Introduction: The menisci are two crescent-shaped fibrocartilages situated on the articular surfaces of the tibia. They deepen the tibia articular surfaces, and thus allow them to articulate more securely with the femoral condyles[1]. The menisci protect the joint articular cartilage (by acting as a buffer between femoral and tibial surface while loading), provide joint lubrication, and increase joint stability (by providing congruity between femoral and tibial articular surfaces). The aim of this study was to improve a previously developed dynamic 3D computational knee model by including representation of the menisci. The predicted tibio-femoral kinematics of the model with menisci and without menisci were compared to experimental kinematics. In addition, predicted contact forces between the femur and tibia were compared for walking and squatting activities.

Materials and Methods: Knee geometries (tibia, femur, patella, articular cartilage, medial and lateral menisci, and ligaments) for the model were taken from MRI of a cadaver knee that was also tested in a dynamic knee loading device. 3D Slicer (www.slicer.org) was used to convert MR images into 3D geometries. In a previous study, a computational model of the knee was developed using MSC.ADAMS software (MSC Software Corporation, Santa Ana, CA)[2]. This model was placed within a validated model of a dynamic knee loading machine. In continuation, we have used this model as a basis for our research and have added a discrete body representation of the menisc (Fig1).

The menisc geometries were separated into sixteen discrete rigid bodies. The medial and lateral menisci were represented by eight separate geometries that interact through field elements. The field element can apply a translational and rotational action-reaction force between two parts. To specify a stiffness matrix for the field element, each meniscus was assumed to be a transverse isotropic material. This class of material is described by five independent elastic constants: circumferential modulus; transverse modulus; Poisson’s ratio which is defined as ratio of the contractile strain in transverse plane to tensile strain in the circumferential direction under the load in circumferential direction; Poisson’s ratio , which is the Poisson’s ratio within transverse plane and shear modulus, which describes shearing in a plane including the fiber direction [3].

The meniscal attachments (horns) were modeled using one dimensional spring elements which were non-compressive and linear in tension. The horn stiffness was determined by using the modulus for the ligament, averaging the cross sectional area and length. The resultant stiffness was similar to Donahue’s report [4]. Also, deformable contacts were applied to the meniscus, femur and tibia by using Hertzian contact theory and meniscus material properties. Inputs to the simulation were forces and torques produced by the actuators of the dynamic knee loading device during a simulated squat and walk [2].

Results: The predicted tibio-femoral kinematics of the model with menisci and without menisci were compared to experimental kinematics during a simulated 5 second walk and 10 second squat. Experimental kinematics were measured using on Optotrak 3020 system with markers rigidly attached to the femur and tibia.

The position and orientation of the tibia were compared in the local femoral coordinate system. The rigid body position was represented in the Cartesian X, Y, Z coordinate system and the orientation was represented in Euler Parameters. For example, in the 5 second walk cycle, tibia root mean square (RMS) errors for model without menisci were: X= 13.9670mm, Y= 12.9228mm, Z= 19.7407mm, Q1: 0.0203, Q2= 0.0417, Q3= 0.0421 and Q4= 0.0902. For model with menisci; X= 11.9431mm, Y= 12.4726mm, Z= 14.8863mm, Q1=0.0189, Q2=0.0401, Q3=0.0308 and Q4=0.0732. From this view in the model with menisci, the rms errors of tibia location were lower than the model without the menisci. On the other hand, the comparison of contact force between two models was represented. It was obvious that the contact force in the model with menisci was less than the model without menisci throughout the process (Fig 2).

Discussion: This study indicates that by including the menisci in the model, the kinematic results between the model and experimental data improved. The menisci also attributed to the decrease in the femur and tibia contact force. In the future, for better representation of the dynamic knee behavior under complex motion, the present ligaments will be broken down into a series of spring/damper elements connected by spheres. By assigning deformable contacts to the spheres and bone, wrapping can be characterized. With this advancement to the model, improved correlation between the kinematics of the model and experimental testing are expected.


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