Biomechanics of Joints and Orthopaedic Implants
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Lecture 18
Motion Capture System

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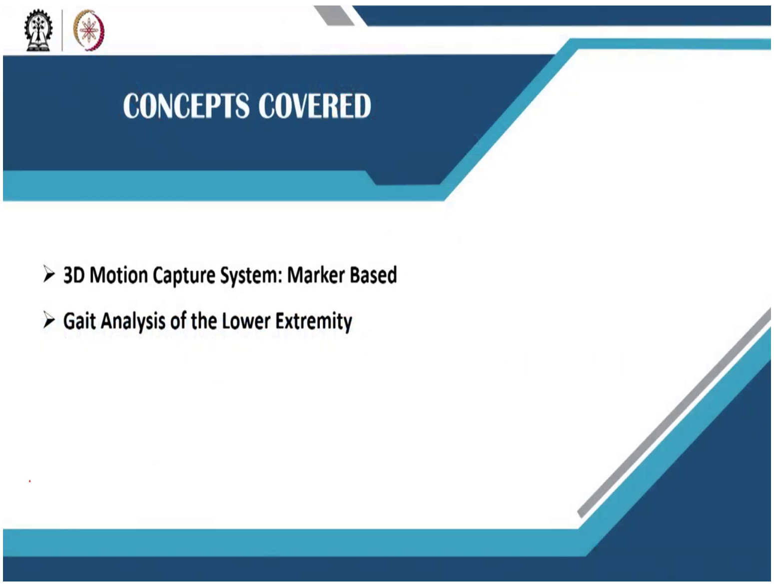

Good morning everybody. Welcome to the final lecture that is lecture 5 of week 3, module 3, on Motion Capture System. The lecture comprises of marker based 3D motion capture system and gait analysis of the lower extremity.

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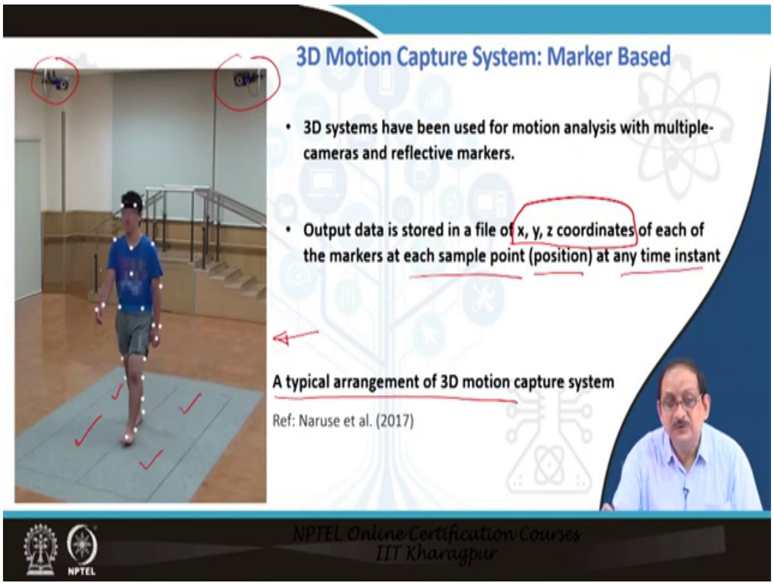

Let me reintroduce the marker-based 3-D motion capture system, which we had discussed in the earlier lecture. A typical arrangement of the 3-D motion capture system is shown in this figure. The 3-D motion capture system consists of multiple cameras and reflective markers, as can be seen in the figure. It comprises ten cameras mounted from the ceiling, only two are visible here and four force plates placed in the middle of the walkway.

The white circles represent reflective markers of 14-millimetre size. The output data of the motion capture system is stored in a file that consists of the x y z coordinates of each of the markers at each sample point, which is the position of the marker at any instant of time.

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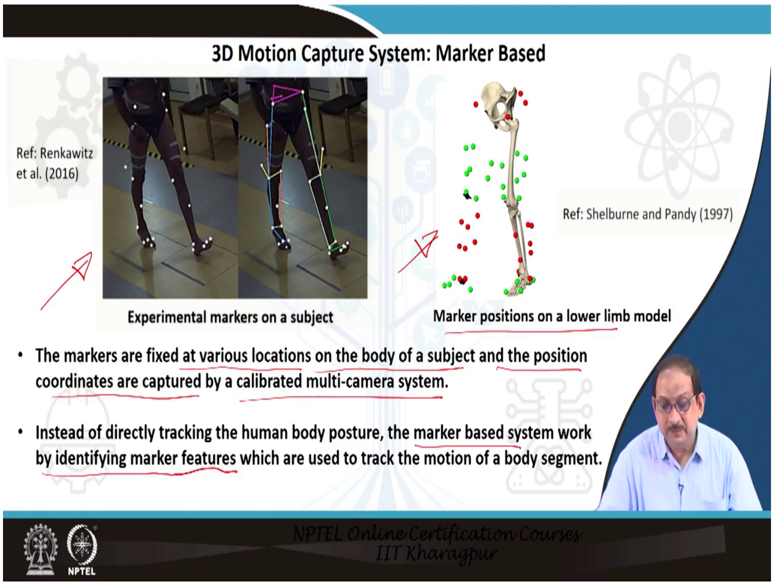

Let us discuss a little more in detail about the marker-based motion capture system. The markers are fixed at various locations on the body of a subject as indicated in the figure, and the position coordinates are captured by a calibrated multi-camera system. Instead of directly tracking the human body posture, the marker-based system works by identifying the marker features used to track a body segment's motion. This is indicated very clearly in the lower limb model. So, the marker positions in the lower limb model will be used to track the motion of a body segment.

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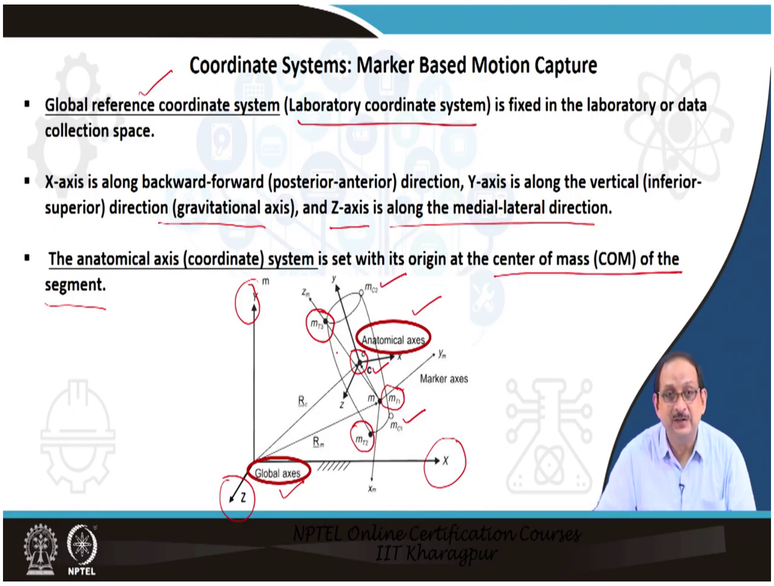

Now, there are several coordinate systems used in the marker-based motion capture system. So, it is important to know more in detail about the coordinate systems involved. So, the first coordinate system that needs to be defined is the global coordinate system which is the laboratory coordinate system, and this is fixed in the laboratory space or the data collection space as indicated in the figure as well.

So, the x-axis of the global coordinate system is along the backward-forward direction or posterior-anterior direction, the y-axis is located along the vertical direction, which is the inferior-superior direction along the gravitational axis, and the z-axis indicated here in the figure is along the medial-lateral direction.

Now, the anatomical coordinate system as indicated in the figure is set with its origin at the center of mass of the body segment. In this figure, one can notice the markers denoted by mT1, mT2, and mT3. So, the markers are indicated by mT1, mT2, and mT3, as shown in the figure. And there are two calibration points, just to show only two points, mC1 and mC2 are the calibration points in the figure.

And the center of mass of the body segment is C, which is the point C as indicated in the figure. We continue the discussion with the coordinate systems.

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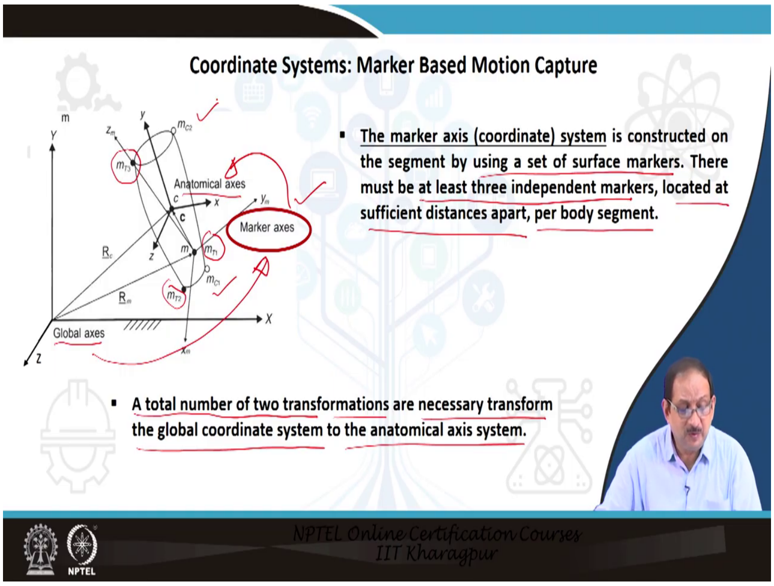

So, in this next slide, we define another coordinate system, which is the marker coordinate system. We had earlier defined the global coordinate system and the anatomical coordinate system. Now, we need to define the marker coordinate system. The marker coordinate system is constructed on the body segment by using a set of surface markers as indicated by mT1, T2, and then mT3. There must be at least three independent markers located at a sufficient distance apart.

So, at least three independent markers located at sufficient distance apart per body segment are necessary for the motion capture system. A total number of two transformations are necessary to transform the global coordinate system to the anatomical coordinate system. The first transformation that is required is from the global coordinate system to the marker coordinate system.

So, the first transformation matrix transforms from global coordinate system to marker coordinate system and the second one transforms the marker coordinate system to the anatomical coordinate system. Calibration points as indicated by mC1 and mC2 help to define the transformation matrix, which transforms from the marker coordinate system to the anatomical coordinate system.

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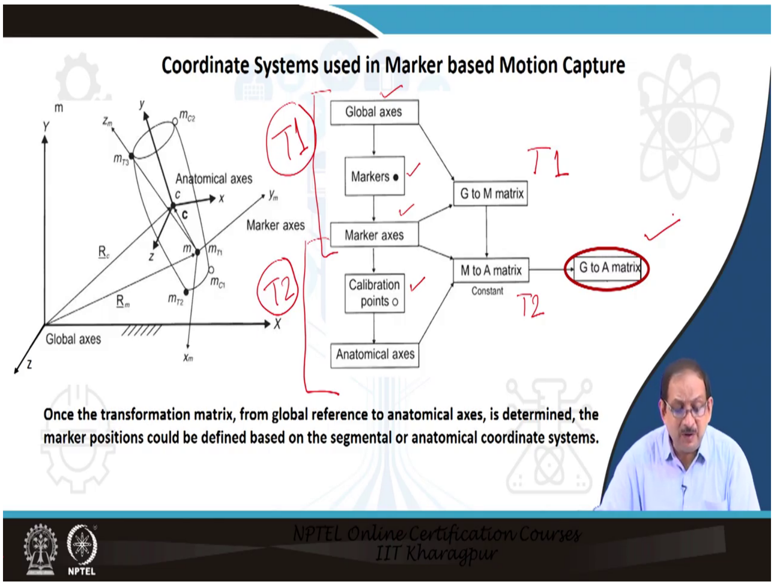

Let us summarize the coordinate systems and the transformations required. So, from the global axis to the marker axis or the global coordinate system to the marker coordinate system. The first transformation, say T1, is used based on the marker data. So, T1, the first transformation transforms from global coordinate system to the marker coordinate system using the position of the markers. The second transformation T2 transforms the marker coordinate system to the anatomical coordinate system using the calibration points as indicated in the figure.

So, global to marker transformation matrix is obtained. So, the global to marker transformation at matrix is obtained from the T1 transformation and from marker to anatomical coordinate system is obtained from the transformation T2. Combining these two transformations T1 and T2, we can find the transformation from the global coordinate system to the anatomical coordinate system. So, once this transformation matrix from global to anatomical coordinate system is determined, the marker positions could be defined based on the segmental or anatomical coordinate system.

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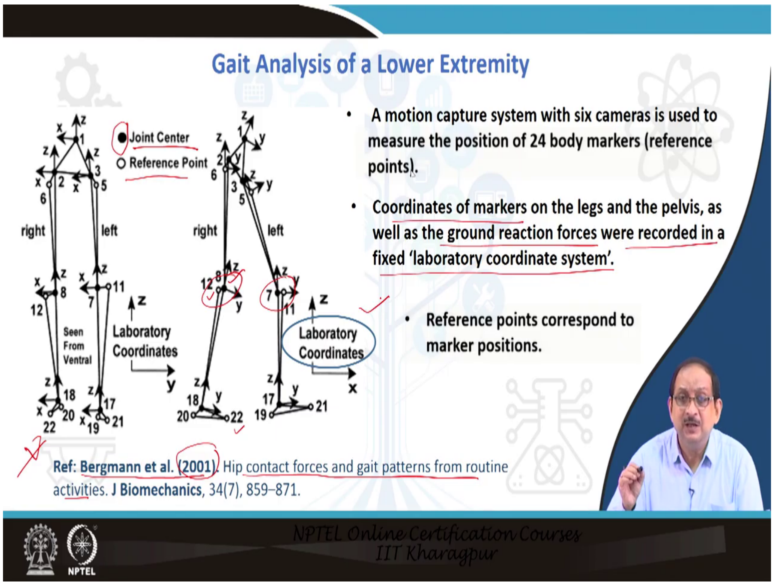

Let us come to the second topic of this lecture on gait analysis of a lower extremity. So, the discussions of this part of the lecture will be based on a pioneering study by the Bergman group in Germany on hip contact forces and gait patterns from routine activities published in Journal of biomechanics in the year 2001.

Now, a motion captures system with six cameras is used to measure the body position of 24 body markers as indicated in the figure. This figure is presented from the study, published study in the Journal of biomechanics. So, in this figure, we can see upto 22 body markers. There is another point which is indicated by the full black circle that is the Joint Center.

So, in the figure as presented here in this slide, we can see reference points indicated by white circles and the Joint Center indicated by full black circles. So, the coordinate of the markers and the ground reaction forces were recorded in a fixed laboratory coordinate system in this study. The motion capture system generates a file containing the x, y, z coordinates of each marker. Each of these markers at each sample point or position at any given instant of time.

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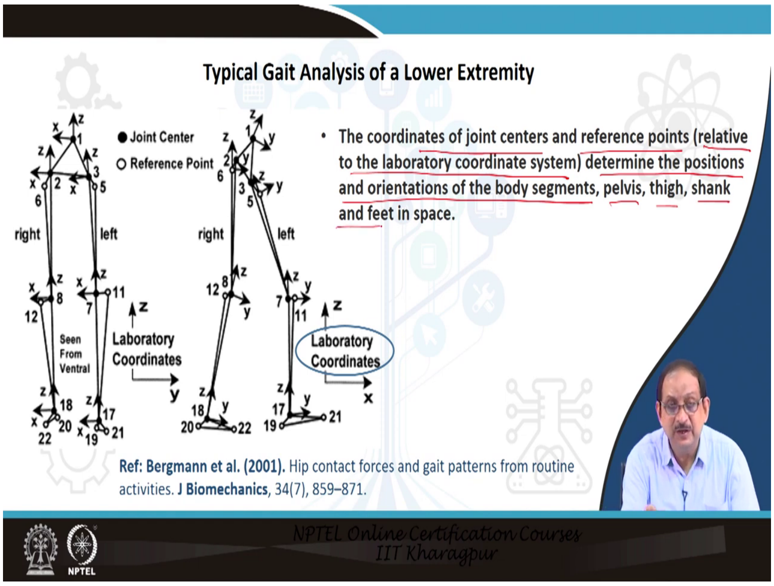

We continue with the gait analysis system. The coordinates of the joint centers and the reference points or the calibration points relative to the laboratory coordinate system determine the positions and orientations of the body segments. So, we determined the positions and orientation of the body segment; it may be pelvis, it may be high, it may be shank, and feet in the space.

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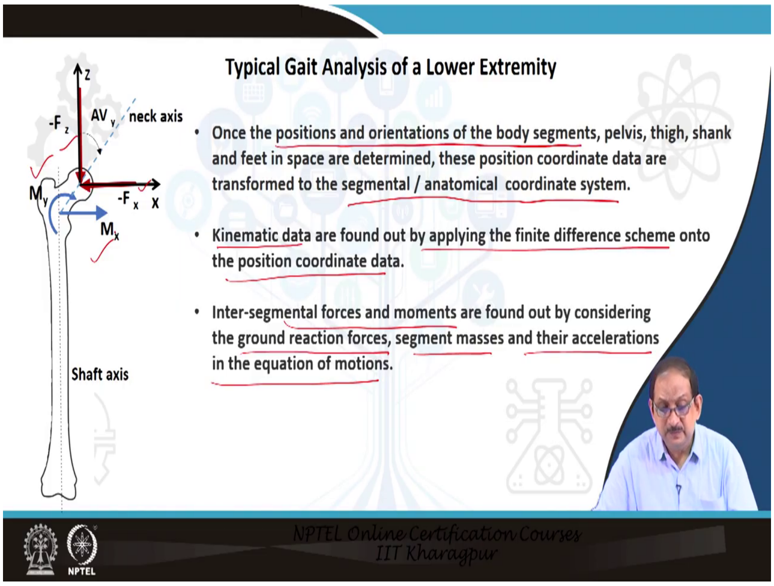

So, once we determine the position and orientation of a body segment, these position coordinates can be transformed to the segmental anatomical coordinate system.

The kinematic data are found out by applying the finite difference scheme. So, the kinematic data can be found out by applying finite difference scheme to the position coordinate data. The intersegmental forces and moments can be found out by considering the ground reaction forces, the segmental masses, and their accelerations in the equations of motion.

So, we can find out the joint reaction forces as indicated here in the figure. Only two components are indicated Fx and Fz. We can also determine the joint moments as indicated herein say, for instance, the hip joint reaction force and moments.

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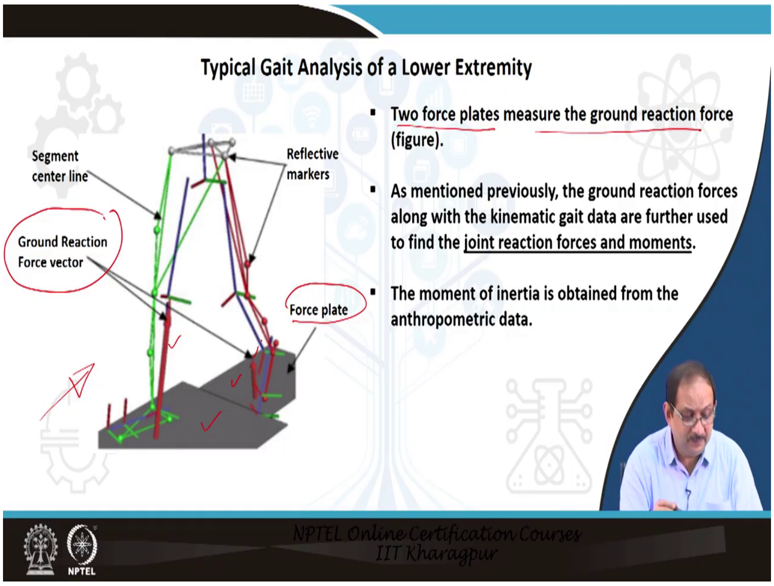

Now, a typical arrangement with the lower extremity model is shown in the figure. So, the two force plates measure the ground reaction forces. So, the force plate is indicated here, and it is giving us the ground reaction force vector.

As mentioned previously, the ground reaction forces along with the kinematic gait data are further used to find out the joint reaction forces and moments. The moment of inertia is obtained from the anthropometric data. The anthropometric data consists of the length and mass properties of each body segment.

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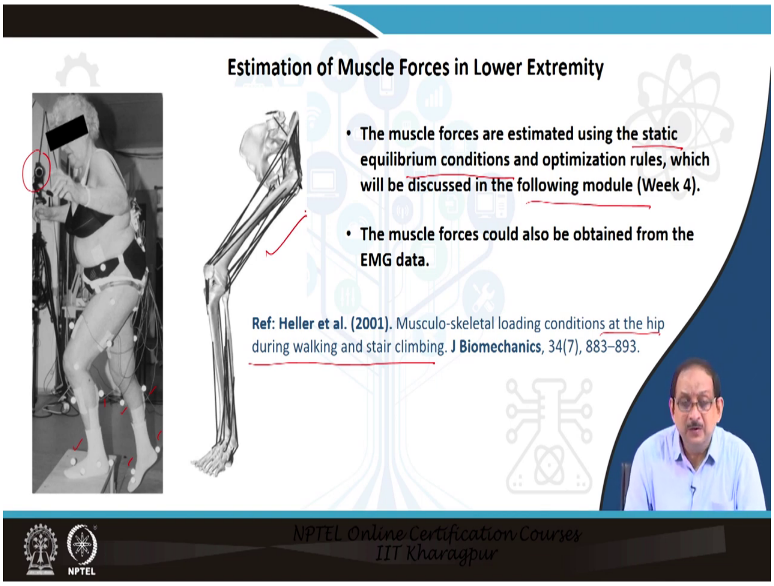

Now, muscle forces can also be estimated in the lower extremity. The muscle forces are estimated using static equilibrium conditions and optimization rules, which will be discussed in detail in the following module in week 4. The muscle forces could also be obtained using EMG measured data.

Now, a pioneering study by the Heller-Bergman group, on the Musculoskeletal loading conditions at the hip joint during different daily activities like walking and stair climbing, was carried out, and the study was published in journal biomechanics. Both the study, the Bergman and the Heller study together was published in 2001.

And the figure on the left, you can see, is a part of that study where a subject is ascending stairs. So, that is an activity stair ascent, and you can see very clearly the marker positions on the body of the subject. And of course, the subject measurements are carried out in a laboratory setup with a camera. There are several cameras; only one camera is visible here. Later on, our musculoskeletal model of the lower extremity is shown here in this figure, which was a part of the study by the Heller and Bergman group.

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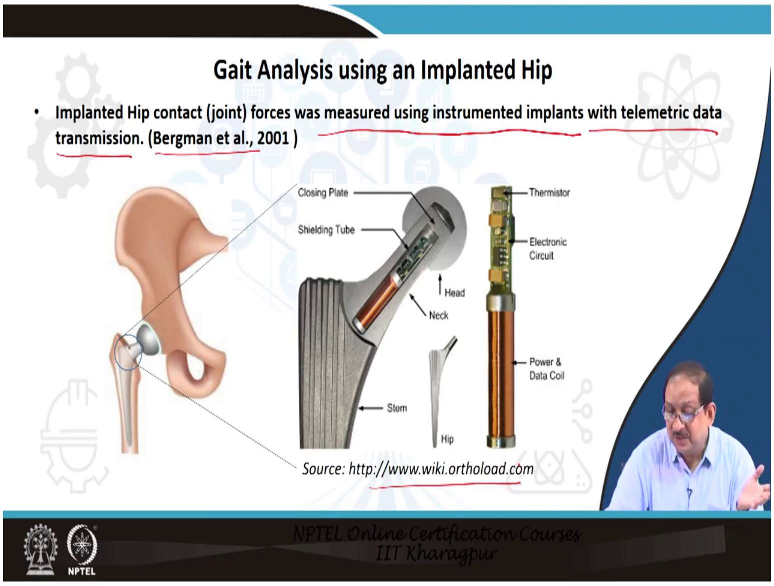

Now, gait analysis has been carried out also using implanted hip. Now, it may be noted that measuring hip joint reaction force or hip contact force in vivo conditions in a patient is almost impossible. Therefore, implanted hip contact or joint reaction force was measured using instrumented implants inbuilt with telemetric data transmission arrangements or instrumentation.

So, this was a part of the study of Bergman as I introduced in the earlier slide. The details of the arrangement in the instrumented implant with the telemetric data transmission instrumentation can be found out on the orthoload website and briefly indicated here in this slide.

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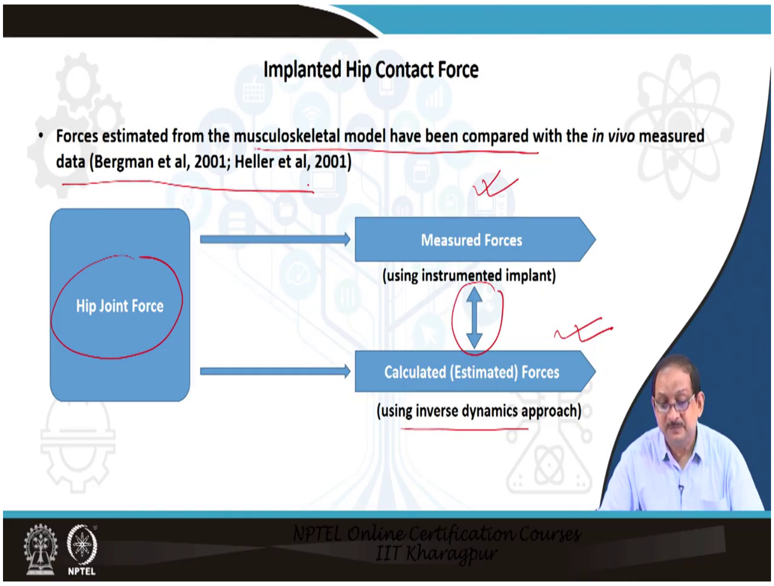

Now, the hip joint reaction force or hip contact force can be calculated or estimated, and it can be measured using instrumented implants. So, these two procedures are different procedures where the measured forces result out of direct measurements using an instrumented implant and the calculated (estimated) forces. Calculated or estimated forces can be obtained using an inverse approach, which we will also be discussing later in the following module in week 4.

The forces estimated from the musculoskeletal model have been compared. So, these calculated and estimated forces can be directly compared with the measured in vivo measure data. And this was carried out in the two pioneering studies by Bergman and Heller as indicated earlier.

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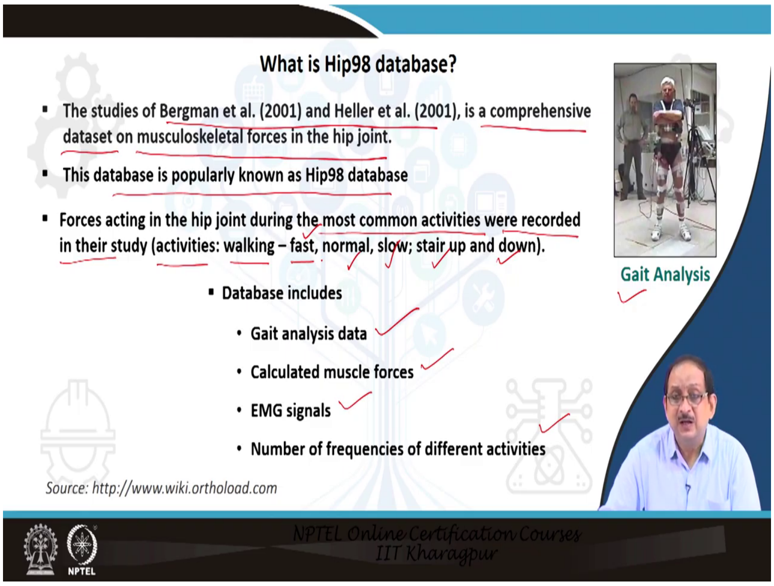

Now, what is hip98 database? Let me introduce at this point, the hip98 database is based on a gait analysis and 3D motion capture system. The studies of Bergman and Heller is a comprehensive dataset on musculoskeletal forces in the hip joint. This database is popularly known as the hip98 database. Forces acting in the hip joint during most common daily activities were recorded in their study.

So, the activities ranged from walking, different types of walking fast, normal, slow, stair up and stair down. The database includes gait analysis data, calculated muscle forces, EMG signals, and a number of frequencies of the different activities like the different types of walking, stair climbing and stair down. Now, the studies showed that the forces estimated using the musculoskeletal models were good approximations of the in vivo measured hip joint forces experience during these daily activities.

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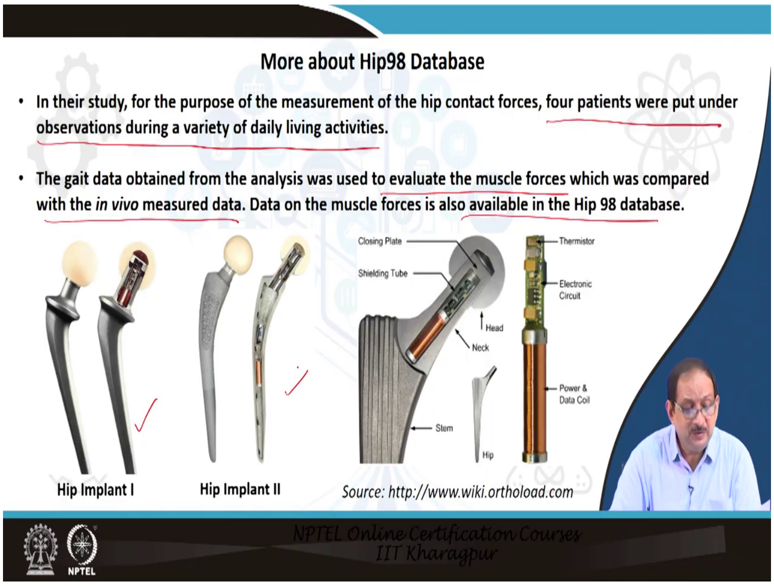

So, in their study, for the purpose of measurement of the hip contact forces, four patients were put under observation during a variety of daily living activities. The gait data obtained from the analysis was used to evaluate muscle forces which were compared with the in vivo measured data. The data on the muscle forces is available in the hip98 database.

Now, in this study by Bergman and Heller, two types of implants were used to measure the hip contact forces for four patients. So, the first one type one was cemented implant, and the second type, type two was uncemented implants. So, type one had one recipient, one patient, and type two had the other three recipients.

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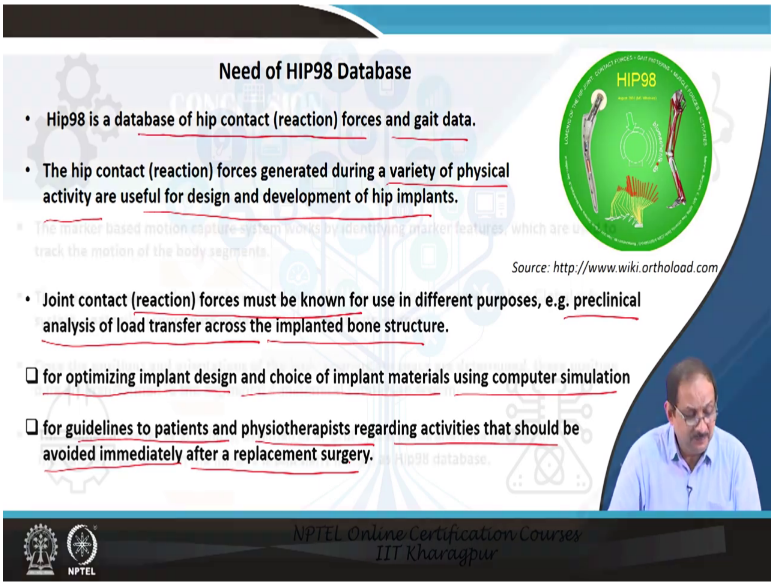

Let us discuss about the need of hip98 database or the usefulness of the hip98 database. The hip98 is a comprehensive database of the hip contact or hip joint reaction forces along with the gait data. The hip contact forces generated during various physiological activities; daily living activities are useful for the design and development of hip implants. The joint reaction forces must be known for use for different purposes.

For example, pre-clinical analysis of load transfer across the implanted bone structure is an important area where the hip joint reaction force or hip contact force data is of vital importance. So, we can summarize that the hip contact forces can be useful for optimizing hip implant design and choice of implant materials using computer simulations with finite element analysis.

It can also serve as guidelines to patients and physiotherapists regarding activities that should be avoided immediately after the replacement surgery is done on a patient.

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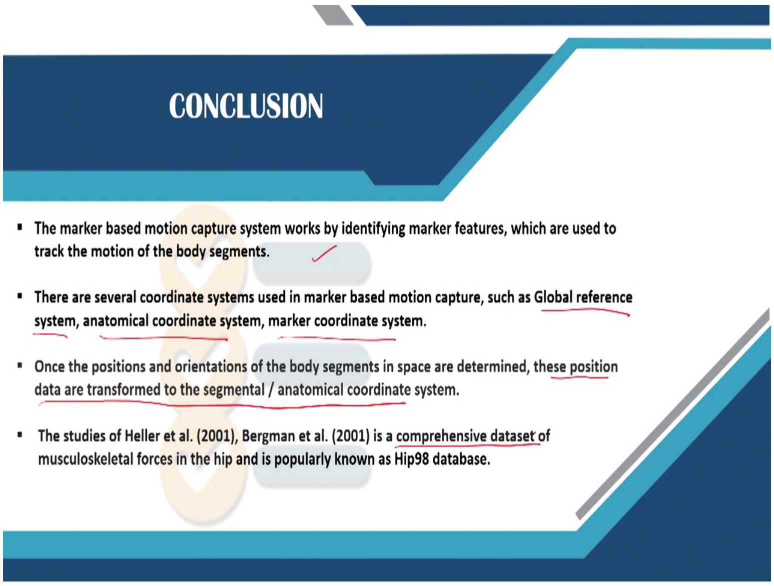

Let us come to the conclusions of this lecture. The marker based motion capture system works by identifying marker features, which are used to track the motion of the body segments. There are several coordinate systems used in the marker based motion capture system such as the global coordinate system, the anatomical coordinate system, and the marker coordinate system.

Once the positions and orientations of the body segments in space are determined, these position data are transformed to the segmental or anatomical coordinate system. The pioneering studies of Heller and Bergman is a comprehensive data set of musculoskeletal forces in the hip and is popularly known as hip98 database.

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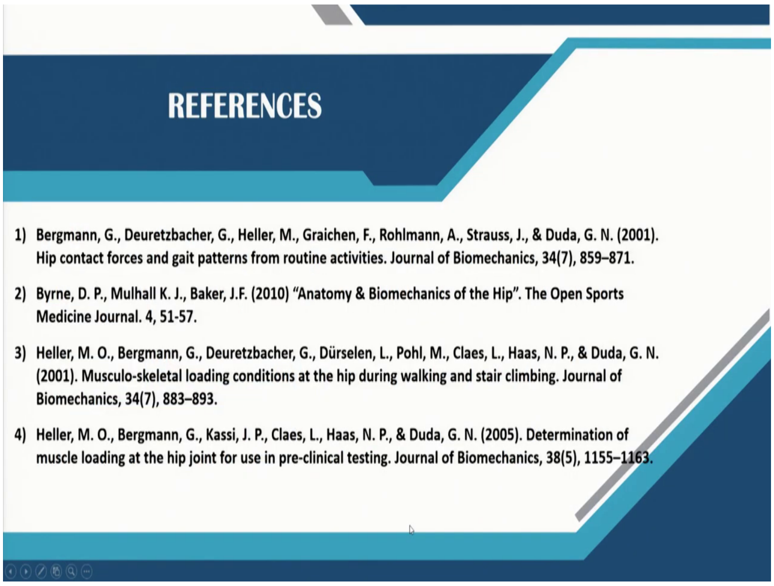

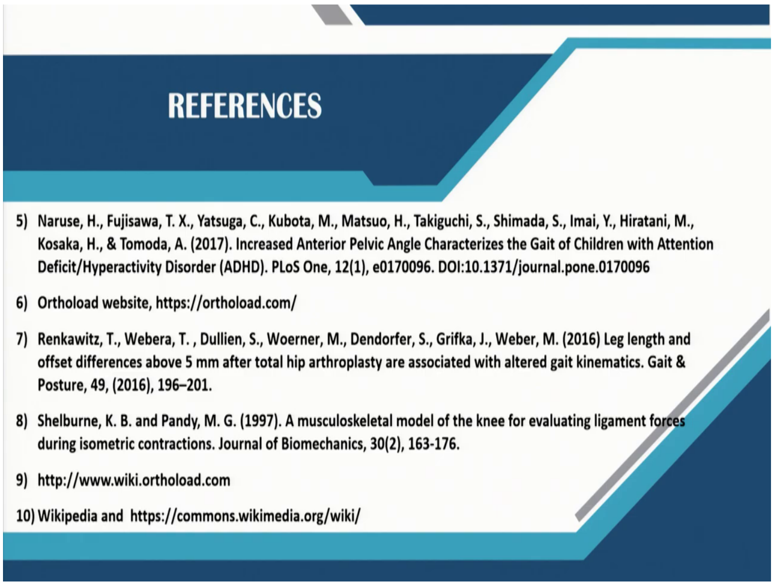

The references are listed here, based on which the lecture was prepared. Thank you for listening.