Tibiofemoral Contact Mechanics following a Horizontal Cleavage Lesion in the Posterior Horn of the Medial Meniscus

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Introduction: The medial meniscus has been shown to aid in load distribution, bearing 60% of the load in the knee. Several studies have shown that changes in tibiofemoral contact mechanics, leading to cartilage degeneration, can occur following traumatic tears to the medial meniscus, such as a radial tear. However, it is not clear if degenerative tears also have such an effect on contact mechanics and thus cartilage degeneration. One common type of degenerative tear is the horizontal cleavage lesion (HCL). The HCL is a horizontal tear of the meniscus, predominantly occurring in the region of the posterior horn, separating the meniscus into a top and bottom flap. Therefore, in this study, we sought to determine if an HCL of the posterior horn of the medial meniscus would result in changes in tibiofemoral contact mechanics, as measured by peak contact pressure and contact area, which can lead to cartilage degeneration.

Methods: Ten fresh frozen human cadaveric knee specimens (7 Male and 3 Female; 3 Left and 7 Right) with average age of 77 years (range: 55 - 91 yrs) were analyzed. Each knee was dissected to the capsule, preserving all ligaments and the quadriceps tendon. In order to assess contact pressure, the specimens were placed in a laxity testing rig. The tibia was fixed vertically to the base of the testing rig and the femur was held in a frame, such that the epicondyles were aligned with transverse rods (Figure 1). Vertical cables extended from these rods to a pneumatic cylinder placed below the rig to apply compressive forces to the femur. Horizontal cables were also connected from the transverse rods to servo motors on the four corners of the rig which applied shear and torque to the femur. A Krackow locking suture was fastened through the preserved quadriceps tendon and attached to the femoral frame with a cable to allow the patella to properly track on the femur during testing. To flex the knee, elastic bands were used in combination with a cable extending from the femoral frame to a pneumatic cylinder at the inferior posterior edge of the rig. This allowed the knee to be flexed dynamically from hyper-extension (−5o) to 135o in 15 seconds. The angle throughout testing was recorded using an optical motion tracking system (MicronTracker Sx60, Clarion Technology Inc., Toronto, Ontario, Canada), which tracked black and white targets attached to the femoral frame. With the knee positioned in the rig, a Tekscan pressure sensor (4011N, TEKSCAN Inc, Boston, MA) was inserted under the menisci through an anterior arthrotomy, and held in place with sutures which were passed through a 5mm posterior portal. Prior to use, each sensor was equilibrated, calibrated and conditioned according to the manufacturer’s recommendations. The sensor was connected to a computer and using the I-Scan software the contact maps throughout flexion were recorded. The I-Scan software and motion tracking system were synced to begin recording at the same time for each test, such that at any moment during testing the angle and contact map were known.
The knee was first set in -5° and a compressive force of 500 N applied. The knee was then flexed to 135° as the angle and contact maps were recorded. The knee was then returned to hyper-extension and a 500 N compression with 100 N posterior shear (PS) was applied. Once again the knee was flexed to 135° as the angle and contact maps were recorded. This was repeated for a 500 N compression with the remaining shear and torque forces (2.5 Nm internal torque (IT), 100 N anterior shear (AS), 2.5 Nm external torque (ET)) as well as with a low compression of 100 N compression only (100 N Comp). The compression/shear and compression/torque ratios used were based on the instrumented knee data from Heinlein et al. and D'Lima et al. The force combinations were always applied to the femur in the same order for all ten knees and were intended to represent a wide range of loading conditions in function. With testing of the intact knee complete, an HCL of the posterior horn of the medial meniscus was created by an orthopaedic surgeon using standard arthroscopic instrumentation and technique. The aforementioned testing protocol was then repeated with the HCL. A new sensor was used for the HCL testing to eliminate any loss of sensitivity that could occur with a previously used sensor.

After the HCL testing was complete, the knee with the sensor still inserted, was stripped of all soft tissue, including the ligaments. Using a probe, the inner boundary of the medial meniscus on the sensor was mapped. Based on this map of the neutral meniscus, 4 regions were defined: 1) Anterior region - where the anterior horn was present, 2) Central region - where the central body was present, 3) Posterior region - where the posterior horn was present and 4) Uncovered region - where the meniscus was not present. For each loading condition the peak contact pressure and contact area were recorded in each region of the medial compartment at -5°, and then in 15° increments from full extension (0°) to 135°. The Shapiro-Wilk test was performed with a p-value > 0.05 to test for normality. The Wilcoxon signed-rank test, with significance of p < 0.05, was used to determine if there were differences in peak contact pressure and contact area in each region between the intact knee and that with the horizontal cleavage lesion.

**Results:** Observing the data for each loading condition (Figure 2), statistically significant increases in peak contact pressure were found for all conditions except when a 500 N compression was applied with a 2.5 Nm External Torque. Statistically significant decreases in contact area (6% decrease on average) were only found for the 500 N compression only and the 500 N compression with 2.5 Nm Internal Torque loading conditions (Figure 2B). The region where statistically significant increases in peak contact pressure (13% increase on average) occurred varied depending on the loading condition, although the uncovered and central regions were most common (Figure 2A). The greatest increase in medial peak contact pressure was found to occur between 45 and 90 degrees of flexion. This was true of all regions where a statistically significant increase in peak contact pressure was found for a given loading condition (Figure 3).

**Discussion:** To the authors’ knowledge, this is the first study to assess the consequence of an HCL of the posterior horn of the medial meniscus, on peak contact pressure and contact area. Insight into the biomechanical impact of such a tear is valuable to understanding how osteoarthritis might progress with this pathology. The data from this study indicated that the HCL resulted in a statistically significant increase in peak contact pressure (average 13% increase) primarily in the central and uncovered regions. This is particularly important as these regions are predominantly where full thickness lesions occur in cases of severe OA. However, the increase in peak contact pressure following the HCL was much less than what has historically been noted for total or partial meniscectomy.
Significance: This suggests that a horizontal cleavage lesion will result in moderate but significant changes in tibiofemoral contact mechanics which can lead to cartilage degeneration. However, such osteoarthritic changes would likely take many years to develop and may not have a short term clinical impact.

Figure 1. Laxity testing rig with knee in full extension (Left) and 135° of flexion (Right)
Figure 2. Statistically significant increases in peak contact pressure (A) and decreases in contact area (B) for each loading condition. Only regions with statistically significant changes for each loading condition are shown. Standard error shown. 500 N = 500 N Compression Only; PS = 500 N Compression with a 100 N Posterior Shear; IT = 500 N Compression with a 2.5 Nm Internal Torque; AS = 500 N Compression with a 100 N Anterior Shear; 100 N = 100 N Compression Only.
Figure 3. The greatest increase in peak contact pressure was found between 45° and 90° for all regions and loading conditions where statistical significance was noted (as shown in Figure 5). Standard error shown.

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