Biomechanics of Joints and Orthopaedic Implants
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Lecture 13
Biomechanics of the Spine

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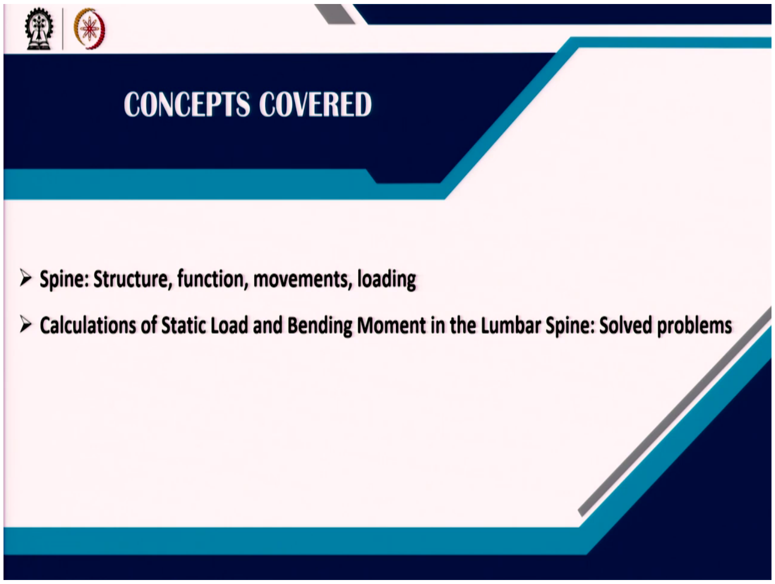

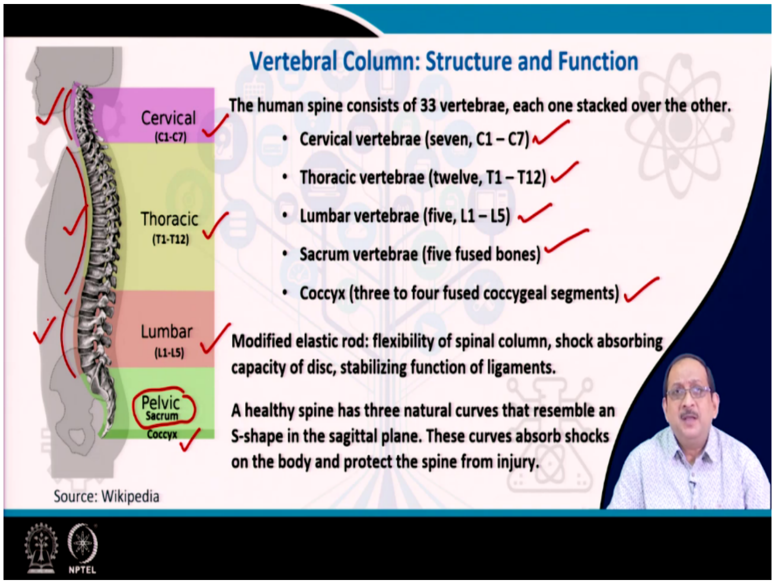

Good morning everybody. Welcome to the lecture on the biomechanics of the spine. In this lecture, we will discuss the structure, function, movements, and loading of the spine, emphasising the lumbar spine, followed by calculations of static loads and bending moments in the lumbar spine using some solved problems.

The vertebral column, also known as the backbone or the spine, is a part of the actual skeleton. The human spine consists of 33 vertebrae, each vertebra stacked over the other. It consists of the cervical, thoracic, and lumbar vertebrae. There are 12 vertebrae in the thoracic segment and 5 vertebrae L1 to L5 in the lumbar segment.

The sacrum consists of 5 fused bones in the pelvic region, followed by the coccyx, where there are 3 to 4 fused coccygeal segments. The vertebral, the spine, sorry, the spine can be considered as a modified elastic rod because of the flexibility of the spinal column, the shock-absorbing capacity of the disc and the stabilising function of the ligaments. A healthy spine has three natural curves that resemble an S shape in the sagittal plane. These curves absorb shocks on the body and protect the spine from injury.

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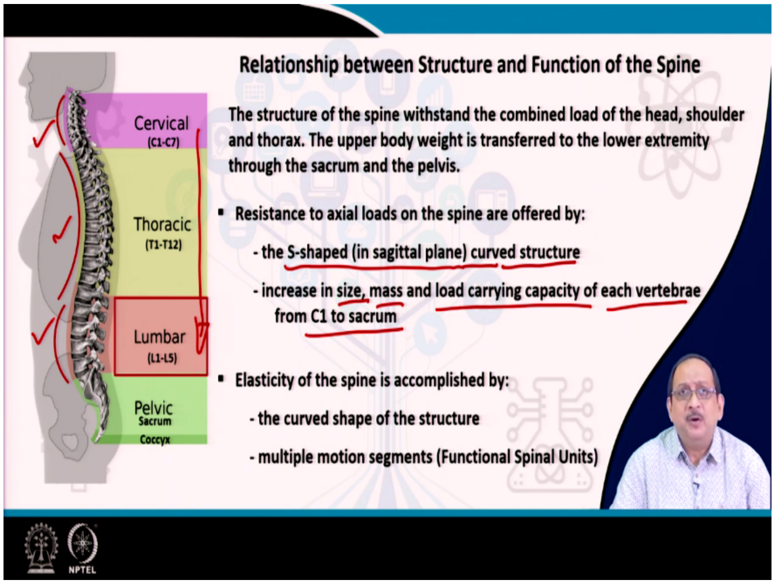

Let us discuss about the relationship between the structure and function of the spine. The structure of the spine withstand the combined load of the head, shoulder and thorax. The upper body weight is transferred to the lower extremity through the sacrum and the pelvis. The resistance to the axial loads on the spine is offered by the S curve in the sagittal plane. It is an S-shaped curved structure.

Due to the increase in size, mass, and load carrying capacity of each vertebra, we move from C1 to the sacrum. The elasticity of the spine is accomplished by the curved shape of the structure as indicated earlier and the multiple motion segments or the functional spinal units. We would be focusing further discussions mainly on the lumber spine segment because the it carries the bulk of the upper part of the body weight.

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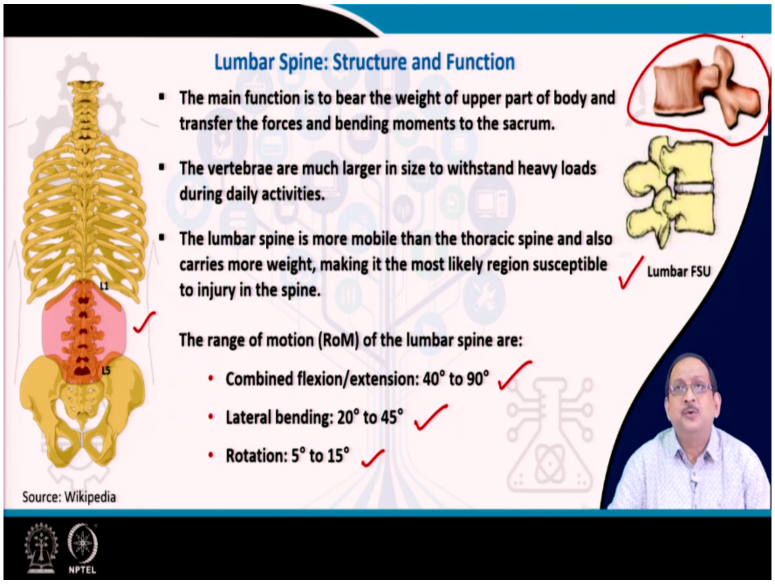

Now, let us come to the lumbar spine. As you can see, it is located in the lower part of the vertebral column, and the primary function of the lumbar spine is to bear the weight of the upper part of the body and transfer the forces and bending moments to the sacrum. The vertebrae in this part of the structure or the segment are much more significant to withstand heavy loads during daily activities.

The lumbar spine is more mobile than the thoracic spine and carries more weight making it the most likely region susceptible to injury in the whole spinal structure. The range of motions offered by the lumbar spine is combined flexion and extension.

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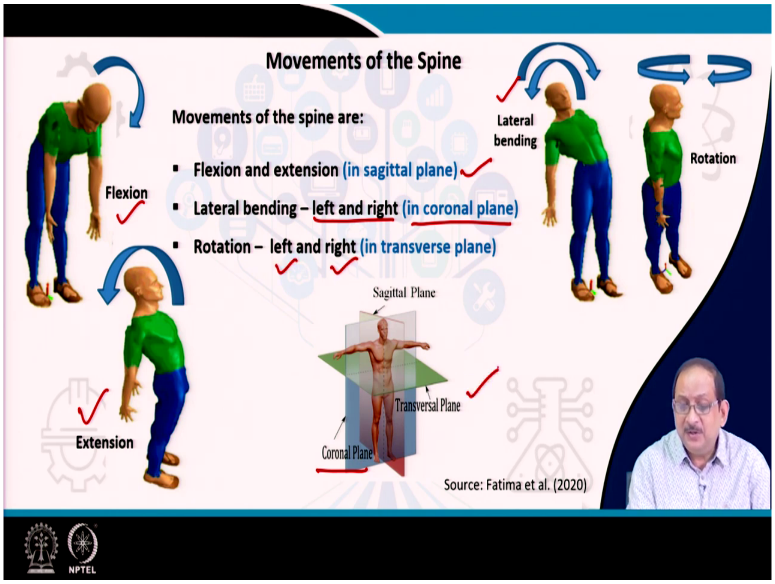

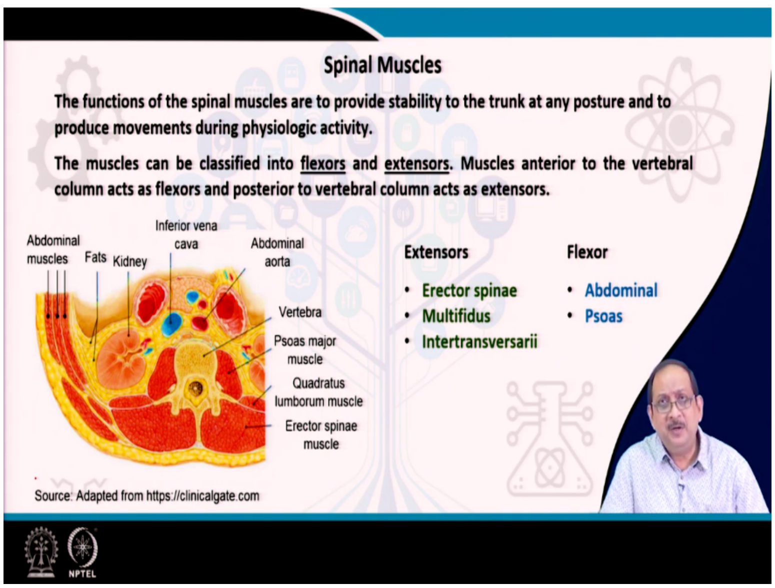

Let us discuss the movements of the spine, flexion and extension in the sagittal plane as follows: bending forward and backwards in the sagittal plane, left and right lateral bending in the coronal plane, and left and right rotation in the measured in the transverse plane.We would now focus on the spinal muscles. The functions of the spinal muscles are to provide stability to the trunk at any posture and to produce movements during physiologic activity. The muscles can be broadly classified as flexors and extensors, the muscles anterior to the vertebral column acts as flexors, and posterior to the vertebral column acts as extensors. The extensors muscles are erector spinae, multifidus and intertransversarii. The flexor muscles are abdominal and psoas.

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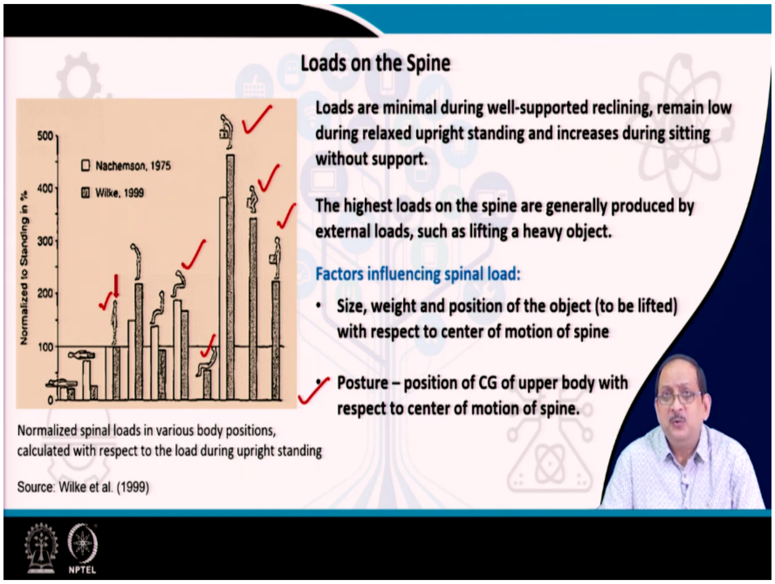

Let us discuss the loads acting on the spine. On the left, we can see a multiple bar diagram that presents normalised spinal loads in various body positions calculated with respect to the load during upright standing, as indicated in the figure. The loads are minimal during well supported reclining, it remain low during relaxed upright standing, and increases during sitting without support.

The highest loads on the spine are generally produced by external loads such as lifting a heavy object. The factors influencing the spinal loads are the size, weight and position of the object to be lifted with respect to the centre of motion of the spine. And the second important point is the posture, position of the centre of gravity of the upper part of the body with respect to the centre of motion of the spine.

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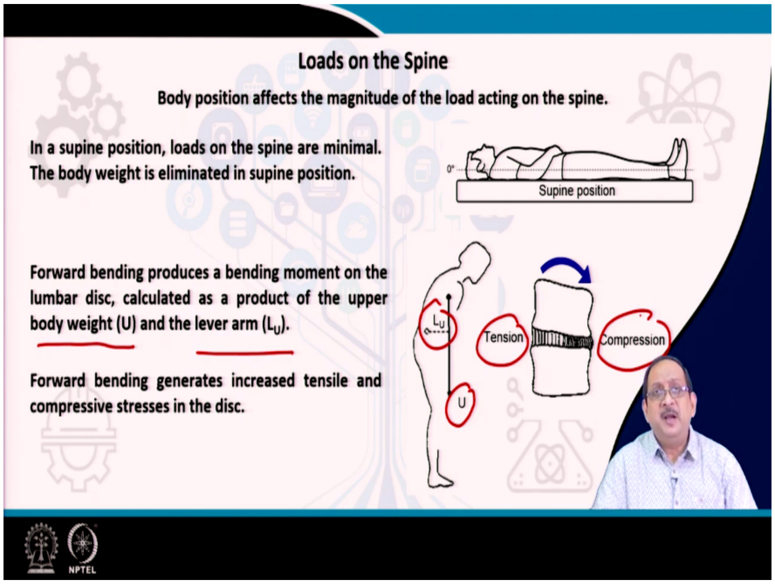

Now, the loads on the spine are dependent on the body position, and the body position affects the magnitude of the load acting on the spine. In the supine position, loads on the spine are minimal because the body weight is eliminated. Forward bending produces a bending moment on the lumbar spine calculated as a product of the upper body weight and the lever arm.

The lever arm is indicated as L_u and the weight of the upper part of the body as U. Forward bending generates increased tensile and compressive stresses due to bending in the vertebral functional unit. The forward bending causes increased tensile and compressive stresses in the disk due to the bending action.

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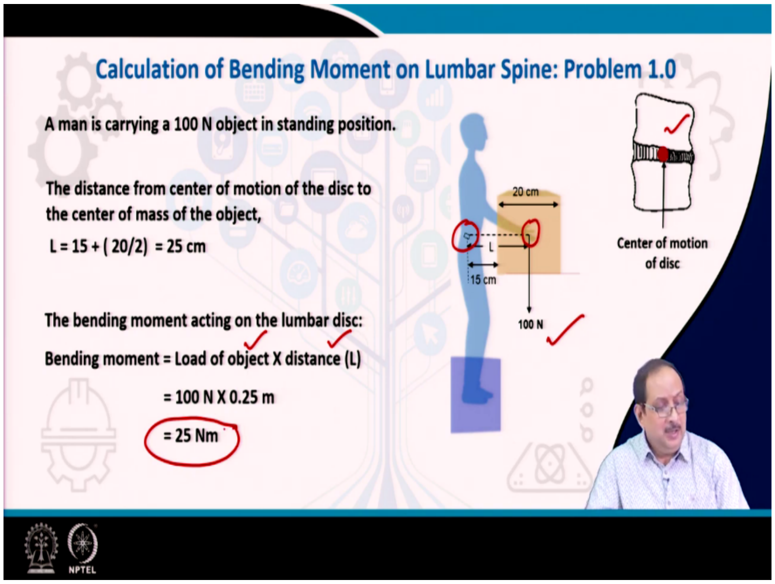

Now, let us move towards the second part of the topic that is based on a calculation of bending moment on the lumbar spine. The first numerical problem is a relatively simple problem, but it presents the idea of the effect of the load position and the posture, how these two factors affect the forces and bending moment on the lumbar spine. Now, consider a man is carrying a weight of 100 N in a standing position.

The centre of motion of the disk in a functional spinal unit is indicated here. Now, the bending moment acting on the lumbar disk is equal to the load of the object and the lever arm, which is given here by L. So, if you multiply the load of 100 N by the lever amount of 0.25 m, then we actually can calculate the bending moment on the lumbar spine as 25Nm.

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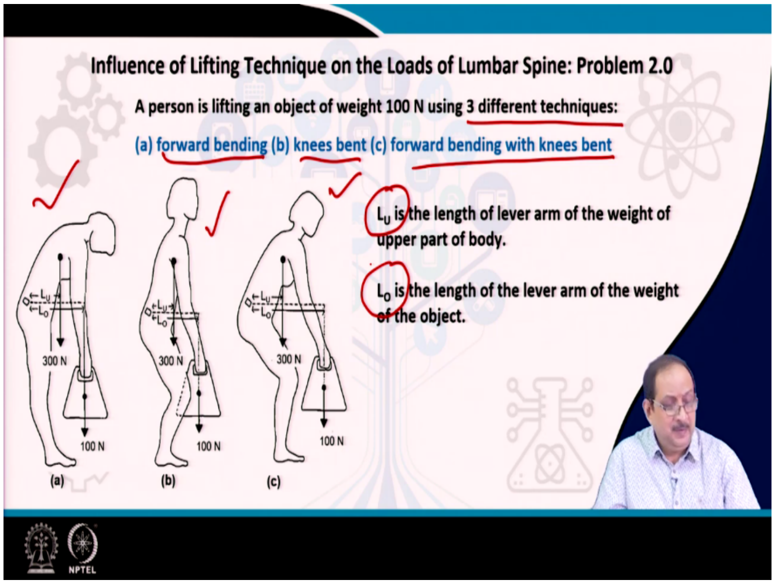

The second problem presents the influence of the lifting technique on loads of the lumbar spine. So, a person is lifting an object of the same weight 100 N using three different methods. So, one is the forward bending, which is indicated in figure (a). The weight is carried closer to the body with knees bent but more erect, in case (b). In the third case (c), it is forward bending with knees bend.

So, the L_u, the lever arm of the weight of the upper part of the body and L_o, the length of the lever arm of the weight of the object are different for three different cases. So, we will take up each case and calculate the bending moment.

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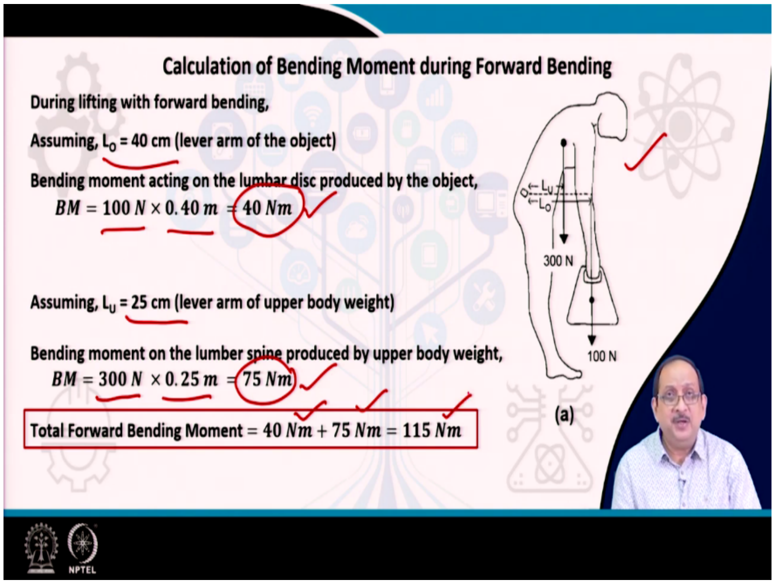

So, the first case is a calculation of the bending moment during forward bending. So, during lifting with forward bending as indicated here in this figure, the lever arm can be taken as 40 centimeter. So, assuming the lever arm as 40 cms, we can calculate bending moment acting on the lumbar disk produced by the object is equal to 100 N multiplied by the lever arm and that is 40 Nm.

Assuming L_u as 25 cm. The bending moment on the lumbar spine produced by the upper part of the body is 300 N multiplied by 0.25 m which gives a bending moment of 75 Nm. So, the total forward bending moment is the sum of these two bending moments 40 Nm plus 75 Nm and that gives 115 Nm.

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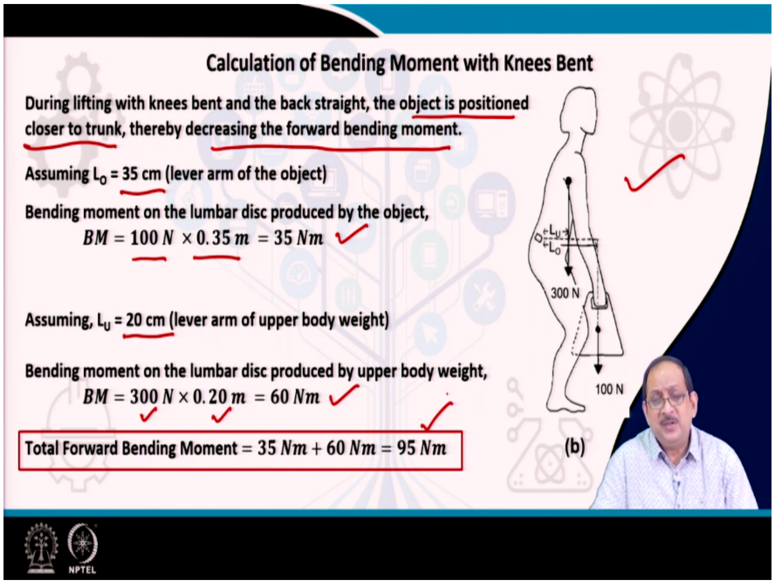

Now, the second case is much more in an erect position, but the knees are bent, and the object is positioned closer to the trunk. This is a critical position, thereby decreasing the forward bending moment. The following calculations can prove it.

So, assuming L_o as 35 cms, the bending moment on the lumbar disk produced by the object is 100 N multiplied by 0.35 m, which gives me 35 Nm as the bending moment. Assuming L_u as 20 cm, the bending moment on the lumbar disk produced by the upper part of the body is 300 N multiplied by 0.20 meters equals 60 Nm. So, the total forward bending moment is calculated as 95 Nm, which is the sum of the bending moment produced by the object and the bending moment produced by the upper part of the body. This value is less than the value calculated in the first case, case a.

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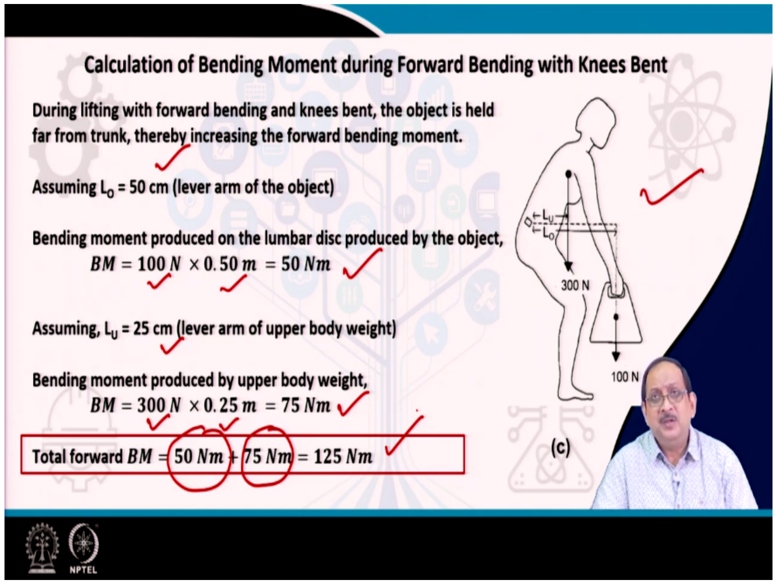

In the third case, we are calculating the bending moment during the forward bending with knees bent. In this case, the object is held far from the trunk, as you can see in the figure. So, assuming the lever arm of the object, L_o as 50 cm, the bending moment can be calculated as 100 N multiplied by 0.50 m that is 50 N m.

Assuming L_u as 25 cm, the bending moment produced by the upper body weight is 300 N by 0.25 m gives a bending moment of 75 Nm. So, when we add these two bending moments, 50 Nm and 75 Nm, the total forward bending moment is calculated as 125 Nm, the highest among all three cases.

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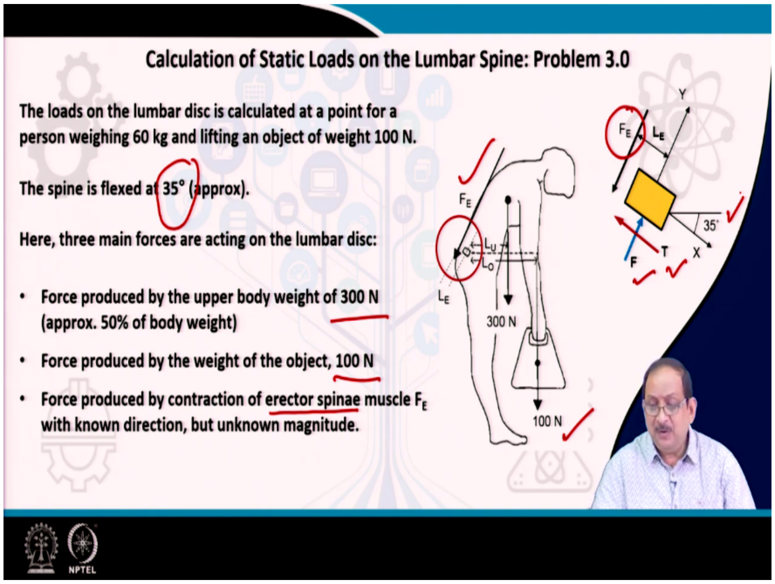

Let us now discuss the static loads, we will perform some calculations of the static loads on the lumbar spine and this is the third problem that we will we are undertaking. The loads on the lumbar disc are calculated at a point for a person weighing 60 kg and lifting an object of 100 N. So, 100 N is the object's weight, and we assume that the spine is flexed at 35 degrees approximately. In this case, we identify three main forces acting on the lumbar disc, the forces produced by the upper part of the bodyweight that is 300 N assuming approximately 50 % of the body weight, total body weight.

The first one is the force produced by the upper body weight of 300 N, approximately half of the body weight. The second point is the force produced by the weight of the object that is 100 N. The third is the force produced by the contraction of the erector spinae muscle indicated by force, F_e with its direction known, but the magnitude unknown. So, we try to zoom in on this lumbar segment and try to get a more detailed picture of the forces acting on the lumbar spine in this position. So, we have the axial forces acting on the lumbar disc, the tangential forces or the shear forces acting on the lumbar disc. Here, you can see the erector spiny muscle force F_e acting at the lever arm L_e and this unit or the lumbar disc is oriented at 35 degrees to the vertical and horizontal axis.

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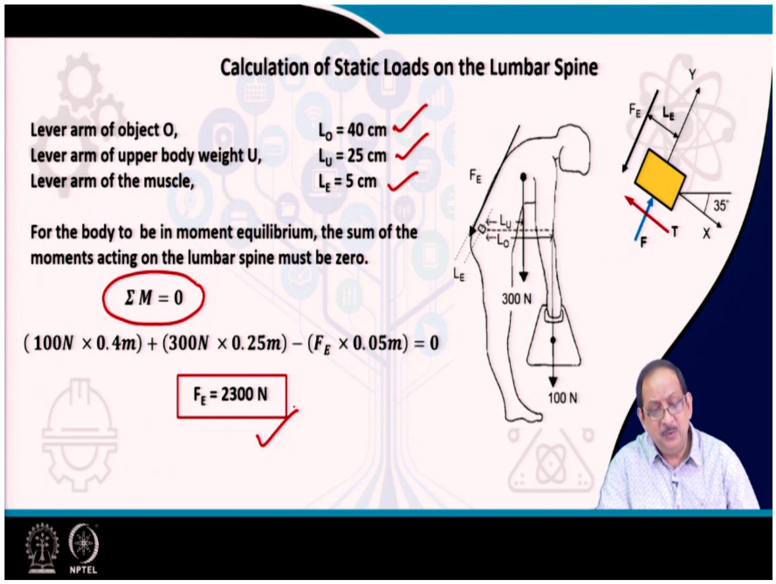

Let us continue with the calculations of the static loads on the lumbar spine and identify the lever arms. So, the lever arm of the object O is 40 cm, the lever arm of the upper body weight U is 25 cm and lever arm of the muscle is 5 cm. Now, for the body to be in moment equilibrium, the sum of the moments acting on the lumbar spine must be equal to 0. So, we add all the moments about the centre of motion of the lumbar spine and equate it to 0.

Upon solving the equation, the force applied by the muscle erector spinae is equal to 2300N.

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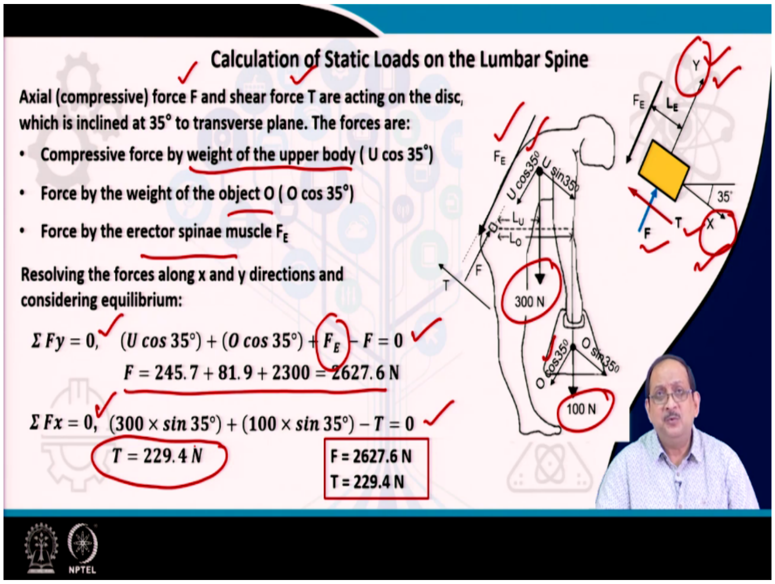

Let us focus our attention on the calculation of static loads on the lumbar spine. So, we will be calculating the axial force F and the shear force T, as indicated in the figure, acting on the disk inclined at 35 degrees to the transverse plane. The weight of the upper part of the body is denoted by U and is equal to 300 N.

So, the component acting along the Y direction is U Cos (35), the weight of the object O as indicated in the figure. So if we take the component of object weight along the Y direction, it is O Cos (35). The third force is the muscle force of the erector spinae muscle, which is indicated as a F_E and is oriented along the Y direction, as shown in the figure.

Now, if we resolve the forces along X and Y directions and consider equilibrium, we can generate two equations, one along the Y direction, one along the X direction, which will, stated here in the slide. From each of these equations, we can determine the value of the axial compressive force F.

$$\Sigma F_y = 0,\ \ U\,Cos(35) + O(35)\ + F_E - F = 0$$

$$F = 245.7 + 81.9 + 2300 = 2627.6\,N$$

$$\Sigma F_X = 0, \; U\,Sin\,(35) + \,O(35) \; - T = 0$$

$$T = 229.4\,N$$

In this equation, we can substitute the value of a $F_{E,}$ which we had calculated in the earlier slide. And from the second equation, we can find out the value of the shear force T. So, finally, we solve that the compressive force F is 2627.6 N and the shear force T is 229.4 N.

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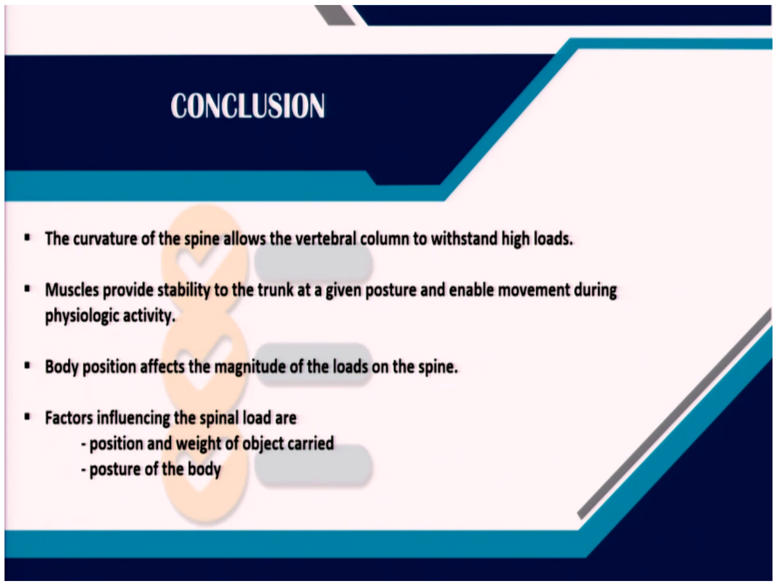

Let us come to the conclusions of this lecture on the spine. The curvature of the spine allows the vertebral column to withstand high loads. The muscles provide stability to the trunk at a given posture and enable movement during physiological activity. Body position affects the magnitude of the loads on the spine. And the factors influencing the spinal loads are the position and weight of the object carried and the body's posture.

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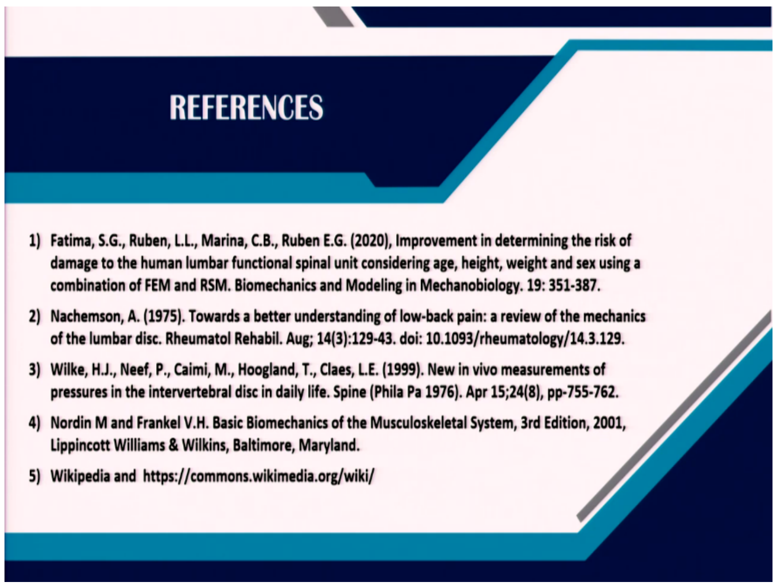

The list of references is presented here based on which we have prepared the lecture. Thank you for listening.