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

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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

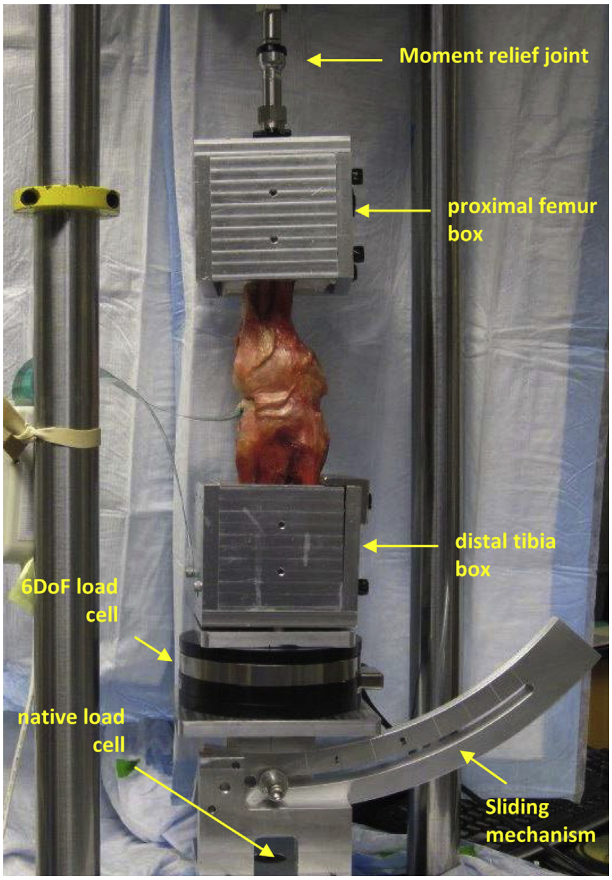

Fig 1. An outline of the testing jig with key components and a left knee mounted onto the jig. (DoF, degree of freedom.)

polymethylmethacrylate. The polymethylmethacrylate blocks were placed and secured into the jig, ensuring the joint line was perpendicular to the mechanical axis of the mechanical testing system at 0° flexion angle via a laser guide (Fig 2). Knees were loaded axially at twice the body weight and 0° flexion angle (1310-2437 N), simulating the average joint reactive force the knee experiences during normal gait.[19] Axial loads for 10° and 20° flexion angles were calculated and applied for the said angles (1290-2400 and 1231-2290 N, respectively). For each testing condition and flexion angle, the knees were loaded axially for 20 cycles at a rate of 1 Hz. The native load cell of the load frame was used to control the load frame, and the 6DoF load cell was used to record loads and torques along X (anterior-posterior, posterior + direction), Y (medial-lateral, lateral + direction), and Z (superior-inferior, superior + direction) axes. Under these conditions, data were recorded for average and peak tibiofemoral contact pressures and contact area in the intact medial meniscus (group 1) with the jig placed in 0°, 10°, or 20° of flexion respectively (Fig 2), for 20 cycles each, to simulate various phases of the gait cycle.[19]

After the MCL was then taken down, an HCT was made in the medial meniscus under direct visualization with a #11 surgical blade just superior to the apex. The tear extended to within 1 mm of the joint capsule and extended from the anterior horn to the posterior horn (Fig 3A) at the approximate midpoint of the meniscus.

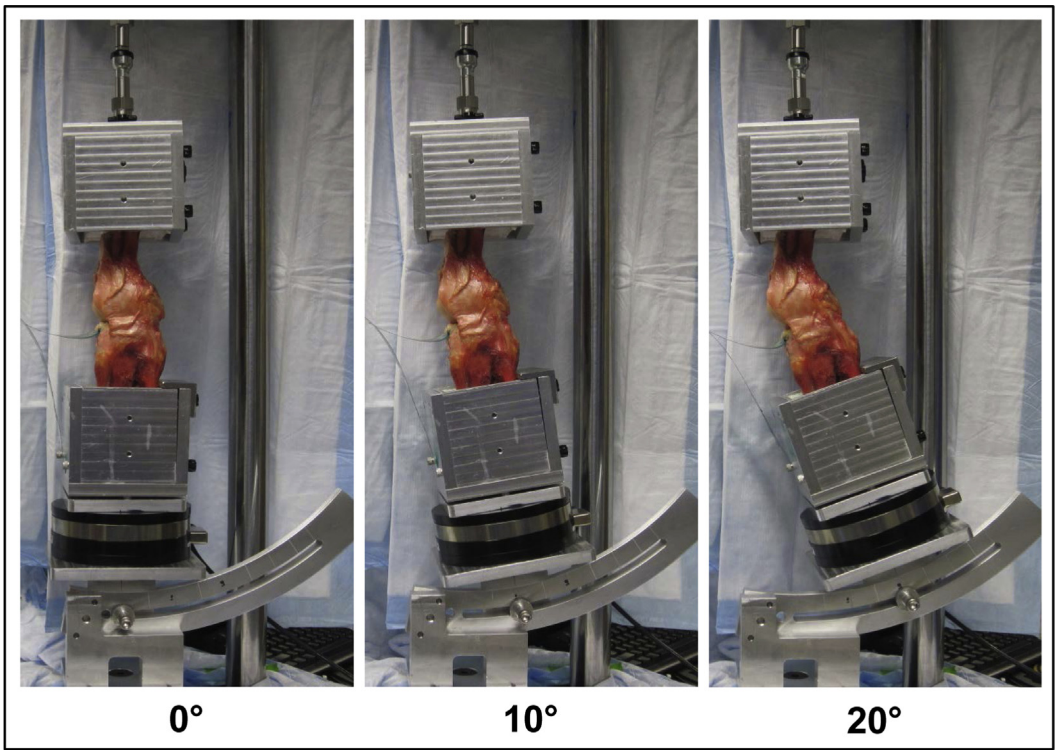

Fig 2. The tibiofemoral axial loading apparatus employed in this study at 0°, 10°, and 20° settings with a left knee.

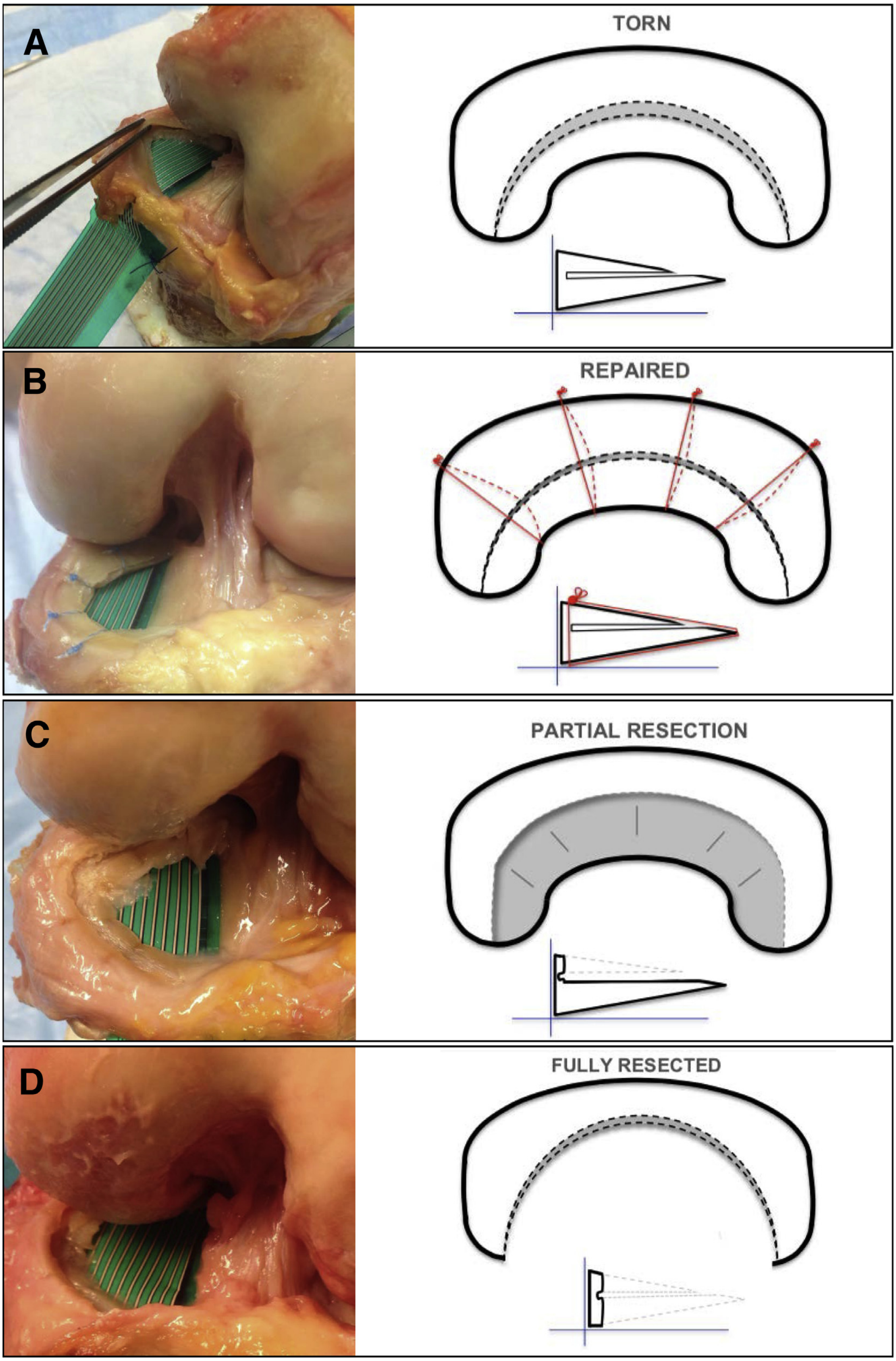

Fig 3. The experimental testing states (torn [A], repaired [B], partially resected [C], and fully resected [D]) presented in this study with a left knee.

The location and size of tear were confirmed by visual inspections. The MCL osteotomy was repaired and the loading regimen was repeated, and we analyzed tibiofemoral contact area and pressure for the torn meniscus and recorded for the varying degrees of flexion (group 2).

The meniscus was then repaired in an open fashion with an all-inside, vertical loop technique. Four vertical loops of 2-0 UHMWPE suture (Teleflex, Morrisville, NC) were spaced evenly along the length of the torn meniscus (Fig 3B) and tied with surgeon's knots. The sutures were placed via the use of a suture passing device (NovoStitch; Ceterix Orthopaedics, Menlo Park, CA). The loading regimen was repeated for the repair group (group 3). The repair sutures were removed and the upper leaflet resected to within 2 mm of the meniscal periphery to simulate a partial meniscectomy and the sample was loaded (group 4) (Fig 3C). Lastly, the remaining lower meniscal leaflet was resected back to a stable rim (2 mm from capsular attachment) to complete a subtotal meniscectomy. The loading process was repeated (group 5) (Fig 3D).[3] During the entire testing process, the Tekscan sensors were monitored for crinkling.

Statistical Analysis

Tibiofemoral contact pressures average 6 ± 1.5 MPa in the medial compartment of normal knees and 7.4 ± 1.5 MPa in knees with the medial meniscus resected.[3] When these values are used as a guide, a sample size of 10 was calculated to result in 80% power to detect a 20% change in contact pressure based on analysis of variance (nQuery Advisor ver. 7.0; Statistical Solutions, Saugus, MA). The Shapiro-Wilk test for normality was used to evaluate the distribution of the data. When a normal distribution was assumed, 2-way analysis of variance with the estimated marginal means method and Tukey post-hoc analysis was performed with group (intact, full-thickness tear, repair, partial meniscectomy, and subtotal meniscectomy) and flexion angle (0°, 10°, 20°) as fixed factors and contact pressure and contact area as dependent variables. SPSS software (version 21.0, Chicago, IL) was used for data analysis. All reported *P* values are 2-tailed, and $P < .05$ was considered statistically significant.

Results

The presence of a HCT significantly increased average peak contact pressure and reduced effective average tibiofemoral contact area at 0°, 10°, 20° of flexion compared with the intact state ($P < .03$) (Fig 4). The increase in contact pressure was approximately 70% after creation of the HCT. Repairing the HCT resulted in peak contact pressures and areas that were restored to within 15% of baseline, statistically similar to the intact state at all angles tested ($P < .05$). Partial meniscectomy, through the removal of the superior leaflet, significantly increased average peak contact pressure and reduced average contact area at all degrees of flexion compared with the intact state ($P < .05$), with pressures approximating the unresected HCT status.

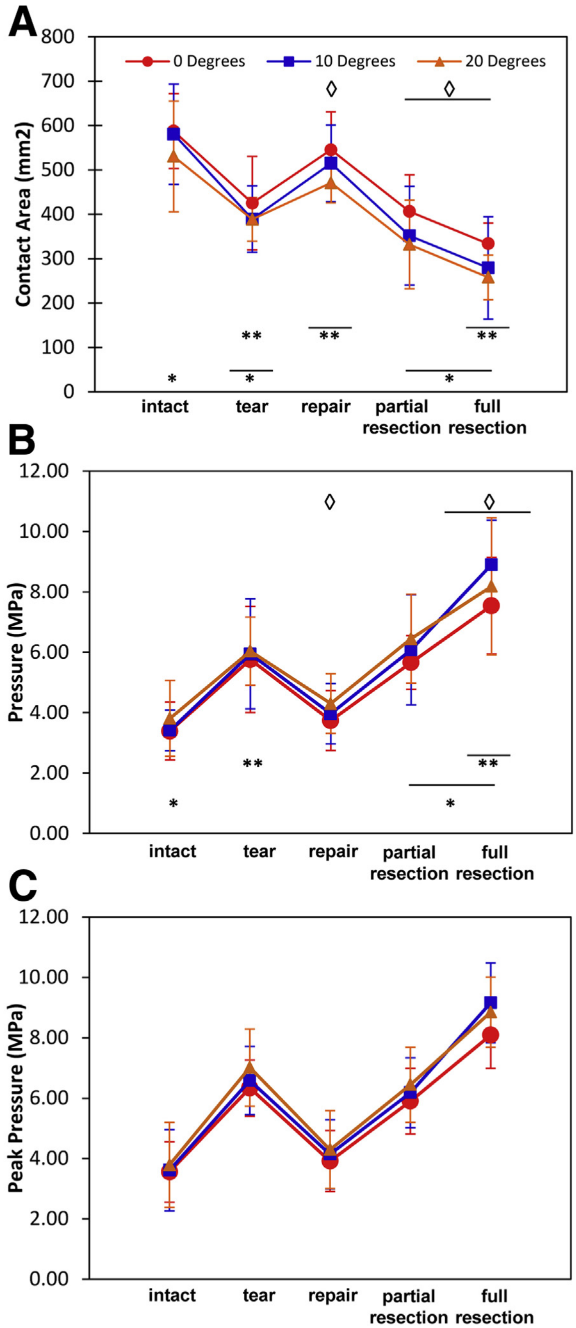

Fig 4. Tibiofemoral contact area (A) along with average (B) and peak (C) contact pressures for each of the 5 test states (intact, torn, repaired, partial, and total resection). Single asterisk (*) denotes difference between intact state with other states; double asterisk (**) denotes difference between tear state and other states; and diamond symbol denotes difference between repaired state and other states.

Although partial meniscectomy decreased the average contact area and increased the average peak contact pressure from baseline by a greater amount than the torn state, the difference between the torn and partial meniscectomy conditions was not statistically significant. Compared with the intact and repaired states,

Table 1. Load and Torque Data From the 6-Degree of Freedom Load Cell for All Axes

Angle, °	Condition	Fx, N	Fy, N	Fz, N	Mx	My	Mz
0	Intact	53.73	104.89	−1702.46	0.97	5.61	0.20
	SD	43.86	47.61	189.35	7.18	4.13	0.68
0	Tear	50.22	102.80	−1693.77	1.20	5.37	0.42
	SD	50.62	31.16	193.63	5.10	5.18	0.61
0	Repair	47.72	105.64	−1696.22	1.15	5.60	−0.14
	SD	56.37	47.75	186.21	8.26	7.07	0.74
0	Part res	50.26	102.90	−1719.32	1.42	5.36	−0.48
	SD	55.28	44.58	190.70	7.65	6.40	0.52
0	Full res	67.28	104.88	−1729.79	0.87	4.61	−0.44
	SD	63.63	41.86	191.23	7.49	7.94	0.73
10	Intact	213.08	204.14	−1664.48	21.94	32.69	1.14
	SD	58.28	43.99	190.84	5.90	5.58	1.49
10	Tear	219.20	212.74	−1676.55	24.82	36.86	1.08
	SD	47.50	45.08	188.10	7.78	5.25	1.26
10	Repair	190.37	212.69	−1672.86	31.20	27.00	1.54
	SD	44.51	56.01	178.37	9.99	7.59	1.33
10	Part res	191.63	202.32	−1683.35	27.60	28.07	1.52
	SD	49.64	54.90	185.29	8.96	7.49	1.36
10	Full res	210.35	208.12	−1680.01	26.09	30.27	1.82
	SD	66.40	52.19	180.09	8.38	7.90	1.32
20	Intact	350.06	298.44	−1620.92	47.57	58.45	2.22
	SD	52.30	51.86	148.91	5.66	7.75	1.82
20	Tear	370.73	303.64	−1634.72	47.56	62.86	2.17
	SD	59.26	60.46	153.96	8.54	8.98	1.99
20	Repair	343.26	301.31	−1610.24	56.45	56.31	2.24
	SD	45.50	69.02	163.22	8.09	8.93	1.96
20	Part res	331.37	289.63	−1628.28	44.48	59.25	2.16
	SD	56.69	71.65	153.81	9.75	8.75	2.06
20	Full res	367.04	303.52	−1622.47	51.93	61.06	1.96
	SD	55.24	59.98	155.04	7.20	7.56	2.15

NOTE. F denotes force in x, y and z axes (Fx, Fy, and Fz), while M denotes moment in x, y and z directions (Mx, My, and Mz).
res, resection; SD, standard deviation.

subtotal meniscectomy increased the average peak contact pressure by more than 100% and decreased the average tibiofemoral contact area by approximately 50% at all degrees of flexion ($P < .0001$).

Increasing flexion angle was associated with decreased average contact areas by 10% to 15% in the presence of a tear, repair or meniscectomy, with 20° flexion resulting in larger reductions in contact areas. In the intact state, little difference in average contact area was observed between 0° and 10° flexion, and a small difference was observed at 20° flexion. Moreover, increasing flexion angle resulted in some differences in contact pressure, predominantly in the partial and full resection states. Contact pressure values in the intact, torn, and repaired states were very similar between all flexion angles.

Review of the data found that they were normally distributed. Measurable pressures were observed both under the meniscus and between the femoral condyle and tibial plateau, with maximum pressures observed between the femoral condyle and tibial plateau in all conditions. Results from the 6DoF load cell revealed no differences in forces and torques in the anterior-posterior and medial-lateral directions among groups (intact, tear, repair, partial meniscectomy, and subtotal meniscectomy) across all flexion angles (P values greater than .05 for all cases) (Table 1).

Discussion

A large HCT in the medial meniscus decreased tibiofemoral contact area, leading to increased contact pressures when the knee was at or near full extension. When the tear was repaired with a vertical suture configuration, the contact area and pressure improved and returned almost to baseline. With resection of the superior leaflet and subtotal meniscectomy, the contact area was reduced and contact pressure increased proportionally to the amount of meniscus removed. This behavior was consistent throughout knee flexion (0°, 10°, and 20°).

Historically, symptomatic HCTs have been treated with the use of benign neglect or subtotal resection of the inferior or superior lamina of the meniscus.[20] In previous studies, the presence of a HCT has been associated with joint degeneration.[15] Partial meniscectomy has been performed to alleviate pain and prevent the progression of tears.[20]

Several attempts have been made to understand the clinical impact of a horizontal tear and its treatment with meniscectomy. Arno et al.[21] confirmed that contact area decreases and contact pressure increases in knees with a HCT during simulated walking, stair climbing/descending, rising from a chair, and squatting. They concluded that the presence of an untreated HCT may lead to cartilage degradation. It is noteworthy that the horizontal tears created in this study were longer than those in the study of Arno et al.[21] Brown et al.[22] explored the difference in contact area and pressure after partial meniscectomy and total resection for a small horizontal tear during axial loading at full extension. These authors created a tear near the posterior horn of the medial meniscus and the resection was of the inferior leaflet rather than the superior leaflet resected in the present study. Their work, in contrast to other published investigations and the present study, suggested no significant change in contact area for any condition other than the total resection. Although this study found no significant detrimental effects from removing the inferior leaflet of HCTs, our study found significant increases in contact pressure when the superior leaflet was removed[22] Haemer et al.[4] tested small and large tears and found that both partial meniscectomy and total resection of large tears caused a significant increase in contact pressure. None of these investigations explored the effect of suturing the tear together to simulate a repair.

HCTs of the meniscus can present a clinical dilemma for orthopaedic surgeons. Leaving the tear alone may result in tear progression, resulting in increased contact pressures and degeneration of the articular cartilage[20] (Arno et al.,[21] Haemer et al.[4]). Alternatively, resection of one leaflet of the horizontal tear may be palliative but result in a permanent loss of meniscal tissue. In their study, Brown et al.[22] showed minimal detrimental effects if the inferior leaflet is resected. The present study showed significant changes in contact area and contact pressure when the superior leaflet was resected. Both studies agree that resecting both leaflets will lower contact area and increase contact pressures, similar to a subtotal resection. As a third option, the horizontal tear could be repaired. If the tissue heals, a patient's symptoms may resolve. By preserving their meniscus and its function, further degeneration may be avoided by restoring the contact area and contact pressure to near normal.

At present, there are few studies describing the clinical results after a repair of horizontal cleavage meniscus tears. In recent systematic review, Kurzweil et al.[16] found only 9 studies in the literature dating back to 1980 that included at least one clinical outcome. These studies included repairs of 98 HCTs and noted success with freedom from reoperation in approximately 78%.

More recently, Pujol et al.[17] studied open repairs of HCTs with and without the use of platelet-rich plasma. At a mean follow-up of 34 months, only 3 of 34 patients did not respond (91% success). The study noted no significant differences in failure rate between patients treated with and without platelet-rich plasma. Likewise, Ahn et al.[18] followed 32 patients after a symptomatic HCT repair. The tears were treated with all-inside suture technique and marrow stimulation. At an average of 45.6 months, only 3 repairs had failed, resulting in a 91% success rate. Second-look arthroscopy in 11 patients revealed 1 repair that had failed to heal. Lastly, Salle de Chou et al.[23] studied 2 groups of patients receiving open repairs of HCTs. One group of 18 patients was followed for more than 2 years, whereas the other group of 9 patients was followed for more than10 years. Both groups showed positive clinical results on their Lysholm and International Knee Documentation Committee scores as well as decreased magnetic resonance imaging signal in all patients. Most importantly, the positive results achieved obtained in the short term were maintained in the long term.

Limitations

As for limitations, this investigation was a controlled laboratory experiment, not an in vivo clinical trial. As such, it would be inappropriate to extrapolate our data to clinical outcomes. The tears studied were large by design and may not be applicable to smaller HCTs. Moreover, an open repair technique was used in this study because pressure sensor placement required a wide dissection. All-inside arthroscopic techniques may not produce the same results.

In this investigation, each specimen was subjected to an axial load at varying degrees of knee flexion. We did not recreate the complex mixture of axial loading, translation, rotation, and shear that is present in vivo. Similarly, the effects of a torn, resected, or HCT on the knee's ligamentous stability was not investigated. The coronary ligaments were resected partially to allow the pressure film to lie flat on the tibial plateau. This partial resection of this tissue may have increased the meniscal motion. For comparison, the same methodology was used in the controls and subsequent torn specimens. As a relative change, our approach may or may not recreate the natural state.

Each specimen was loaded for 20 cycles. They were not tested to failure. As such, the durability of the repair was not tested. Similarly, the impact of the suture on the articular cartilage was not considered. Because the NovoStitch device is relatively new, there is little clinical experience with this repair technique. A recent publication by Saliman[24] provides one perspective regarding the feasibility of placing all-inside circumferential compression stitches to repair meniscus tears in vivo.

Conclusions

The presence of a HCT 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 HCTs 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 HCTs may lead to improved clinical outcomes by preserving meniscal tissue and the meniscal function.

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References

1. Renstrom P, Johnson RJ. Anatomy and biomechanics of the menisci. *Clin Sports Med* 1990;9:523-538.
2. Krause WR, Pope MH, Johnson RJ, Wilder DG. Mechanical changes in the knee after meniscectomy. *J Bone Joint Surg Am* 1976;58:599-604.
3. Bedi A, Kelly NH, Baad M, et al. Dynamic contact mechanics of the medial meniscus as a function of radial tear, repair, and partial meniscectomy. *J Bone Joint Surg Am* 2010;92:1398-1408.
4. Haemer JM, Wang MJ, Carter DR, Giori NJ. Benefit of single-leaf resection for horizontal meniscus tear. *Clin Orthop Relat Res* 2007;457:194-202.
5. Zhang AL, Miller SL, Coughlin DG, Lotz JC, Feeley BT. Tibiofemoral contact pressures in radial tears of the meniscus treated with all-inside repair, inside-out repair and partial meniscectomy. *Knee* 2015;22:400-404.
6. Forkel P, Herbort M, Schulze M, et al. Biomechanical consequences of a posterior root tear of the lateral meniscus: Stabilizing effect of the meniscofemoral ligament. *Arch Orthop Trauma Surg* 2013;133:621-626.
7. Padalecki JR, Jansson KS, Smith SD, et al. Biomechanical consequences of a complete radial tear adjacent to the medial meniscus posterior root attachment site: In situ pull-out repair restores derangement of joint mechanics. *Am J Sports Med* 2014;42:699-707.
8. Baratz ME, Fu FH, Mengato R. Meniscal tears: The effect of meniscectomy and of repair on intraarticular contact areas and stress in the human knee. A preliminary report. *Am J Sports Med* 1986;14:270-275.
9. McDermott ID, Amis AA. The consequences of meniscectomy. *J Bone Joint Surg Br* 2006;88:1549-1556.
10. Englund M, Roos EM, Roos HP, Lohmander LS. Patient-relevant outcomes fourteen years after meniscectomy: Influence of type of meniscal tear and size of resection. *Rheumatology* 2001;40:631-639.
11. Abrams GD, Frank RM, Gupta AK, Harris JD, McCormick FM, Cole BJ. Trends in meniscus repair and meniscectomy in the United States, 2005-2011. *Am J Sports Med* 2013;41:2333-2339.
12. Allen PR, Denham RA, Swan AV. Late degenerative changes after meniscectomy. Factors affecting the knee after operation. *J Bone Joint Surg Br* 1984;66:666-671.
13. von Lewinski G, Stukenborg-Colsman C, Ostermeier S, Hurschler C. Experimental measurement of tibiofemoral contact area in a meniscectomized ovine model using a resistive pressure measuring sensor. *Ann Biomed Eng* 2006;34:1607-1614.
14. Ferrer-Roca O, Vilalta C. Lesions of the meniscus. Part II: Horizontal cleavages and lateral cysts. *Clin Orthop Rel Res* 1980:301-307.
15. Englund M, Roos EM, Lohmander LS. Impact of type of meniscal tear on radiographic and symptomatic knee osteoarthritis: A sixteen-year followup of meniscectomy with matched controls. *Arthritis Rheum* 2003;48:2178-2187.
16. Kurzweil PR, Lynch NM, Coleman S, Kearney B. Repair of horizontal meniscus tears: A systematic review. *Arthroscopy* 2014;30:1513-1519.
17. Pujol N, Salle De Chou E, Boisrenoult P, Beaufils P. Platelet-rich plasma for open meniscal repair in young patients: Any benefit? *Knee Surg Sports Traumatol Arthrosc* 2015;23:51-58.
18. Ahn JH, Kwon OJ, Nam TS. Arthroscopic repair of horizontal meniscal cleavage tears with marrow-stimulating technique. *Arthroscopy* 2015;31:92-98.
19. Kumar D, Manal KT, Rudolph KS. Knee joint loading during gait in healthy controls and individuals with knee osteoarthritis. *Osteoarthritis Cartilage* 2013;21:298-305.
20. Newman AP, Daniels AU, Burks RT. Principles and decision making in meniscal surgery. *Arthroscopy* 1993;9:33-51.
21. Arno S, Bell CP, Uquillas C, Borukhov I, Walker PS. Tibiofemoral contact mechanics following a horizontal cleavage lesion in the posterior horn of the medial meniscus. *J Orthop Res* 2015;33:584-590.
22. Brown MJ, Farrell JP, Kluczynski MA, Marzo JM. Biomechanical effects of a horizontal medial meniscal tear and subsequent leaflet resection. *Am J Sports Med* 2016;44:850-854.
23. Salle de Chou E, Pujol N, Rochcongar G, et al. Analysis of short and long-term results of horizontal meniscal tears in young adults. *Orthop Traumatol Surg Res* 2015;101:S317-S322 (8 suppl).
24. Saliman JD. The circumferential compression stitch for meniscus repair. *Arthrosc Tech* 2013;2:e257-e264.