, one is at that leg and the other one is like that for example. Now to this horizontal this is theta and to this horizontal that is some phi. These are the two angles, there is theta and there is phi at which these fibres are attaching.

And let us assume all the other fibres are parallel to these two given fibres that we have taken. Now, let us study what is happening. I am interested in the force felt by the tendon, I am not interested in what is the force that each of the fibre is producing. Actually, we are interested in that also, but at the end what makes a difference is what is felt here. This is where the external tendon is attaching or the tendon, tendon is attaching.

Tendon means external tender. But then what is these attachments? This is the internal tendon or the aponeurosis. Our interest is the force that is going to be felt at the bone, the force that is going to be felt at the bone is going to be a function of the force that is felt at the tendon. Is it not? Tendon means external tendon. So, what happens here of course contributes to what happens here.

What happens at the fibre of course, contributes to what happens at the external tendon. But it is not a straightforward analysis. Now let us take only one of these angles. I am going to try and analyse this theta, only one. I will assume that there is only one or we are analysing this unipennate case for example and that is theta for example. Now, force F is produced by the muscle fibre, and that fibre is along its long axis, along the axis of the fibre itself, is it not?

Because each fibre is producing force along its own axis. My interest is in finding the amount the contribution of this force to it this direction. Why is that? Because this is the internal tendon which is then going to attach to the external tendon, which is then going to attach to the bone. So, I am interested in this component of the force. I am interested in the vertical component of the force. We know from our early analysis on vectors.

We saw suppose, I am now resolving this force. In this right triangle, I am going to call this as O and I am going to call this as A. In this right triangle sin theta is opposite side by hypotenuse. Is it not? That is AF by OF. The vertical component then is OF sin theta, but OF is the force F. That is F sin theta. What is the maximum value that sin theta can take, that is one. When would that be? When theta is 90 degrees.

That is if this is the internal tendon, and if this is the axis, then theta is 90 degrees. Or in other words, when it is a parallel fibroid muscle, when the internal tendon is parallel to the fibre you are going to have full force transmission. When sin theta is one. But almost always in all other values of theta, which is what you will see in the pennation case, for all other values of theta you will have a case where sin theta is less than 1.

That means that, there is going to be an inefficiency and sometimes theta can be very low also. That means, that a lot of the force that is produced by the fibre is not along the direction of the internal tendon, or the external tendon, or the bone. Lot of it is going to be wasted, not exactly wasted but it is not exactly getting transmitted. So, this angle, plays a crucial role in force transmission.

So, this angle is called as a pennation angle, and a given muscle can have many pennation angles, depending on how many different pennations that it has. A bipennate muscle will have two pennation angles, a multi-pennate muscle can have many pennation angles depending on how many different orientations that these muscles are these fibres are arranged.

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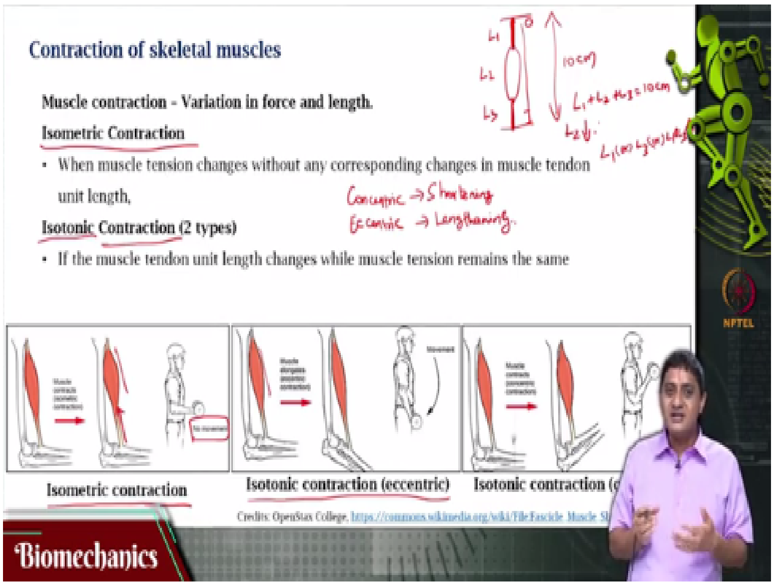


Now, we move on to the next topic in this video, which is types of muscle contraction. Now we saw different types of muscles, based on the arrangement of fibres, fascicles. But the contraction itself can also happen in different types. So, importantly when a muscle contracts, what it means? Contraction means its length reduces. So, this is a variation in length and because there is a force length relationship which is definitive.

A definitive force length relationship exists it turns out that. And for changes in length, you have some specific changes in force. When a muscle contracts without causing any change in the configuration of the bones that are involved, such a contraction is called as an isometric contraction. Iso means equal, metric means in length. Isometric contraction means a shortening contraction means, a shortening or shortening that happens without change in length.

This is a very weird statement. What do you mean by this? Because when I say contraction, it means shortening. And then I am saying the length does not change. How can length change without shortening? Because these two things refer to two different aspects. Contraction, refers to contraction of the muscle. Muscle means the muscle belly itself. This contracts, and then there is a tendon here, and there is a tendon here.

Now suppose there is a bone that is there, there are two bones to which this is attached. Let us call this origin, the insertion. Let us assume that it is having some length say 10 centimetres. If the muscle contracts, but the distance between the bones themselves do not change. What could change? What are all the various links that are involved? This is the tendon length L 1, this is the muscle length L 2, this is the muscle length the other tendon length L 3.

What we know from this is that, L 1 + L 2 + L 3 is 10 centimetres, and this does not change. It remains 10 centimetres. And what we do know, is that L 2 reduces, muscle contracts. That means that L 2 reduces. Since L 2 reduces and since L 1 + L 2 + L 3 remains constant at 10 centimetre. What you immediately realize either L 1 or L 3 or perhaps and more commonly both their length increases because tendon can change in length.

Tendons can deform as the muscle is contracting without changing a configuration at the bone level, at the skeleton level force can still be produced by the muscle. This is a unique case of the isometric contraction. Iso means equal, metric means length, contraction means shortening. This is the shortening that does not cause a change in length. Specifically, this is the shortening of the muscle that does not cause a change in length of the muscle, plus tendon unit, the whole unit.

Muscle plus the two tendons, the whole unit length does not change, but the muscle length alone changes. This is a unique case, the isometric contraction. When do you use this? We do this all the time when I am holding an object, I can produce a force but the configuration will not change. I can that does not mean that I am not producing a force. I can produce a force without changing configuration. We do this all the time.

The other case, is the case when you have an equal force being produced isotonic contraction. Iso means equal, tone is this misnomer that is referred here as the amount of tension, the amount of force that is produced by the muscle. Isotonic contraction means the amount of tension that is found in the muscle. So, this isotonic means, this amount of force that is found in the muscle does not change.

Only the force does not change, the length can and will change. So, in this case, the muscle contracts you see what is happening in the isometric contraction case. The muscle contracts, here the muscle length has reduced and the tendon has pulled up. No movement results no change in the actual configuration, so kinematics when you are measuring geometry of motion, I will find no change.

That does not mean that there is no change at the level of the muscle. At the level of the bones there is no change. This is the case of the isometric contraction. In the case of the isotonic contraction, the tension that you feel or the force that you feel in the muscle remains a constant, but the configuration keeps changing. That is when you perform slow steady movements for example. That is called isotonic contraction.

And this comes in two flavours; concentric contraction and eccentric contraction. Or concentric means short turning contraction, eccentric means lengthening contraction again these names are quite interesting. Because what do you mean by shortening contraction means shortening is it not you would say when you say contraction in general in English, when you say contraction, you are referring to a shortening.

What do you mean a shortening contraction? This means that the movement of the muscle or the change in length of the muscle is along the expected lines. So, the muscle is moving or the bones are moving in a particular direction as per in line with the expectation of the contraction of the muscle based on the contraction of the muscle. So, the muscle is contracting bones are moving as expected.

That is called concentric contraction or shortening contraction. But the other case is when the muscle is contracting but the bones are moving in the opposite direction. And we are wondering can this even happen because you have a case in which the muscle is, you know contracting, but the configuration is elongating when can this even happen. This happens when the external load is much greater than what can be withstood by the muscle itself.

This is the case. So, this is why when we refer to weird people, we call is an eccentric. She is an eccentric; we say this now eccentric means something that is outside the centre. Eccentric and something that is outside the centre, something that is not along the expected lines. We say that person is an eccentric, or an eccentric view. An opinion is an eccentric opinion. Something that is weird, something that is unexpected.

The muscle is contracting and the bones are moving in opposite direction means the muscle is not able to overcome the load that is produced by the external load. Or the muscle is not able to overcome the external load that is imposed on it. Because of this reason even though the muscle itself is contracting, it is not able to change the configuration along the expected direction because of this reason, this is called eccentric contraction.

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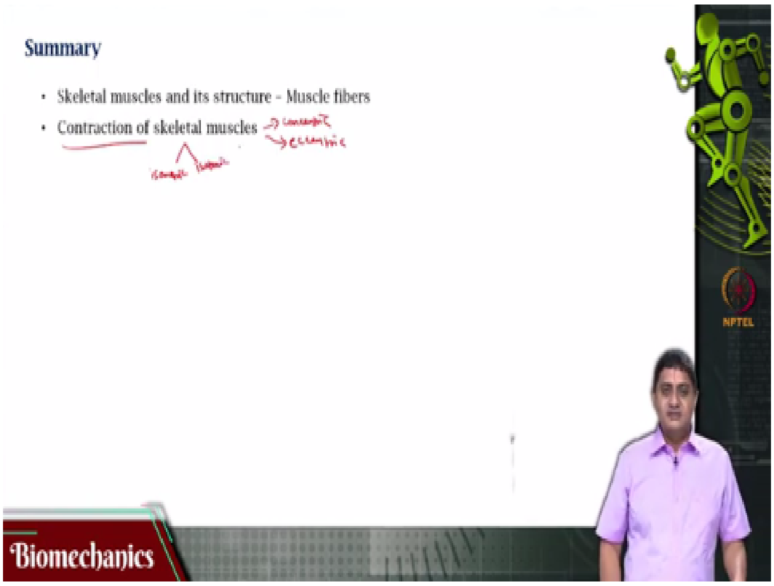


With this we come to the end of this video. So, in this video, we saw the types of muscle fibres, and the arrangement of fibres, pennation; unipennate, bipennate, multi-pennate. Pennation angle, and how pennation causes different effects on the physiological cross-sectional area and anatomically cross section area. And how force transmission efficiency varies as a function of pennation.

We saw different types of contractions; concentric, eccentric and we also saw isometric and isotonic contractions. Thank you very much for your attention.