Biomechanics of Joints and Orthopaedic Implants
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Lecture 20
Joints Kinematics and Kinetics

Good morning everybody. Welcome to the second lecture of module 4, this lecture is on Joint Kinematics and Kinetics.

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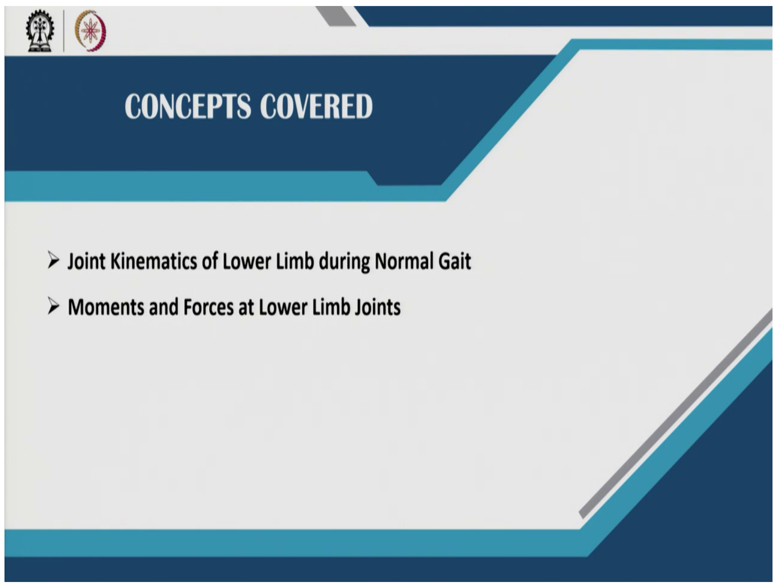

The topics covered in this lecture are lower limb joint kinematics during normal gait and moments and forces at the lower limb joints.

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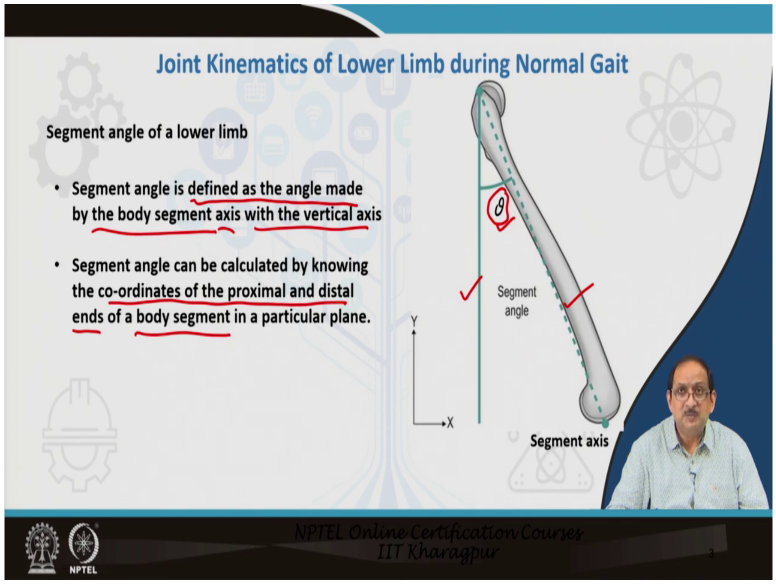

Now, in the topic: joint kinematics of lower limbs during normal gait, I would like to define the segment angle of a lower limb. The segment angle is defined as the angle made by the body segment axis. So, the angle made by the body segment axis with the vertical axis.

The segment angle can be calculated by knowing the coordinates of the proximal and distal ends of the body segment in a particular plane. The required coordinate data is obtained from anatomical markers from the gait analysis at either end of a limb segment. Once the segment orientation is calculated from the marker position, joint angles can be calculated in a spatial reference system.

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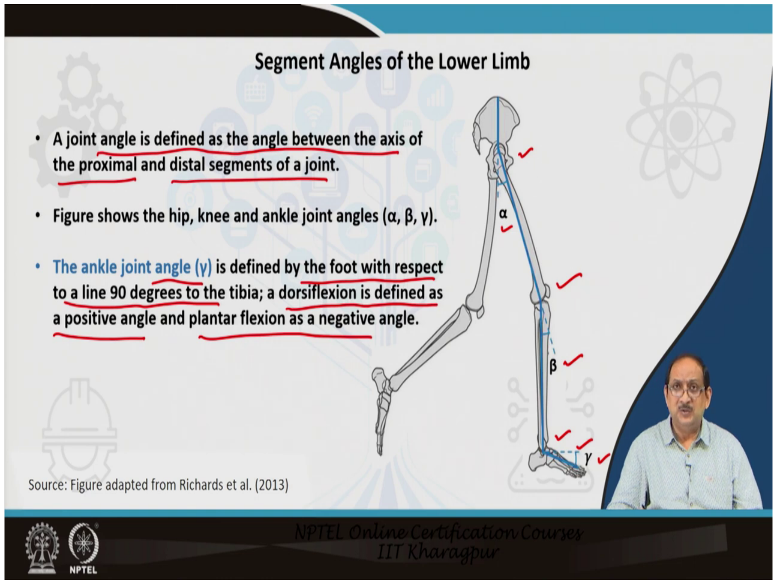

Now, let us now define what joint angle is? The joint angle is the angle between the axis of the proximal and distal segments of a joint. So, the figure shows hip knee and ankle joint angles. So, the hip joint angle is α; the knee joint angle is β; γ is the ankle joint angle. The ankle joint angle γ is defined by the foot with respect to a line-oriented 90 degrees to the tibia.

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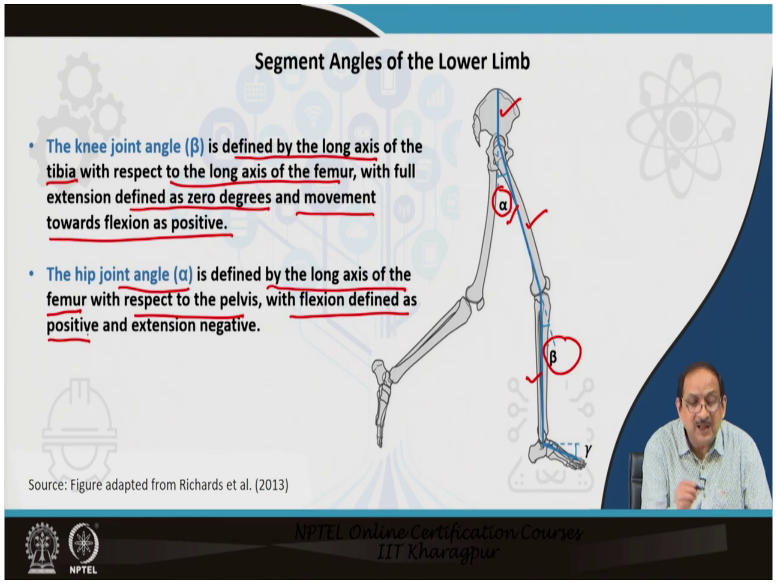

The knee joint angle β is defined by the long axis of the tibia. So, we have the long axis of the tibia here with respect to the long axis of the femur. So, there is a long axis of the femur. So, β is the angle subtended between these 2 axes with full extension defined as 0 degrees.

The hip joint angle α is defined by the long axis of the femur, as indicated earlier concerning the pelvis. So, this is the angle subtended that is the angle α, the hip joint angle with flexion defined as positive and extension as negative.

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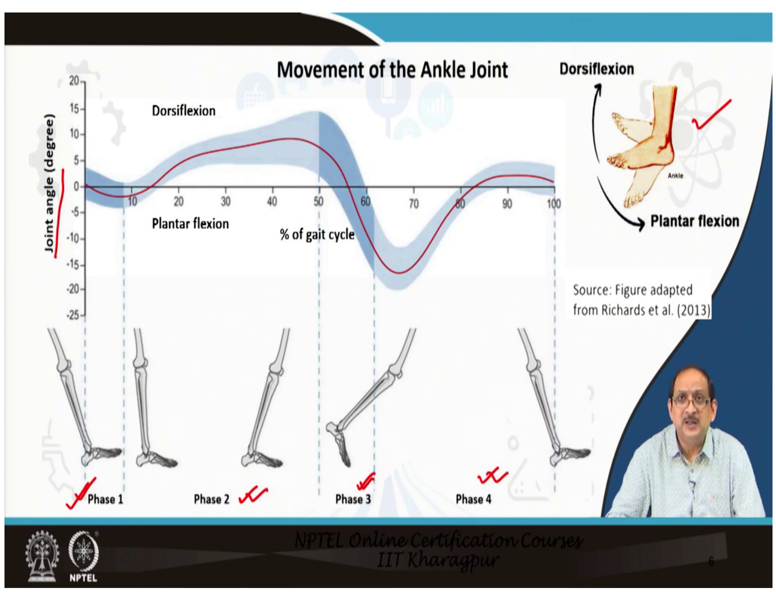

Let us now discuss about the movement of the ankle joint. The figure on the right shows the movements: dorsiflexion and plantar flexion. The variation of the ankle joint angle as shown along the y axis of this figure throughout the gait is presented in this figure. It contains various phases the range of motion of the ankle joint during walking varies between minus 20 degrees and plus 10 degrees.

If you consider phase 1, then phase 1 is the initial contact phase when the foot is pivoting about the heel. During phase 2, foot is flat, the foot becomes stationary and the tibia becomes the moving segment. In phase 3 or during phase 3, it is basically the beginning of the double support phase. The phase 4 is actually the swing phase where the ankle rapidly dorsiflexes. So, during the swing phase, the foot is not in contact with the ground.

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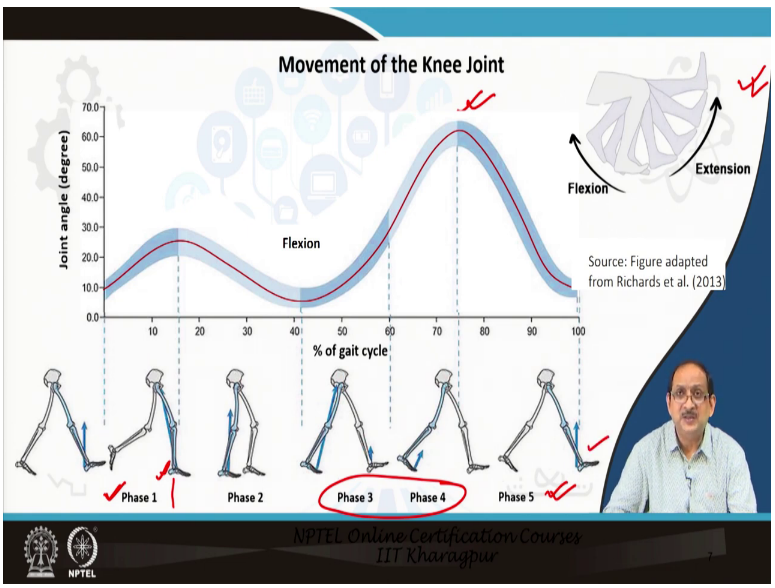

Let us discuss about the movement of the knee joint during the gait cycle and the variation of the joint angle during the walking cycle. On the right of this figure, you can see that the major movement of the knee joint flexion and extension is indicated. Now, how does the joint angle vary during a walking cycle primarily due to the movements flexion and extension is explained here. The flexion and extension of the knee joint is cyclic and varies between 0 to 70 degrees.

These variations may be related to differences in walking speed and subject specific parameters after the initial contact in phase 1, after the initial contact the joint flexes to about 20 degrees.

Knee then begins its second flexion phase, which coincides with the heel lift off. During the initial to mid-swing phase, the knee continues to flex to a maximum of 65 degrees as indicated in the figure, 65 degrees to 70 degrees in phases 3 and 4. During the late swing phase, the knee undergoes a rapid extension for the second heel strike at the end of phase 5.

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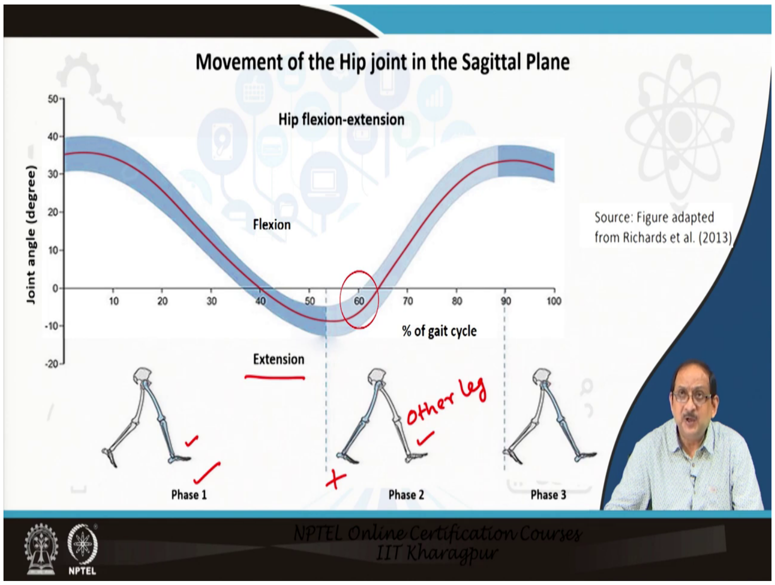

Now, let us discuss the movement of the hip joint which is presented in the sagittal plane. Now, the motion of the hip joint angle in the sagittal plane is explained here in the figure. So, after initial contact in phase 1, the hip extends as the body moves over the limb. So you can see that the hip extends or as the body moves over the limb, the maximum hip extension occurs just after the other leg.

The maximum hip extension occurs just after the other leg makes the heel strike and the weight actually is then transferred to the forward limb and the trailing limb, the trailing limb begins to flex at the hip.

This is the pre-swing phase. The toe actually goes off the ground or leaves the ground at 60 percent of the gait cycle. Please note that similar to the sagittal plane movements of the hip, movement of the pelvis can also be observed in the coronal and transverse planes. However, the variation in angle is small, 5 to 8 degrees.

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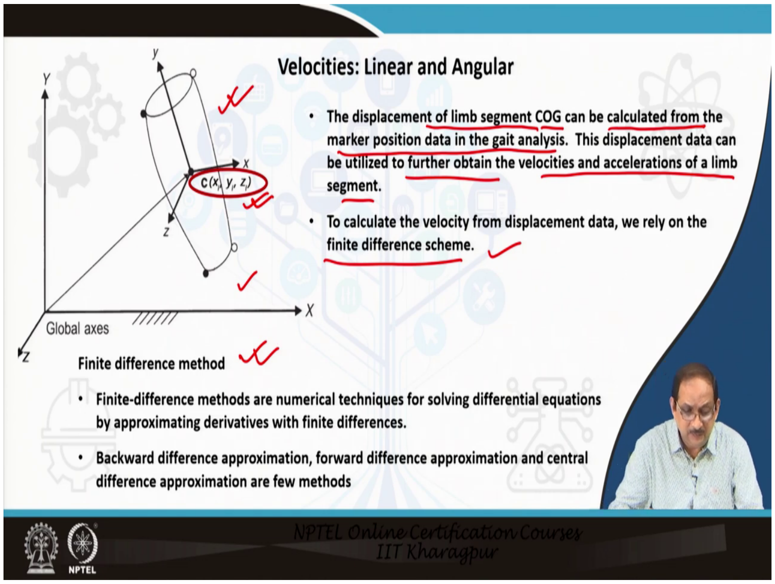

Let us now discuss the velocities the linear and angular velocities. The displacement of the limb segment COG the center of gravity of the limb segment. So, the displacement of the limb segment COG can be actually calculated from the marker position data in the gait analysis obtained from the gait analysis. So, this displacement data can be further utilized to obtain the velocities and accelerations of a limb segment.

So, from marker position data obtained from the gait analysis, we can actually calculate the displacements and the displacement data can be further used to find out velocities and acceleration of a limb segment. To calculate the velocity from displacement, we rely on a finite difference scheme. So, the figure presented here on the left is a figure containing a limb segment where the coordinate x_i y_i z_i indicates the COG with respect to the global coordinate system.

The markers and the reference points of the limb segment are indicated here in the figure as well. Now, let us discuss the finite difference method briefly. The finite difference methods are numerical techniques for solving differential equations by approximating derivatives with a finite-difference by approximating derivatives with finite differences.

The backward difference approximation, forward difference approximation and central difference approximations are the few methods of finite difference method.

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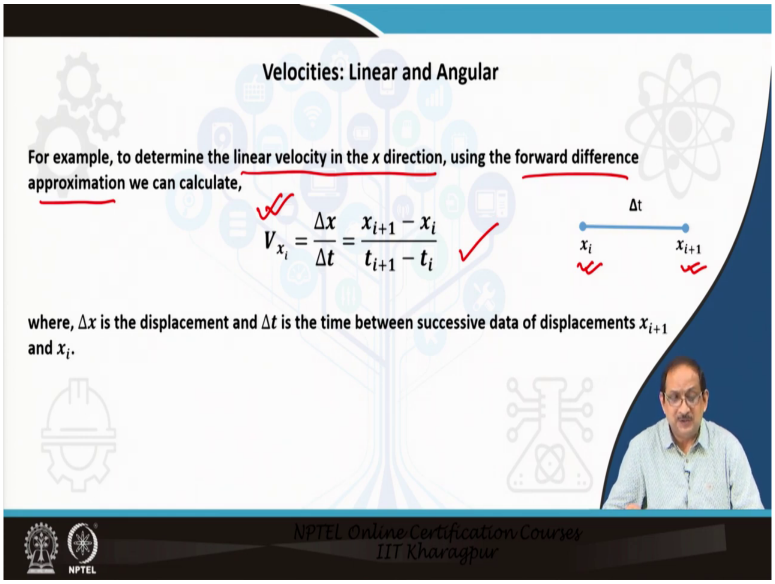

Now, we continue with the method to calculate linear and angular velocities. So, we determine the linear velocity in the x-direction using forward difference approximation and the linear velocity along the x-direction is given by the expression as indicated in the slide. So, we have a displacement data x_i, we have another displacement data at x_{i+1}, and the time duration between these two successive displacements is Δt. So, the Δx, the difference between the successive displacements divided by the time duration Δt will give you the linear velocity along the x-direction.

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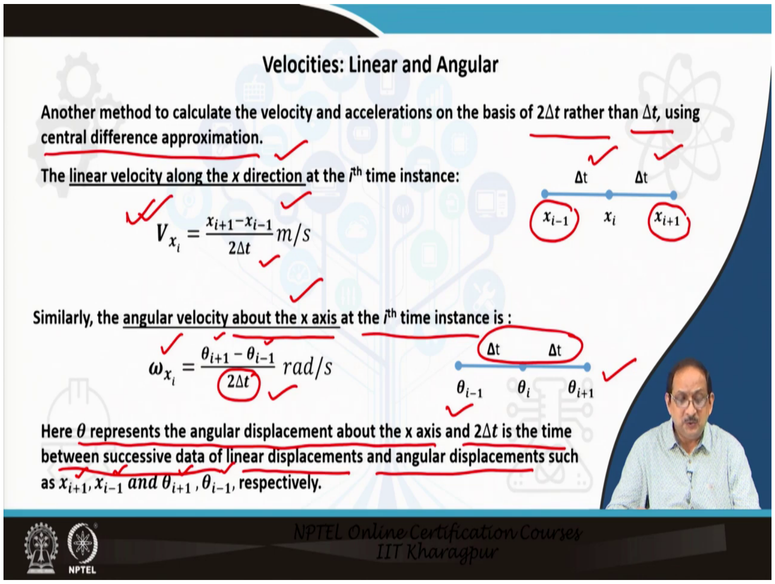

Another method to calculate the velocity and acceleration is based on 2Δt rather than Δt, using central difference approximation.

$$V_{xi} = (x_{i+1} - x_{i-1}) / (2\Delta t)$$

So, the total time difference is 2Δt. So, the difference in displacements divided by the total time difference 2Δt will give you the linear velocity along the x-direction, using the central difference approximation.

Similarly, the angular velocity about the x-axis, please note about the x-axis at the i^{th} time instance is given by ω_{xi}.

$$\omega_{xi} = (\theta_{i+1} - \theta_{i-1}) / (2\Delta t)$$

Here θ represents the angular displacement about the x-axis and 2Δt is the time difference between successive data of linear displacements and angular displacement. It may be remarked here that the central difference method is considered to be more accurate as compared to the forward difference method.

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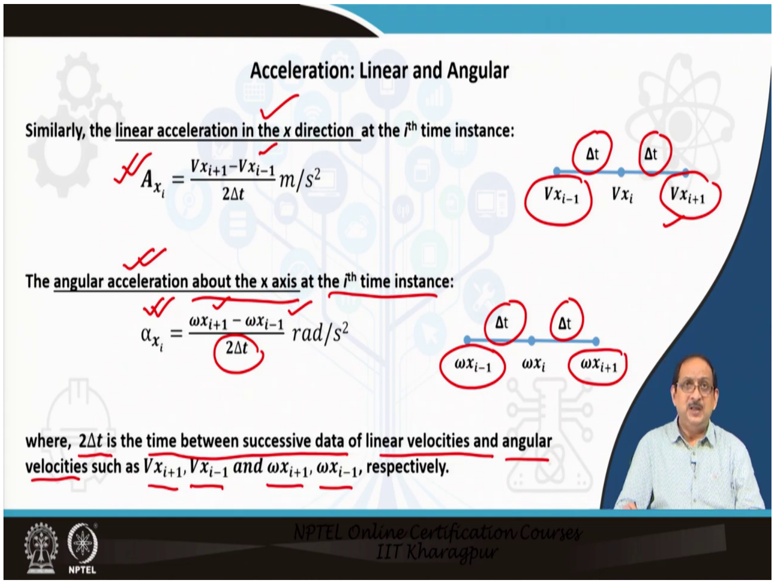

Now, let us discuss the linear and angular acceleration similar to the calculation of velocity. We can calculate the linear acceleration along the x-direction at the i^{th} time instant given by the expression as indicated in the slide.

$$A_{xi} = (v_{i+1} - v_{i-1}) / (2\Delta t)$$

The angular acceleration about the x-axis can be written as:

$$\alpha_{xi} = (\omega_{i+1} - \omega_{i-1}) / (2\Delta t)$$

So, here 2 Δt is the time difference between successive data of linear velocities and angular velocities.

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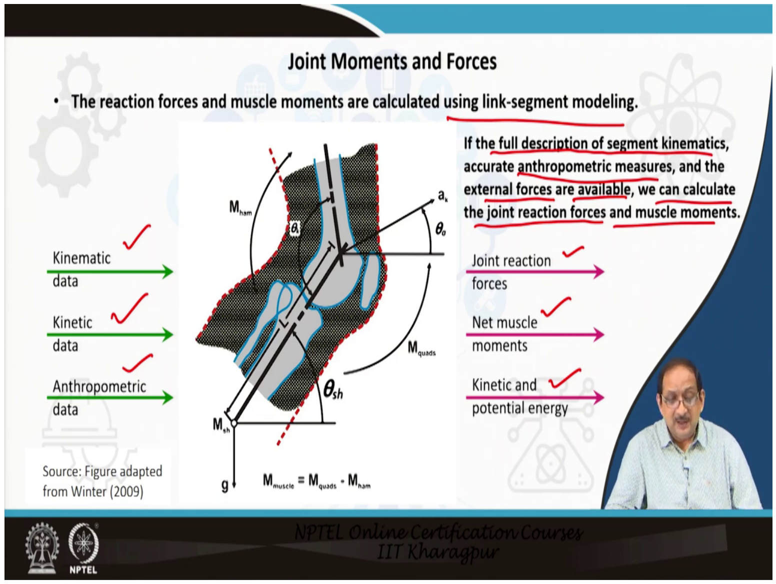

In this slide, we are presenting an overview of how to calculate joint reaction forces and moments using the link segment model. The figure shown in the slide is of a knee joint, side view of knee joint along Medio lateral direction.

If the full description of this segment kinematics, accurate anthropometric measurement or data and external forces are available, we can calculate the joint reaction forces and moments using the link segment modeling approach. So, what can we obtain? We can obtain joint reaction forces, net combined muscle moments and kinetic and potential energy.

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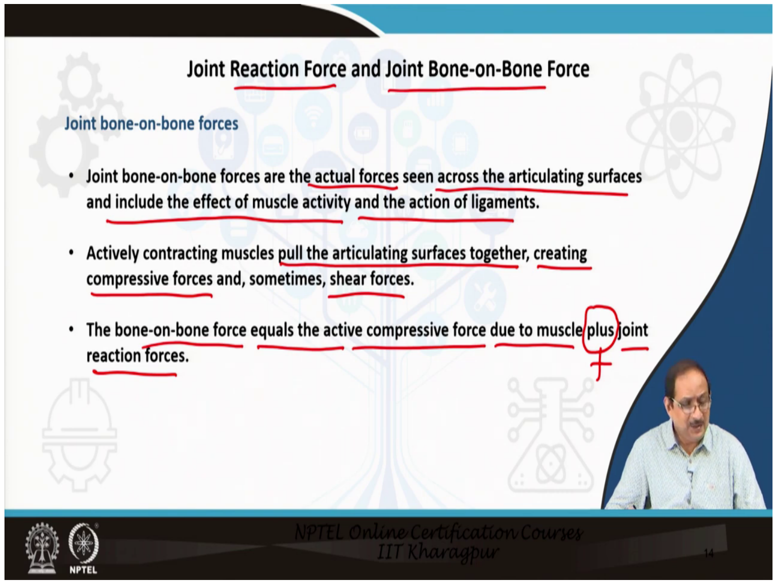

Let us not now highlight on the difference between joint reaction force and joint bone on bone force. Now, joint bone on bone force are the actual forces seen across the articulating surface, across the articulating surfaces. And include the effect of muscle activity and the action of the ligaments. Now, actively contracting muscles pull the articulating surfaces together creating a compressive force and sometimes the shear force.

The bone on bone force actually equals to the active compressive force due to the muscle and ligament + the joint reaction force. However, the difference between the joint bone to bone force and the joint reaction force is minor. It is essential to understand the difference as explained in the following slides.

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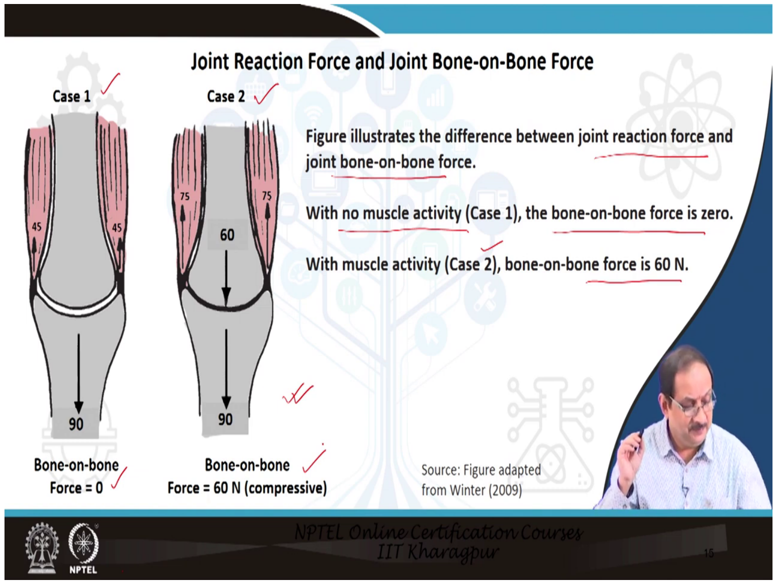

The difference between joint reaction force and joint bone on bone force is illustrated in this slide. Now, in case 1 there is no muscle activity. So, the bone-on-bone force is equal to 0. As indicated in the figure, the bone on bone force is 60 Newton compressive in the second case. Although the difference between the joint reaction force and bone on bone force is minor, the following slide will explain the reasons behind the difference.

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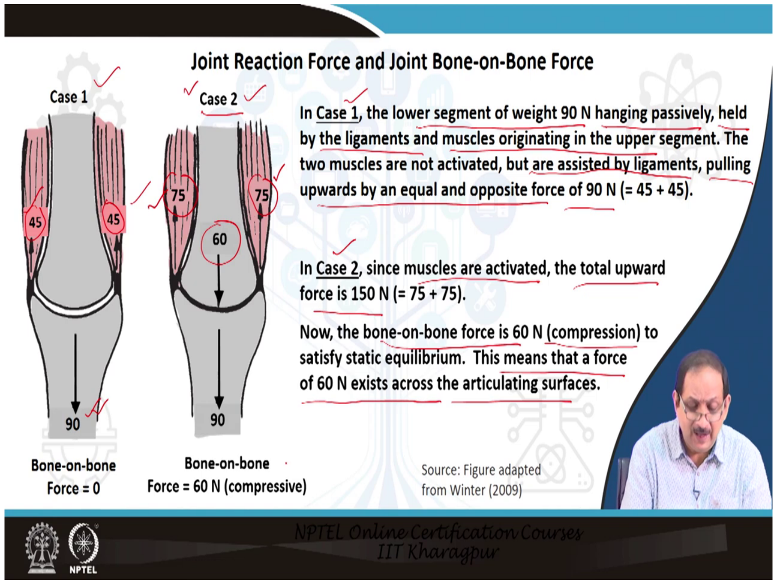

Now, let us consider case 1. In this case, the lower segment weight of 90 Newton is hanging passively, just hanging passively. And it is held by the ligaments and muscles originating in the upper segment, as indicated in the figure. The two muscles are not activated but assisted but are assisted by ligaments pulling upwards by an equal and opposite force of 45 Newtons on both sides. So, the equal and opposite force of total 90 Newton.

In the second case, since the muscles are activated, the total upward force is 150 Newtons. So, the upward force has increased in case 2. Now, the bone-on-bone force is actually 60 Newton compression to satisfy the equilibrium condition. This means that a force of 60 Newton exists across the articulating surface when the muscles are activated as indicated in the figure.

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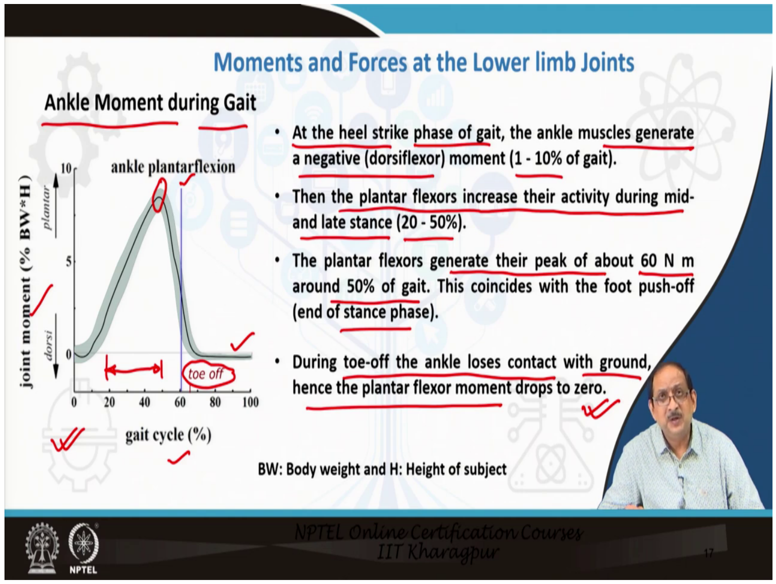

Let us now discuss the joint moments and forces at the lower limb. Let us first consider the ankle moment during a gait cycle. So, in the figure presented on the left the variation of the joint moment during a gait cycle is presented. So, we start with heel strike. So, at the heel strike, that is the initiation of the gait cycle, the stance phase of the gait cycle. The ankle muscles generate a negative dorsiflexor moment.

So, this happens within 1 to 10% of the gait cycle. After that, the plantar flexors increase their activity during the mid and late stance that is from 20% to 50%. During this phase, it is basically from the mid to late stance phase as indicated in the figure. The plantar flexors generate their peak of about 60 Nm around 50% of the gait cycle as indicated in the figure. And this coincides with the foot push-off phase. So, it may be noted that the stance phase terminates at 60% of the gait cycle.

During toe-off, the ankle loses contact with the ground. Hence the plantar flexors moment drops to 0 as indicated in the figure. Because there is no contact between the ankle and the ground from toe off instant, the foot is swinging in air and not in contact with the ground. So, the plantar flexor moment drops to 0.

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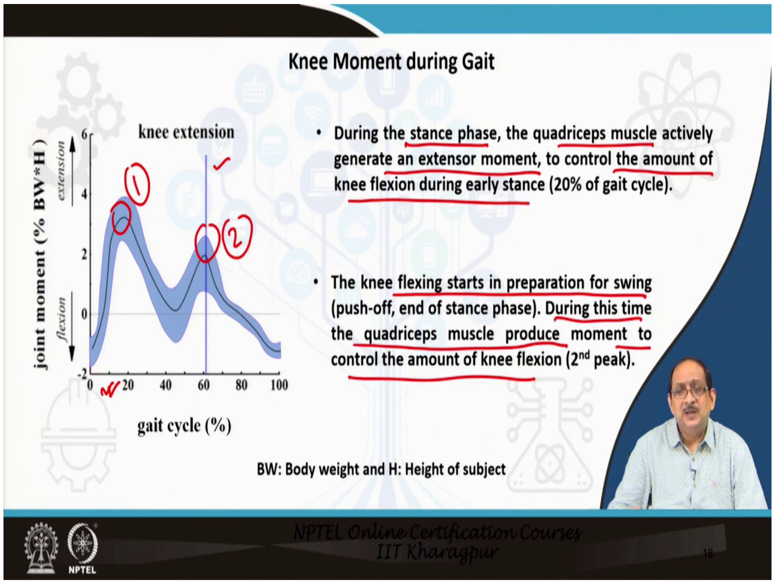

Let us now consider the knee moment during the gait cycle. During the stance phase, the quadriceps muscle actively generates an extensor moment to control the knee flexion during the early stance phase, which is 20% of the gait cycle. So, this is the activity of the quadriceps muscle that generates the extensor moment. The knee flexing starts in preparation for the swing phase.

This starts after the stance phase, as indicated in the figure around 60% of the stance and 60% of the gait cycle. During this time, the quadriceps muscles produce a moment to control the amount of knee flexion so, that is where the second peak of the knee joint moment occurs. So, the first peak occurs at around 15 to 20% of the gait cycle. And the second peak is happening about 55 to 60% of the gait cycle.

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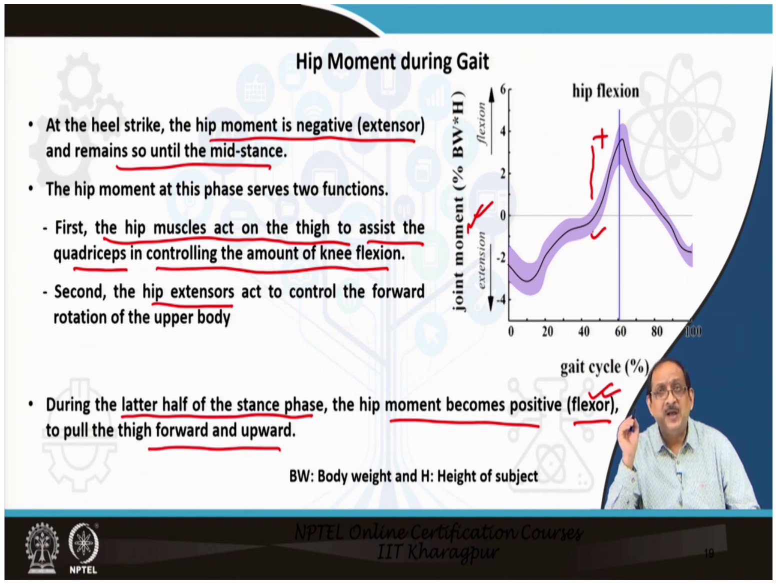

Let us now discuss the hip moment during gait. Here in the figure, the hip joint moment is plotted against the gait cycle. At the heel strike, the hip moment is negative because of the extensor activity and remain so until the mid-stance as indicated in the figure. The hip moment at this phase serves two functions. First, the hip muscles act on the thigh to assist the quadriceps in controlling knee flexion.

And second, the hip extensors act to control the forward rotation of the body. During the later half of the stance phase, as you can see here. The hip moment becomes positive due to the activity of the flexors to pull the thigh forward and upward. So, the hip moment becomes positive due to flexors, muscles that pull the thigh forward and upward.

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Now finally, we come to the variation of hip joint forces at the lower limb. So, in this figure, we have plotted the hip joint reaction force, the knee joint reaction force and the ankle joint reaction force in one slide. And the reaction force is expressed in terms of body weight, and the x-axis is the percentage of the gait cycle. Now both, the hip and knee joint exhibit two peaks. During the normal gait cycle, the first peak occurs approximately around 15% of the gait cycle.

And the second peak occurs around 45 to 50% of the gait cycle for the hip joint and the knee joint. The second peak of the joint reaction force is experienced during heel-off instance, around 45 to 50% of the walking cycle. At this instant, the ankle joint also experiences its maximum joint forces.

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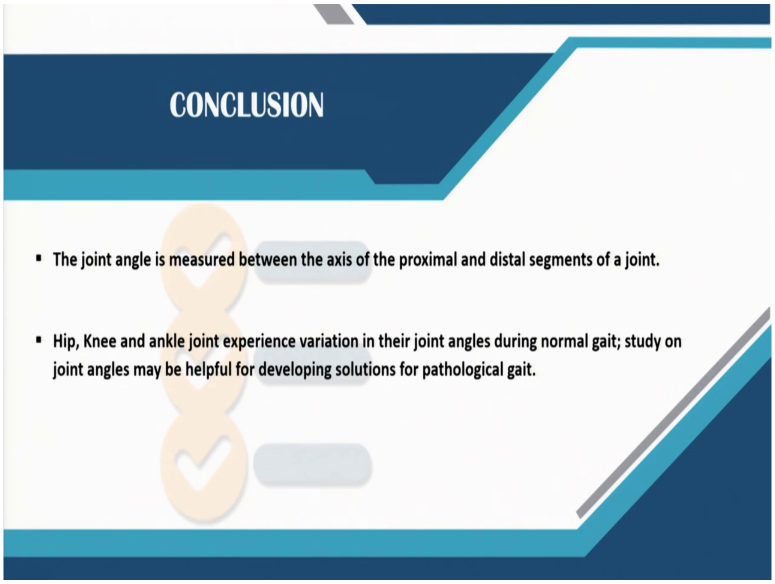

Let us come to the conclusion of this study. The joint angle is measured between the axis of the proximal and distal segments of a joint. Hip, knee, ankle joints experience variation in their joint angles during normal gait. So, study on the joint angles may be helpful in developing solutions for pathological gait.

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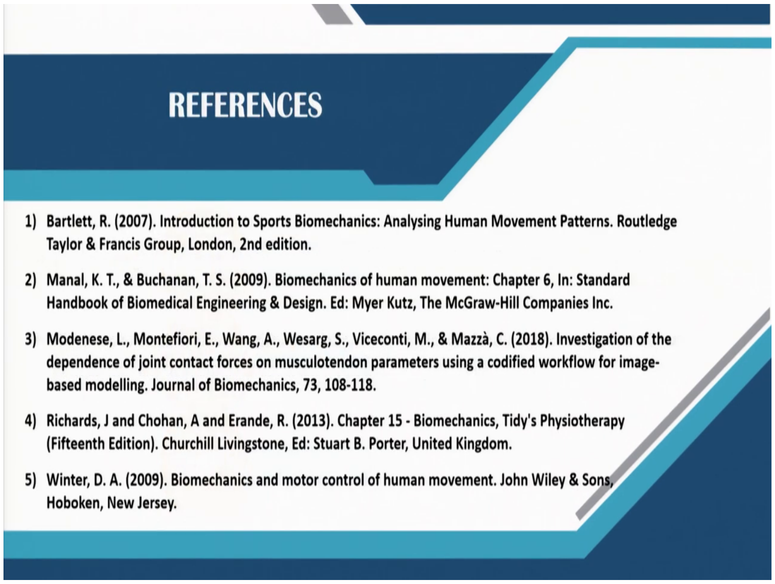

The list of references are mentioned in this slide based on which the lecture has been prepared. And thank you for listening.