Changes in Contact Area in Meniscus Horizontal Cleavage Tears Subjected to Repair and Resection

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Purpose: To assess the changes in tibiofemoral contact pressure and contact area in human knees with a horizontal cleavage tear before and after treatment. **Methods:** Ten human cadaveric knees were tested. Pressure sensors were placed under the medial meniscus and the knees were loaded at twice the body weight for 20 cycles at 0°, 10°, and 20° of flexion. Contact area and pressure were recorded for the intact meniscus, the meniscus with a horizontal cleavage tear, after meniscal repair, after partial meniscectomy (single leaflet), and after subtotal meniscectomy (double leaflet). **Results:** The presence of a horizontal cleavage tear significantly increased average peak contact pressure and reduced effective average tibiofemoral contact area at all flexion angles tested compared with the intact state ($P < .03$). There was approximately a 70% increase in contact pressure after creation of the horizontal cleavage tear. Repairing the horizontal cleavage tear restored peak contact pressures and areas to within 15% of baseline, statistically similar to the intact state at all angles tested ($P < .05$). Partial meniscectomy and subtotal meniscectomy significantly increased average peak contact pressure and reduced average contact area at all degrees of flexion compared with the intact state ($P < .05$). **Conclusions:** The presence of a horizontal cleavage tear in the medial meniscus causes a significant reduction in contact area and a significant elevation in contact pressure. These changes may accelerate joint degeneration. A suture-based repair of these horizontal cleavage tears returns the contact area and contact pressure to nearly normal, whereas both partial and subtotal meniscectomy lead to significant reductions in contact area and significant elevations in contact pressure within the knee. Repairing horizontal cleavage tears may lead to improved clinical outcomes by preserving meniscal tissue and the meniscal function. **Clinical Relevance:** Understanding contact area and peak contact pressure resulting from differing strategies for treating horizontal cleavage tears will allow the surgeon to evaluate the best strategy for treating his or her patients who present with this meniscal pathology.

The meniscus serves to dissipate force across the articular surface by increasing the contact area between the concave distal femoral condyle and the relatively flat tibial plateau.[1,2] Multiple studies have shown that removal of meniscal tissue lowers the contact area and increases contact pressure.[3-7] It is thought that the resulting elevated tibiofemoral contact pressure leads to degenerative changes of the articular cartilage.[8,9]

Tears in the meniscus compromise the load distribution function of the meniscus. In the clinical setting, the torn tissue often is removed to alleviate immediate symptoms; however, tissue removal predisposes the knee to arthritis.[3] Studies also show that greater amounts of tissue removal are associated with worse long-term outcomes in patients.[10] For this reason, approaches that preserve meniscal tissue and potentially prevent future degeneration have been growing.[2,11-13]

Most biomechanical studies have concentrated on vertical or radial tears, with little in the literature published on horizontal cleavage tears (HCTs) until recently. HCTs divide the meniscus into an upper and lower lamina, relatively parallel to the tibial plateau. They are among the most common meniscal tears[14] and

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have been associated with degradation of knee cartilage.[15] The presence of a horizontal tear may cause symptoms leading to arthroscopic intervention. HCTs frequently are treated with partial meniscectomy (single leaflet resection), subtotal meniscectomy (resection of both leaflets), or conservative treatment. Haemer et al.[4] studied the impact of partial and subtotal meniscectomy for small and large horizontal tears in a goat model and showed that both partial and subtotal meniscectomy led to significant elevations in contact pressure for large tears. A recent systematic review examined all reported outcomes after HCT repair attempts and showed a success rate similar to that reported for other tear types that are repaired more commonly.[16] Subsequently, 2 additional clinical studies reported success rates of more than 90% for HCT repair, raising the question related to the biomechanical rationale for such repairs.[17,18]

The specific aim of this study was to assess the changes in tibiofemoral contact pressure and contact area in human knees with a HCT before and after treatment. We hypothesized that resection of one or both lamina of a large HCT in the medial meniscus leads to elevation in contact pressures in the knee, which may be mitigated through repair.

Methods

Preparation, Repair, and Loading

Ten intact fresh frozen human cadaveric knees (donor weight 66 ± 11 kg, donor height 169 ± 8.1 cm, donor age 67 ± 7 years, 5 male and 5 female) were acquired (Medcure, Providence, RI) and evaluated by an orthopaedic surgeon (B.S.B.) to exclude those with grade 3 or 4 cartilage lesions (no specimens were excluded). The skin and subcutaneous fat were removed from the specimens, followed by the underlying muscle and extensor mechanism. Care was taken to preserve the integrity of the joint capsule, collateral ligaments, and cruciate ligaments. On gross examination, each showed no evidence of significant arthritis or meniscal tearing. The femur and tibia were cut 10 cm from the joint line.

To gain access to the medial compartment, an osteotomy was performed at the femoral origin of the medial collateral ligament (MCL) so that the superficial and deep fibers could be taken down as a continuous sleeve. The bone was then repaired in situ with a 50-mm × 3.5-mm cortical screw and washer. This technique was chosen because it does not affect tibiofemoral contact pressures.[3] To allow the testing film to lie flat on the tibial plateau, an incision was made beneath the anterior and posterior horns of the meniscus along the joint line, and approximately 1 cm of the coronary ligaments was resected without disrupting the meniscal root, meniscofemoral ligaments, or the remaining capsular attachments.

A calibrated pressure sensor (4010N; 44 mm × 68 mm × 0.2 mm, 422 sensels, 25 sensels/cm^2 density; Tekscan, South Boston, MA) was wrapped in adhesive film (Tegaderm, Nexcare; 3M, Saint Paul, MN) and was inserted under the medial meniscus flush with the tibial plateau. Sensors were calibrated for repeatability according to manufacturer's protocol. The sensor was secured with 2 #1 PDS sutures (Polydiaxone suture; Ethicon, Somerville, NJ) placed through the periphery of the sensor and the periosteum of the tibia.[3]

Before insertion, the pressure sensor was calibrated with a loading frame (Instron 8511; Instron, Norwood, MA) with its native load cell (2500 N limit). Three calibration pressures within the expected minimum and maximum tibiofemoral contact pressure ranges of the study were applied, and the entire matrix area of the sensor was loaded to ensure precise calibration. The sensors were instructed to collect pressure data at a sampling rate of 100 Hz during cyclic loading experiments and at a sampling rate of 4 Hz during the ramped loading tests to ensure a consistent peak pressure measurement. The ramped loading tests also acquired pressure data at 4 Hz for 10 seconds once the maximum load was achieved. Data acquisition for each specimen was finished after the ramped loading tests.

The tibiofemoral loading protocol was based on the work of Bedi et al.,[3] in which the authors analyzed tibiofemoral contact pressures for radial tears in cadaveric lateral menisci. The flexion angles were chosen to recreate the tibiofemoral contact pressure profile transitioning from stance[3] to normal walking gait before execution of the swing mechanism, where load on the meniscus is minimal. Although a measurement at 0° best resembles a well-established loading scheme, load bearing occurs at various flexion angles; thus, additional testing at flexion angles of 10° and 20° was investigated for potential variations in loading behaviors surrounding the meniscus.

A simplified testing jig was designed to apply axial load to the knee joint at varying flexion angles. The jig consisted of 2 boxes to mount the embedded ends of the proximal femur and the distal tibia. The distal tibia box was mounted on a 6-degree of freedom (DoF) load cell (Omega 160; ATI Industrial Automation, Apex, NC) and a sliding mechanism to allow for the selection of different flexion angles. The testing jig was mounted on the load cell (2500 N limit) of the load frame (Instron 8511; Instron). The proximal femoral box was attached to a ball joint before being connected to the hydraulic actuator of the load frame (Fig 1). The knee was placed in the testing jig by potting the tibial and femoral diaphyses into a block mold with the use of