Biomechanics of Joints and Orthopaedic Implants
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Lecture 11
Biomechanics of the Elbow Joint Part-I

Good morning everybody. Welcome to the NPTEL online certification course. The second module, lecture 4 is on the biomechanics of the elbow joint. This is part one of the lecture, followed by part two.

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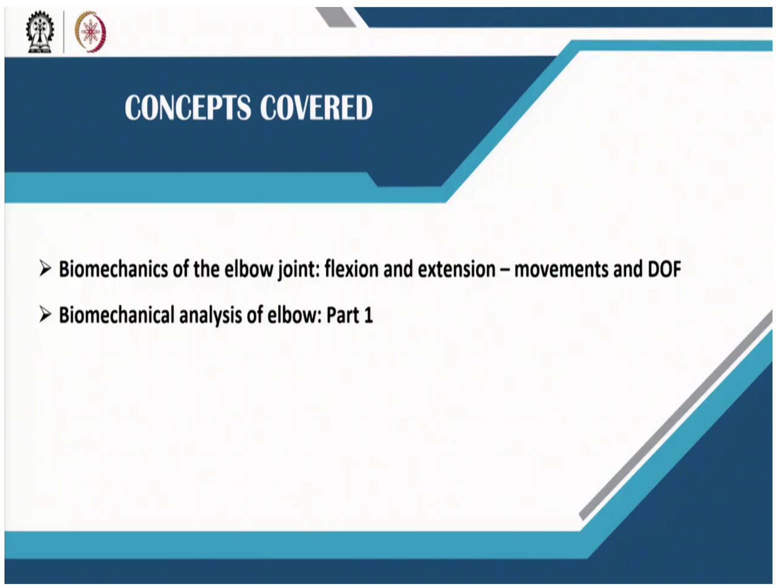

The concepts covered in this lecture are as follows: the biomechanics of the elbow joint; the movements; the degrees of freedom during flexion and extension, the primary movements of the elbow joint and subsequently, we will be discussing a problem on biomechanical analysis of the elbow; the part one of the problem will be discussed in this lecture followed by part two of the problem later in a separate presentation.

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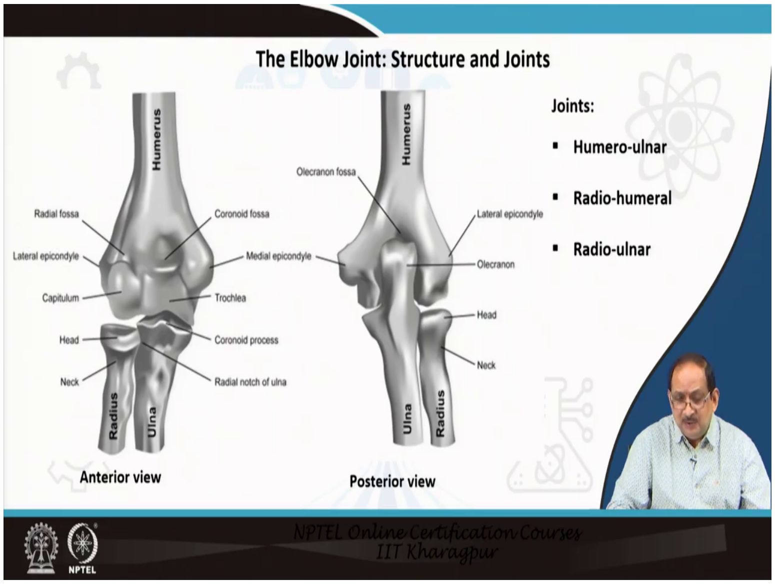

Let us revisit the structure, and the joints of the elbow joint, which is constituted of the following joints, the humeroulnar joint, the radio humeral joint and the radioulnar joint. A detailed lecture on the structure and function of the elbow joint was earlier discussed in module one. We will be briefly discussing the structure and the movements in this lecture, which deals with the basic biomechanics of the elbow joint.

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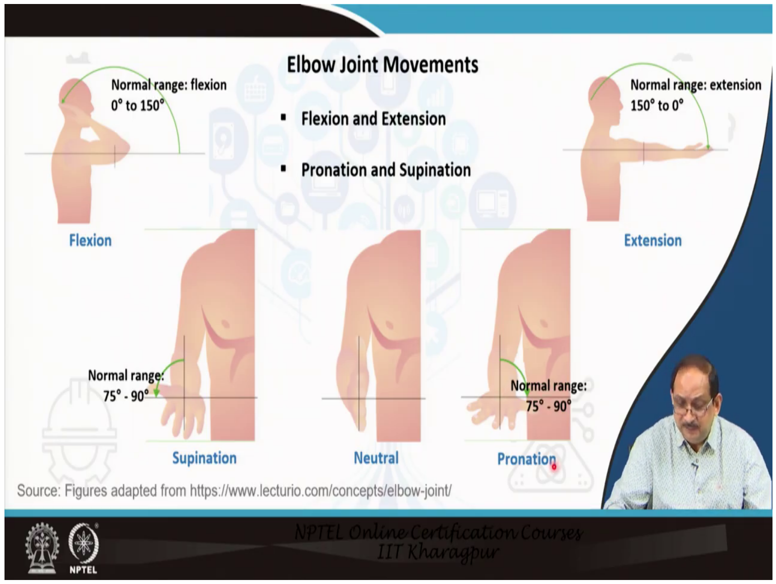

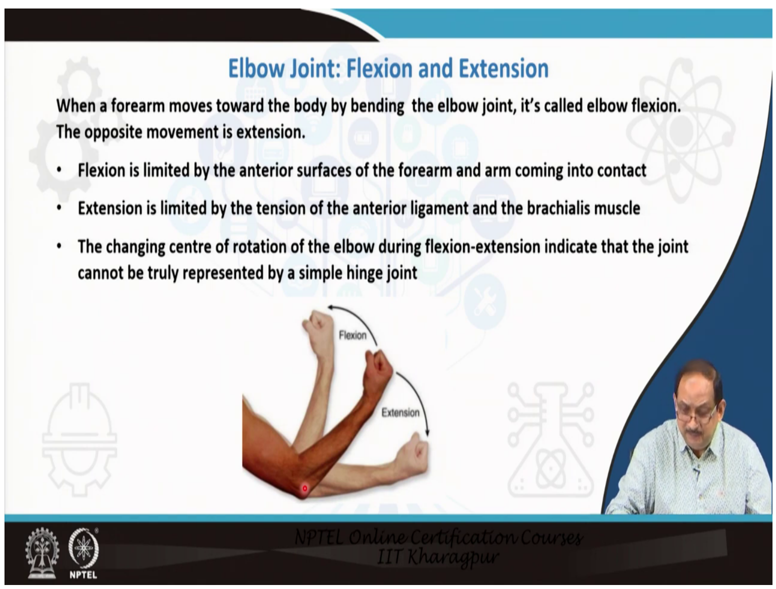

The movements offered by the elbow joint are flexion, extension and pronation supination. So, you can see here the range of normal, range of flexion is from 0 to 150 degrees and the opposite movement is known as extension, from the neutral position, if we rotate the arm outward, then it is called supination, rotating the forearm inward is called pronation.

In this lecture, we will concentrate on the elbow joint's two major movements, which are flexion and extension. The flexion is limited by the anterior surfaces of the forearm and arm coming into contact with each other.

The extension is limited by the tension of the anterior ligament and the brachialis muscle. The change in position of the centre of rotation of the elbow during the movement flexion-extension indicates that a simple hinge joint cannot truly represent this joint.

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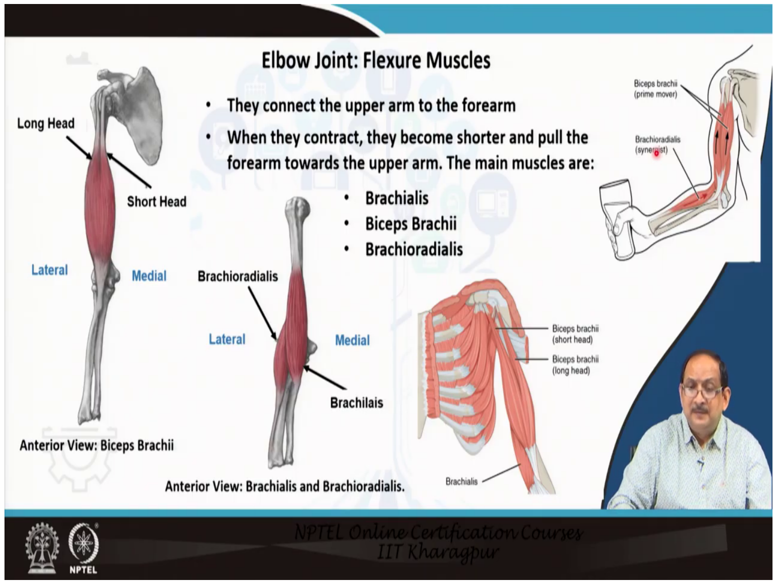

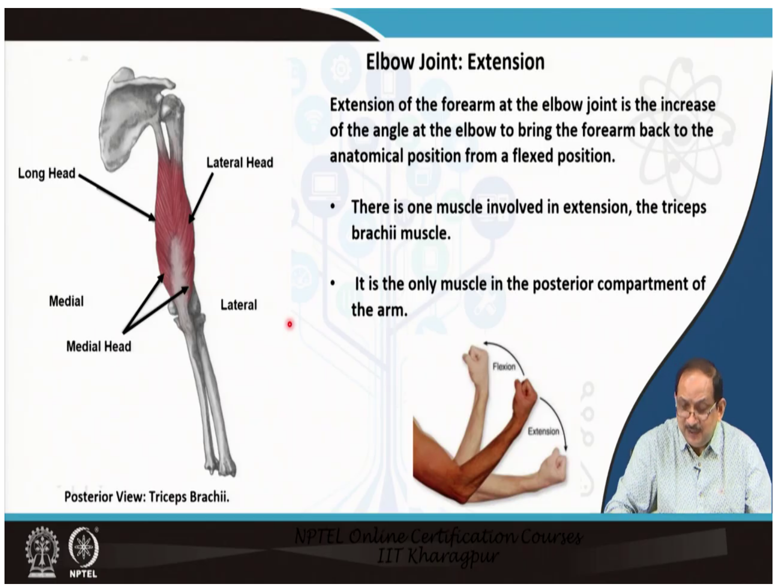

Let us summarize the flexor muscles that contribute towards this movement flexion, the flexure muscles; the major muscles are the brachialis, the biceps brachii and the brachioradialis. They connect the upper arm to the forearm; When they contract during flexion, they become shorter and pull the forearm towards the upper arm.The elbow extension is the extension of the forearm at the elbow joint. This movement involves an increase of the angle at the elbow to bring the forearm back to the anatomical position from a flexed position. So, we are getting the forearm back to the neutral position from a flexed position due to the movement extension. The triceps brachii muscle is the only major muscle involved in extension.

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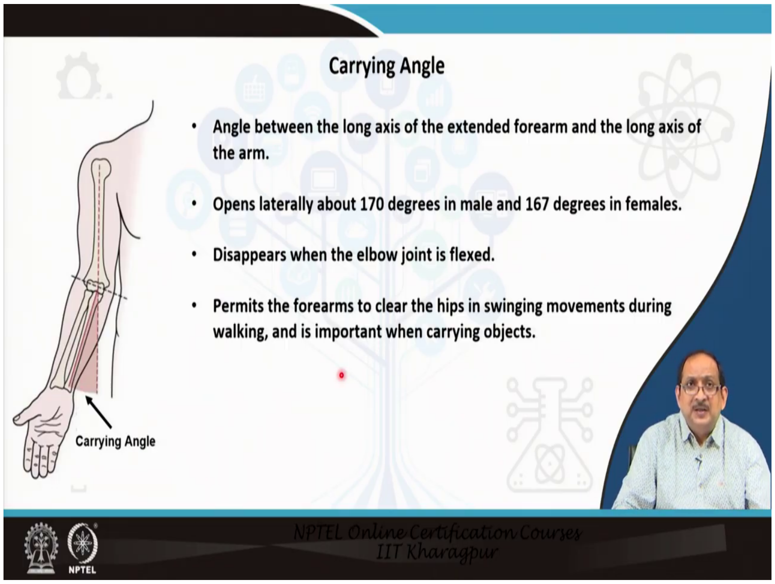

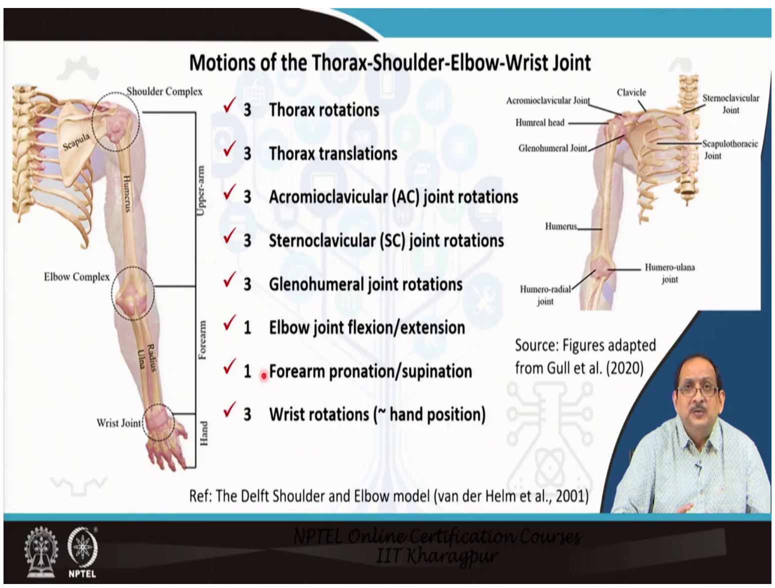

Let us now discuss an crucial angular measurement which is known as the carrying angle. This is the angle between the long axis of the extended forearm and the long axis of the arm. It opens laterally about 170 degrees in males and 167 degrees in the case of female subjects.

However, it disappears when the elbow is flexed. So in a flexed position, the carrying angle disappears. The carrying angle permits the forearm to clear the hips in swinging movements during walking and is crucial when carrying objects. Let us discuss the motions offered by the thorax-shoulder-elbow-wrist complex. So, individually we have the shoulder complex, the elbow complex, and the wrist joint; together, it forms a critical upper extremity complex responsible for an extensive range of movements. Now, let’s consider the movements of each joint. We have three thorax rotations and three thorax translations with respect to a rigid frame. The motions offered by the shoulder joint are as follows: three acromioclavicular joint rotations, three sternoclavicular joint rotations and three glenohumeral joint rotations. Each of these joints is a spherical joint. That’s why each joint offers three rotational degrees of freedom.

The elbow joint offers two motions; flexion-extension and pronation-supination. So, we have two movements by the elbow joint.

The wrist joint offers three wrist rotations.

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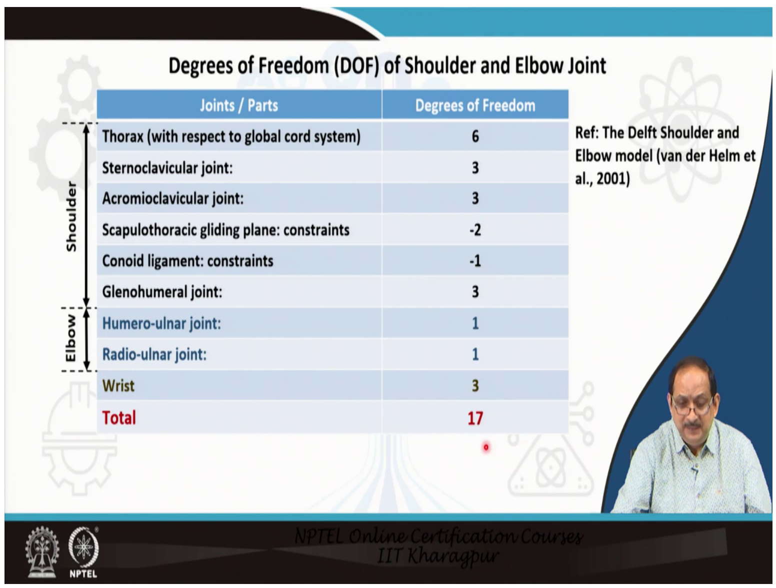

Based on these motions, the degrees of freedom of the shoulder, elbow, wrist joint can be summarized based on the model proposed by the Delft shoulder group. The model is quite popular and famously called the Delft shoulder-elbow model proposed by the Frans van der Helm group at the Delft University of Technology. The degrees of freedom of the thorax with respect to the global coordinate system or rigid frame is six such that it consists of three rotations and three translations.

The scapulothoracic gliding plane is modelled with the thorax as an ellipsoid on which two points of the medial border are sliding. So two degrees of freedom are constraints, and that is the reason we put a minus sign. Two constraints are offered by the scapulothoracic gliding plane.

An additional constraint is applied by the assumption that the conoid ligament is rigid. So, it leads to a negative one due to the assumption that the conoid ligament is rigid. Now, this is mostly the shoulder complex with its degrees of freedom listed corresponding to each joint. If we now move to the elbow, as discussed earlier, we have two rotations. So, we have one about the humeroulnar joint, the other about the radioulnar joint.

The wrist offers three rotations. It has three degrees of freedom. The total degree of freedom of the shoulder- elbow- wrist complex comes out to be 17 upon adding the above-mentioned degrees of freedom of each constituent.

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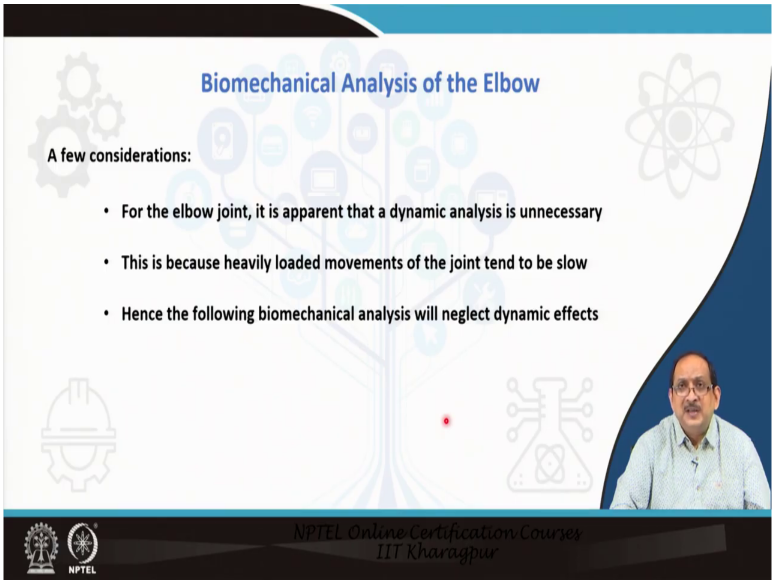

Now, let us move to the biomechanical analysis of the elbow. Here, we define a numerical problem for the elbow joint. Dynamic analysis is not considered because heavily loaded movements of the joint tend to be slow. Hence, the following biomechanical analysis will neglect the dynamic effects, and will be considering a biomechanical analysis of the elbow based on static analysis.

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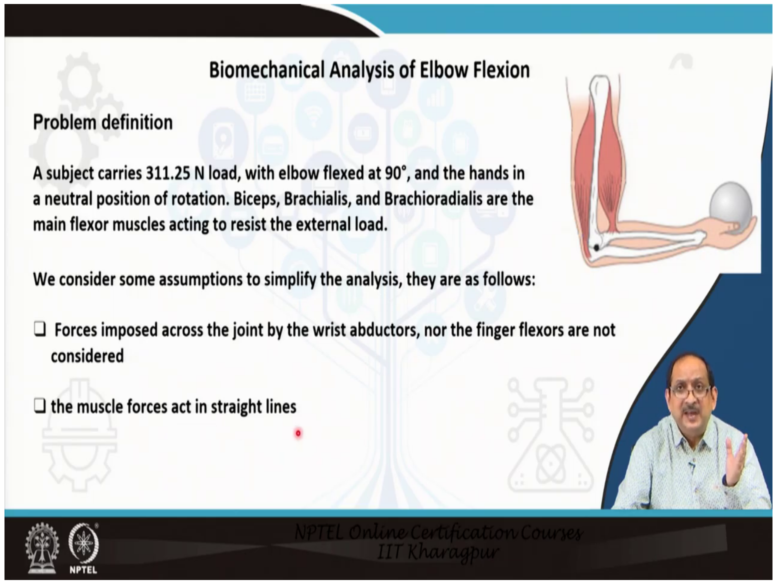

Let us define the problem. So, you can see that a subject is carrying a load of 311.25 N. The elbow position is flexion at 90 degrees. The subject is carrying a load and the hands are in neutral position of rotation. So there is no rotation like the pronation or supination. The biceps brachialis and brachioradialis are the main flexor muscles acting to resist the external load.

Now, to proceed with the problem, we first consider some assumptions to simplify the analysis. The first assumption is regarding the forces imposed across the joint by the wrist abductors or the finger flexors. The muscles of the wrist or the finger flexors are not considered in the analysis. The muscle forces acting on the elbow and considered in this analysis are assumed to act in straight lines.

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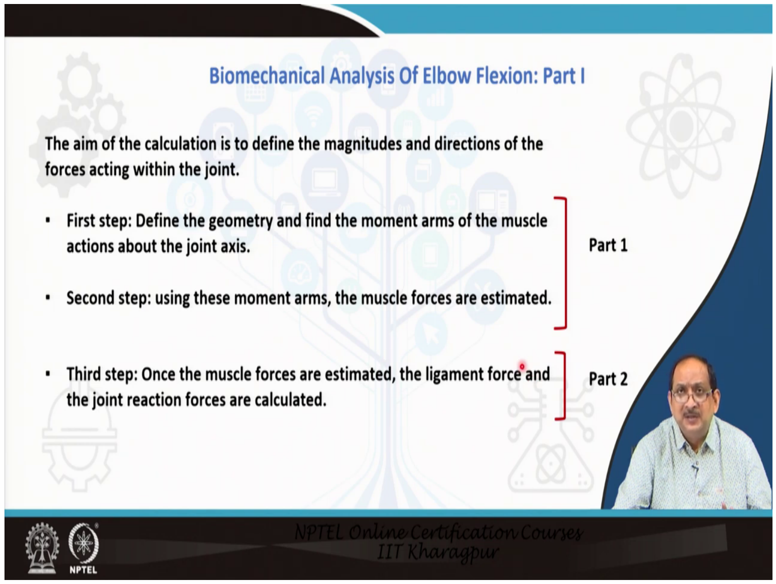

Now, let us first look into the two parts of the problem. The aim of the calculation is to define the magnitude and directions of the force acting within the elbow joint. So, as a first step, we define the geometry and find the moment arms of the muscle activity about the joint axis. Then, in the second step, using these moment arms, we estimate the muscle forces

And in the final third step, once the muscle forces are estimated, the ligament force and the joint reaction forces are calculated. So the first two steps together make the first part of the problem that I will discuss in this lecture. The second part of the problem is much more complex and more elaborate.

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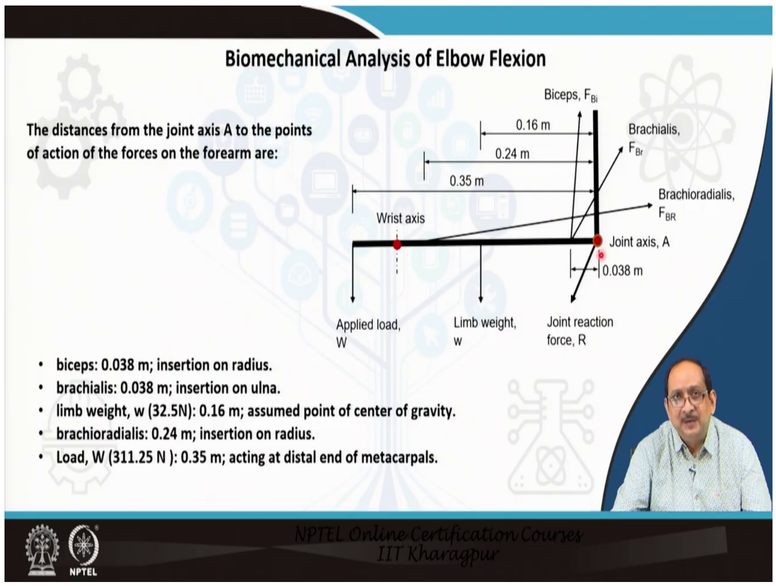

Now, the detailed geometry data of the problem is presented in this slide. The action of the biceps insertion on the radius is 0.38 meters from the joint axis A. The muscle brachialis is also located at a similar distance, but the insertion is on the ulna. The brachioradialis muscle insertion is on the radius. So it is situated at a distance of 0.24 meters from the joint axis A.

The limb weight of 32.5 Newton is assumed to act at the centre of gravity, located at a distance of 0.16 meters from the joint axis A. Finally, the load of 311.25 Newton is assumed to be acting at the distal end of the metacarpals which is 0.35 meters from the joint axis A.

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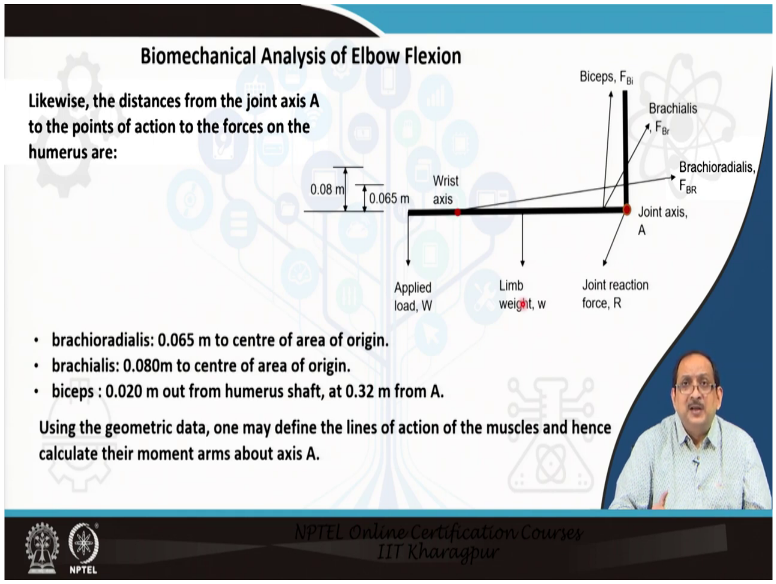

Now, in continuation to the earlier slide, we present the same figure, but here we actually indicate the distance from the joint axis A of the points of action of the muscle forces on the humerus.

So, using the geometric data, we can define the lines of action of the muscles and hence, calculate their moment arms about the joint axis A.

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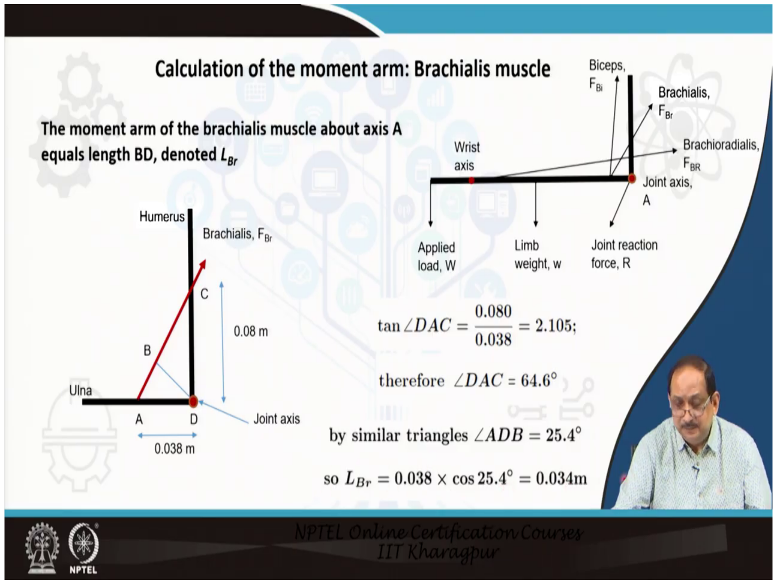

Now, we are entering the calculations on the moment arm of each muscle. The first muscle we consider is the brachialis muscle. So, the moment arm of the brachialis muscle about the axis A equals the length BD, so BD is the moment arm denoted by L_{Br}. So, considering the given geometric data, we can actually calculate the angle DAC as 64.6^{O} considering tan of the angle DAC, the dimensions given we can calculate the actual angle DAC.

So, once we calculate the angle DAC by a similar triangle, we can get the angle ADB calculated as 25.4^{O}. So, the moment arm L_{Br} comes out to be 0.034 meters, as shown in the calculation.

$$tan\angle DAC = \frac{0.080}{0.038} = 2.105; therefore \quad DAC = 64.6^{\circ}$$

$$by\ similar\ triangles\ \angle ADB = 25.4^{\circ}$$

$$so\ L_{Br} = 0.038 \times cos 25.4^{\circ} = 0.034m$$

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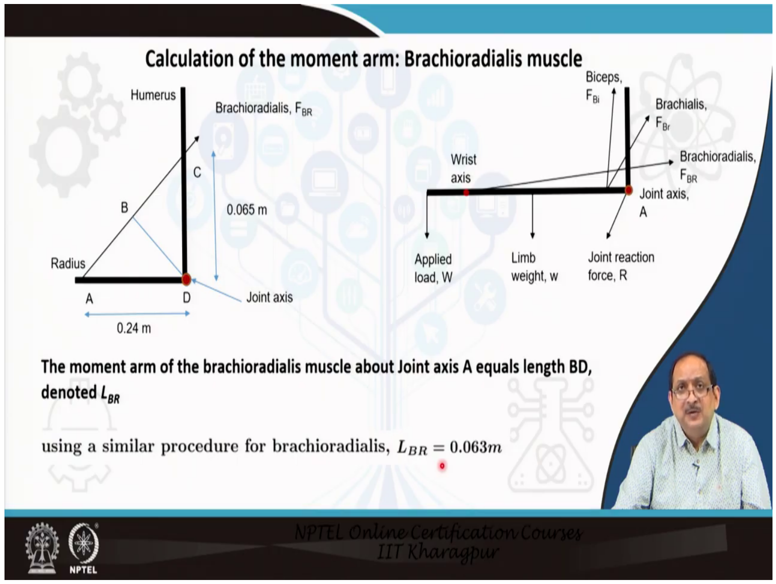

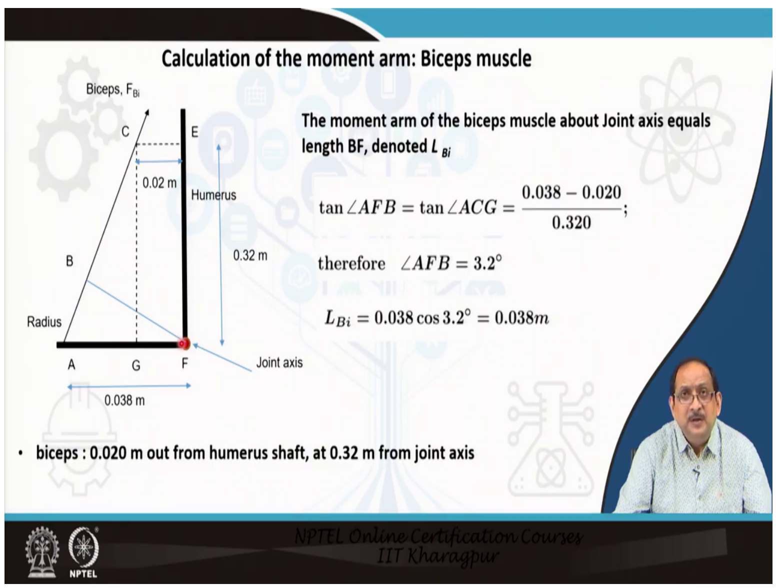

Next is the calculation of the moment arm brachioradialis; following a similar geometric procedure, we can calculate the moment arm of the brachioradialis muscle about the joint axis A, which is calculated as 0.063 meters. The calculation of the moment arm of the bicep muscle is indicated in this slide. So, it can be recalled that a point C on the line of action of the bicep muscle is defined by the data given in the problem.

So, it is 0.02 meters out of the humeral shaft and 0.32 meters from the joint axis vertically upwards. So, we can locate the point C along the line of action of the muscle. We can now calculate L_{Bi} , moment arm of the bicep muscle using simple geometry.

Considering the moment arm of the biceps muscle

$$tan\angle AFB = tan\angle ACG = \frac{0.038-0.020}{0.320}; therefore \quad \angle AFB = 3.2^{\circ}$$

$$L_{Bi} = 0.038cos3.2^{\circ} = 0.038m$$

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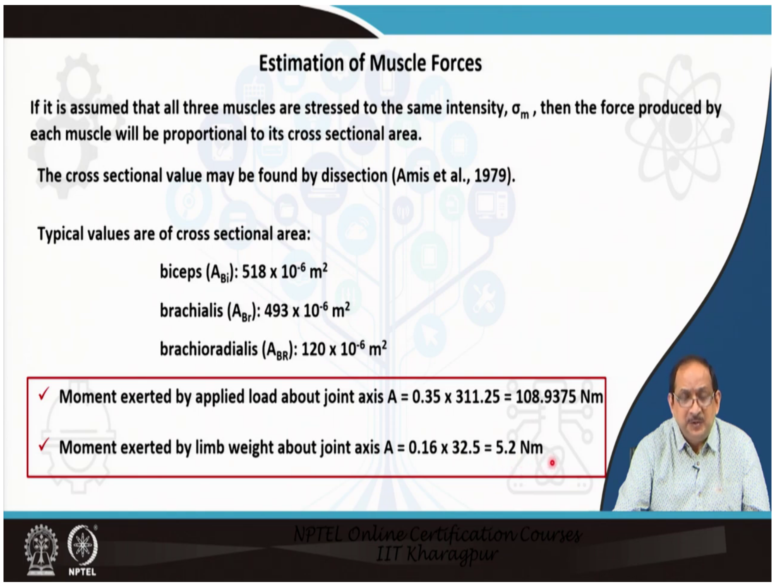

The next step is a significant step involving the estimation of the muscle forces. Now, to undertake the estimation of the muscle forces, it is assumed that all three muscles are stressed to the same intensity. So, if we consider this assumption, so if we consider the stress to be the same in all the muscles, then the forces produced in each muscle will be proportional to its physiological cross-sectional area, the cross-sectional area values of each muscle have been found earlier by dissection and the typical values of the cross-sectional area of the muscles are given here.

So, once we have the stress generated in each muscle, we can multiply the cross-sectional area with the stresses generated in each muscle and then we get the forces and if we multiply the forces with the muscle's moment arm, we get the moments corresponding to each muscle. But before that, we first calculate the moment exerted by the external loads and the external loads.

So the moment is calculated by multiplying the load with the distance from the joint axis A. Therefore moment exerted by the applied load as 108.93 Nm. Now, the moment exerted by the limb weight is also considered as an external moment. Limb weight is assumed to be 32.5 N, and it is acting through the centre of gravity of the limb. So, we get a moment value of 5.2 Newton meters.

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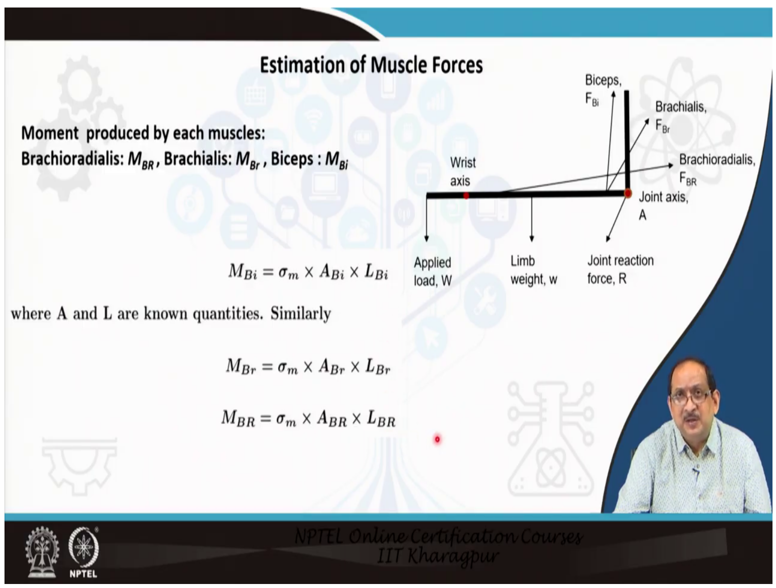

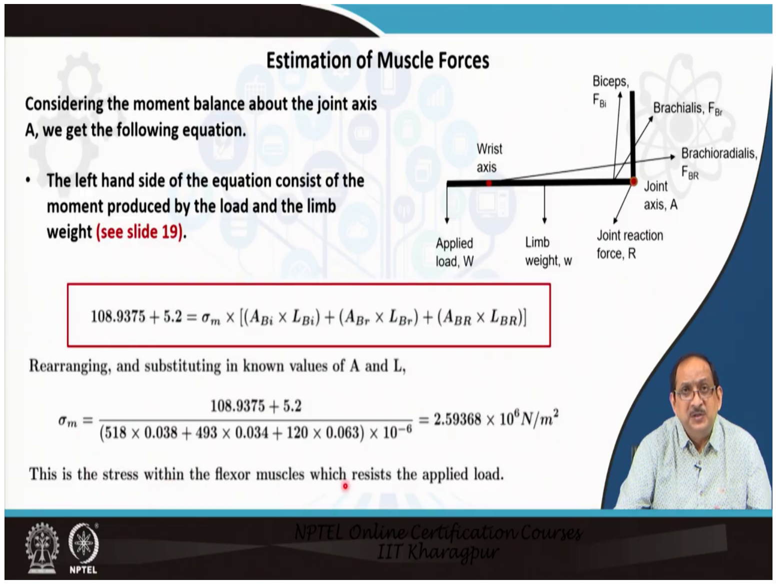

So, we now estimate the moments produced by each muscle. So, the moment produced by each muscle, as I discussed earlier, is the muscle's stress multiplied by the muscle's corresponding physiological cross-sectional area multiplied by the muscle's moment arm. So, for each muscle, we can write the following expressions individually.

Once we have calculated the individual moments corresponding to the muscles and the moments of the external forces, we need to balance these moments since the limb is in equilibrium while carrying the load. So, the moment balance about the joint axis can be considered. On the left-hand side of the equation, we have moments generated by the load and the limb weight.

On the right-hand side, we have the sum of the moments of the muscles, which actually balances the moment of the external load. So, this is a crucial step in the problem, where we undertake moment balance of the muscle forces and the moment applied by the external load. So, when we substitute the values of these variables here, we can calculate the muscle's stress and assume that a muscle is stressed at the same intensity. So, this is the stress within the flexor muscles that resists the applied load.

$$M_{Bi} = \sigma_m \times A_{Bi} \times L_{Bi}$$

where A and L are known quantities. Similarly

$$M_{Br} = \sigma_m \times A_{Br} \times L_{Br}$$

$$M_{BR} = \sigma_m \times A_{BR} \times L_{BR}$$

Hence,

$$108.9375 + 5.2 = \sigma_m \times [(A_{Bi} \times L_{Bi}) + (A_{Br} \times L_{Br}) + (A_{BR} \times L_{BR})]$$

Rearranging, and substituting in known values of A and L,

$$\sigma_m = \frac{108.9375+5.2}{(518\times0.038+493\times0.034+120\times0.063)\times10^{-6}} = 2.59368\times10^{6} N/m^{2}$$

This is the stress within the flexor muscles which resists the applied load.

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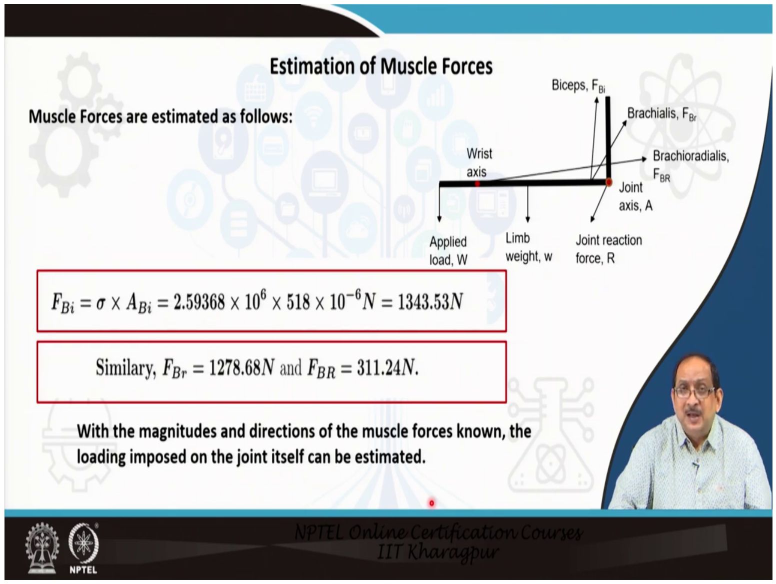
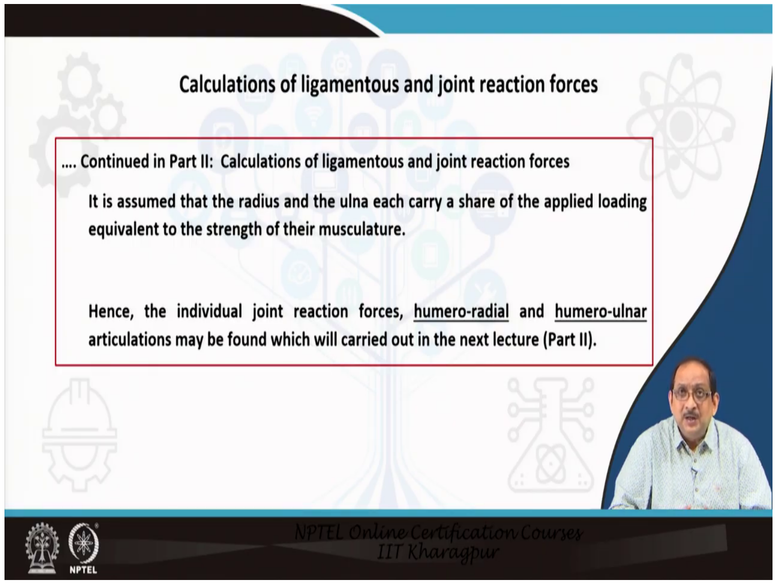


So, using this value of stress and the corresponding cross-sectional area, we can individually calculate the muscle forces. Since the muscle forces are estimated as shown, the loading imposed on the joint itself can be estimated too.

$$F_{Bi} = \sigma \times A_{Bi} = 2.59368 \times 10^{6} \times 518 \times 10^{-6} N = 1343.53N$$

$$Similary,\ F_{Br} = 1278.68N\ and\ F_{BR} = 311.24N.$$



More detailed calculations on the joint reaction forces will be continued in the next lecture. So, it is assumed that the radius and the ulna each carry a share of the applied loading equivalent to the strength of their muscle arrangement.

Hence, the individual joint reaction forces can be estimated, which will be carried out in the following lecture.

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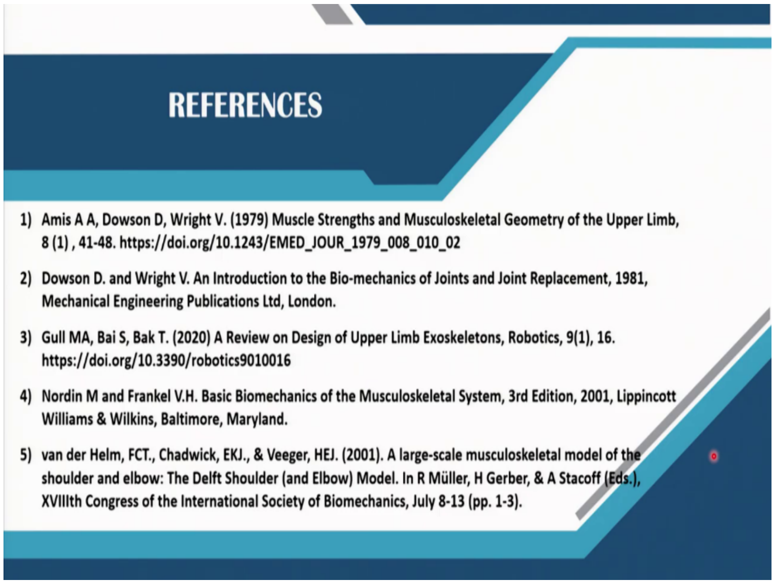

The references based on which the lecture has been prepared are listed here. Thank you for listening.