Relative Stability Provided by the Medial Meniscus and Cruciate Ligaments at High and Low Axial Compressions

Introduction: The ACL, PCL and medial meniscus are important stabilizing structures in the knee joint. Investigating what role they play in stability and mobility is essential to understand how degeneration might occur in the knee. The purpose of this study was to investigate how the ACL, PCL, and medial meniscus respond to compression, shear, and torque. Under high compression, the AP medial displacements are reduced which might imply that the medial meniscus becomes the primary stabilizer. Therefore, it was hypothesized that at a small axial compression, the cruciate ligaments are the primary stabilizers whereas at a large axial compression, the medial meniscus is the primary stabilizer.

Methods:

Knee Samples and Testing Rig: Four cadaveric knees were prepared for testing by removing the superficial tissue while maintaining the knee capsule. Three conical indentations were made on the surfaces of the femur and tibia. The indentations were used as fiducial points to track capsule testing.

Four cadaveric knees were positioned in the desktop knee machine as described by Walker et al. 2010.

The tibia was fixed vertically in the machine. A metal frame was fixed to the femur but not attached to the machine. The femur’s ability to move in all six degrees of freedom allowed the bone to locate in any physical position as different flexion angles, compression, shear or torque were applied to the metal frame (Figure 1).

Test Protocol: The knee can experience up to 2-3 times body weight while performing daily activities such as walking or climbing stairs. This test was meant to simulate everyday movements, the values for compression, shear, and torque were scaled down for testing purposes.

Two different test protocols were used for the four knees tested in this study. All knees were positioned to 0, 30, 60, 90, and 135 degrees of flexion and subjected to 10N and 500N of compression. However, the shear and torque values for knees 1 and 2 (Figure 2) were increased for knees 3 and 4 (Figure 3) to achieve displacements anteriorly, posteriorly, and rotationally. The diagrams show that at 30° degrees of flexion, the knee was subjected to 10N of compression and 15N of anterior shear. The same shear and torque were later applied at 500N of compression.

Each knee was first tested with all structures intact. Following a complete test sequence, the ACL was resected and the test sequence was repeated. After ACL resection, the PCL was resected. Lastly, the Meniscus was removed and the test sequence was again followed.

Fiducial points were digitized for the multiple test positions using a three dimensional measuring system to track knee movement during testing.

After testing was complete, the knee capsule was opened and the bearing surfaces of the femur and tibia were digitized. Solid models were generated of the digitized bearing surfaces and an axis system was fitted to each bone. Rapidform XOR was used to fit the femur with a circular axis system (CA) and a vertical plane was positioned on the posterior surface of the tibia parallel to the long axis of the bone. Fiducial points digitized during testing were used to position the femur and tibia. Anterior, posterior, and rotational movement was quantified by measuring the displacement of the femur’s CA relative to the posterior tibial plane.

Results: After the ACL was resected, there was posterior displacement of the femur relative to the tibia for all test conditions. Once the medial meniscus was removed, there was even further posterior displacement (Figure 4). The removal of the medial meniscus caused an increase in anterior and posterior laxity. Under the test condition with the medial meniscus removed, posterior displacement increased posteriorly at flexion angles of 30° and 60° degrees. Knees 3 and 4 dislocated during several test conditions at 500N of compression due to ligament fatigue caused by using higher shear and torque values and pre-existing medical conditions.

Discussion: The test data does not support the hypothesis that the medial meniscus is the primary stabilizer at large compressions. Rather, the ACL plays an important role in keeping the femur anterior on the tibia regardless of the load applied. However, in the posteriorly displacement position, the medial meniscus played a role as a secondary stabilizer, but in doing so, it is likely to experience higher stresses, which might lead to damage and accelerated progression of cartilage wear.