The American Journal of Sports Medicine
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Am J Sports Med 2012 40: 1863 originally published online July 11, 2012
DOI: 10.1177/0363546512453291

Effects of Serial Sectioning and Repair of Radial Tears in the Lateral Meniscus

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Background: Radial transection of the peripheral fibers of the meniscus could render it nonfunctional; however, the biomechanical consequences of a complete lateral meniscal radial tear and repair in human specimens have not been elucidated.

Hypothesis: A complete radial tear will exhibit knee contact mechanics approaching those of total meniscectomy. Repair of complete radial tears will re-create normal load transmission across the joint.

Study Design: Controlled laboratory study.

Methods: Five matched pairs of fresh-frozen human cadaveric knees were tested in axial compression (800 N) at 2 knee flexion angles (0° and 60°). Six meniscal conditions were sequentially tested: (1) intact lateral meniscus; radial width tears of (2) 50%, (3) 75%, and (4) 100%; (5) meniscal repair; and (6) total meniscectomy. Repairs were pair matched and used either an inside-out or all-inside technique. Tekscan sensors measured tibiofemoral contact pressure, peak contact force, and contact area in the lateral meniscus and medial meniscus.

Results: Complete radial tears of the lateral meniscus produced significant increases in mean contact pressure (P = .0001) and decreased contact area ($P < .0001$) compared with the intact state. This effect was significantly less than that of total meniscectomy ($P < .0023$). Lesser degrees of radial tears were not significantly different from the intact state ($P > .3619$). Mean contact pressure after either repair technique was not significantly different from the intact state (P = .2595) or from each other (P = .4000). Meniscal repair produced an increase in contact area compared with a complete tear but was still significantly less than that of the intact meniscus ($P < .0001$). The medial compartment showed no significant difference between all testing conditions for 0° and 60° of flexion ($P \geq .0650$).

Conclusion: A complete radial meniscal tear of the lateral meniscus has a detrimental effect on load transmission. Repair improved contact area and pressure. Contact pressures for repaired menisci were not significantly different from the intact state, but contact area was significantly different. Biomechanical performance of repair constructs was equivalent.

Clinical Relevance: Repair of complete radial tears improves joint mechanics, potentially decreasing the likelihood of cartilage degeneration.

Keywords: knee biomechanics; lateral meniscus; radial tear; meniscus repair

The majority of collagen fibers within the meniscus are circumferentially oriented. This orientation creates optimal resistance to hoop stresses, which displace the meniscus from the tibial plateau during weightbearing.[6,13] Negative outcomes after meniscectomy have been well documented, with long-term studies of meniscectomized knees demonstrating clinical and radiographic arthrosis.[11,16,30] Several studies have noted a greater incidence of arthrosis after lateral meniscectomy when compared with medial meniscectomy.[1,3,16,17] It has been suggested that a radially oriented meniscal tear, which disrupts the primary circumferential fibers of the meniscus, results in partial extrusion of the meniscus and abnormal load transmission equivalent to total meniscectomy.[22,26] Furthermore, it has been demonstrated that partial radial tears of the medial meniscus do not result in significant increases in contact pressure compared with the intact meniscus, while contact pressures after partial radial tears are also significantly lower than those seen after partial medial meniscectomy.[7] It is presently unknown whether partial radial tears of the lateral meniscus behave similarly to partial radial tears of the medial meniscus. To our knowledge, however, there

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Presented at the 36th annual meeting of the AOSSM, Providence, Rhode Island, July 2010.

One or more of the authors has declared the following potential conflict of interest or source of funding: This study was partially funded by Arthrex Inc. Dr Cole serves as a consultant and receives royalties from Arthrex Inc.

The American Journal of Sports Medicine, Vol. 40, No. 8
DOI: 10.1177/0363546512453291

have been no studies that investigate the biomechanical effects of isolated partial or complete radial tears of the lateral meniscus.

Historically, treatment options for a radial tear of the meniscus have been limited. While partial meniscectomy[18] has been the mainstay of treatment for radial tears, recently, successful management with inside-out repair and all-inside repair of partial radial tears of the lateral meniscus has been reported.[7,8] Whether similar results can be expected for complete tears of the lateral meniscus is presently unknown.

The purpose of the current study was to establish the pattern of biomechanical changes that transpire in the medial and lateral compartments after serial radial transection of the lateral meniscus. Our primary objective was to describe the alteration in load transmission and contact area in the lateral tibiofemoral compartment resulting from varying degrees of radial meniscal tears using a human cadaveric model. Furthermore, repair of complete radial meniscal tears was studied to determine whether normal load transmission and contact area would be restored. Finally, inside-out and all-inside meniscal repair techniques were compared.

The hypotheses of this study were that (1) radial meniscal tears result in disruption of meniscal function with decreased tibiofemoral contact area and increased contact pressure, (2) changes in contact area and pressure after complete radial meniscal tears approach those of total meniscectomy, and (3) both repair techniques of complete radial tears re-create normal load transmission across the lateral hemijoint and exhibit similar contact mechanics to the intact meniscus.

MATERIALS AND METHODS

Specimen Preparation

Five matched pairs of fresh-frozen cadaveric knees from 1 female and 4 male donors were obtained from a tissue bank. The average age at the time of death was 65 years (range, 50-82 years). Approval for the use of cadaveric specimens was granted by our institutional review board. All specimens were inspected to ensure they did not meet criteria for exclusion including deficient ligamentous structures, medial or lateral meniscal tears, or evidence of previous knee surgery. Each knee was first thawed at room temperature overnight, followed by removal of skin, subcutaneous tissue, and muscle with the exception of the popliteus and the extensor mechanism muscles. The tibia and femur were both transected approximately 13 cm from the joint line. Care was taken to preserve the cruciate and collateral ligaments as well as the popliteus muscle to maximize the natural anatomic stability of the joint. The anterior capsule was removed to provide adequate visibility of the joint, while leaving the lateral and posterior capsule intact.

A 4-mm-diameter tunnel was drilled through the femoral condyles, parallel to the joint line, to allow future relocation of the lateral condyle using a 4-mm bolt. A lateral femoral condyle osteotomy was performed to gain complete access to the lateral compartment without compromising ligament integrity. An oblique cut was made using a 0.5-mm oscillating saw blade, beginning just lateral to the femoral origin of the anterior cruciate ligament (ACL) and exiting at the lateral transition of the femoral metaphysis and diaphysis (Figure 1A). This technique is similar to that reported by Dienst et al[9] for the lateral compartment and represents a modification of a protocol initially described by Martens et al[19] for accessing the medial compartment. Martens et al[19] demonstrated no significant change in contact mechanics after osteotomy.

Small anterior and posterior horizontal arthrotomies were made below the level of the menisci to allow insertion of 0.1-mm-thick dynamic pressure-sensitive film (maximum, 1500 psi) (K-Scan 4000, Tekscan Inc, Boston, Massachusetts) in a technique similar to that reported by Van Thiel et al.[27] Sensor pads were placed in both the medial and lateral compartments, and fixation of the sensors was achieved for the duration of the study using Kelly hemostatic clamps. Clamps fixed the sensors posteriorly to the posterior capsule and anteriorly to distal remnants of the anterior capsule (Figure 1A). This dual fixation served to minimize any movement or rotation of the sensors once placed below the meniscus. Anatomic variations in the size of each specimen's meniscus led to variations in the amount of meniscus visualized by the sensors. Care was taken to place the sensors in a position that maximized the amount of visible meniscus, with priority focused on including the center of the lateral compartment and the posterior meniscus. While complete visualization of the ovoid meniscus could not be achieved with square sensor pads, prior fixation of the sensor pads allowed for direct comparison of the visible intact meniscus with the same visible meniscus postradial section.

The femur was secured to a custom jig that used smooth rods to fix the femur in precise prefabricated positions of fixation of 0° or 60° of flexion relative to the fixed tibia (Figure 1B). These joint positions were respectively chosen to represent extension of the knee as well as a single consistent point across the normal range of flexion of the knee. The proximal femoral fixation hole was drilled through the diaphysis, and the distal hole was placed through a close approximation of the axis point of flexion, which aided for consistent alignment between the medial and lateral compartments through the range of motion of the specimen.

The tibia was affixed to a Taylor Spatial Frame (TSF) dynamic external fixator (Smith & Nephew, Memphis, Tennessee) using 2 Schanz pins in the anteroposterior plane and one half-pin inserted at an oblique angle through the proximal tibial metaphysis at 1 cm below the joint line. The TSF is a multiplanar hexapod external fixator, used clinically for limb lengthening and deformity correction. It is composed of proximal and distal hexagonal rings connected by 6 adjustable struts that allow for simultaneous adjustments in translation and angulation along coronal, sagittal, and axial planes. The TSF was used in a manner similar to that previously used by Van Thiel et al,[27] and the same investigator installed the TSF for all 10 specimens, thereby ensuring consistent loading

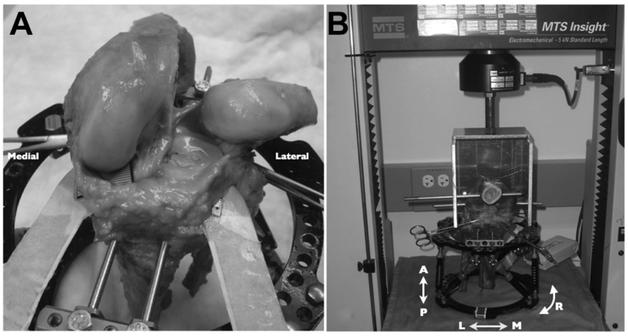

Figure 1. (A) Specimen preparation involving lateral condyle osteotomy, external tibial fixation, and submeniscal placement of pressure-sensitive film. (B) Each specimen was fixed to a custom femoral jig and loaded to 800 N using a materials testing machine (MTS Insight 5). Specimen shown in 60° of flexion. Arrows illustrating degrees of freedom of motion of a Taylor Spatial Frame. A-P, anterior-posterior; L-M, lateral-medial; R, internal-external rotation.

technique. Before testing, the specimen was mounted on a materials testing machine (Insight 5, MTS Corp, Eden Prairie, Minnesota) with the femur affixed to the custom jig in extension and the tibia fixed to the TSF. An initial load of 20 N was applied to visualize the initial contact pressure distribution across the joint and to ensure that the sensors were aligned over the meniscus and, when activated, could incorporate as many pixels as possible. The joint alignment of the specimen was then readjusted by manipulating the multiplanar configuration of the TSF until an approximately equal load distribution between the medial and lateral compartments was visualized. An equal load distribution across both tibial compartments was chosen over the anatomic position of 60% load borne across the medial compartment because of limitations in our laboratory's ability to confirm a precise load distribution between the compartments. Equal load could be visually approximated under the 20-N preload, while an exact 60% to 40% load distribution could not. There was no further manipulation of the natural varus-valgus alignment of the specimen with the TSF or femoral jig. All further testing of the specimen proceeded with the fixed varus-valgus configuration that was independently determined in flexion and extension to maintain a consistent load distribution across both joint compartments throughout serial testing. In a manner similar to that previously described by Dienst et al,[9] the TSF, and thus the tibial component, had unconstrained anterior-posterior and medial-lateral translations and internal-external rotation during the initial preconditioning load of 20 N in the intact state both in flexion and in extension (Figure 1B). At this point, the TSF was fixed on the materials testing machine to minimize anteroposterior shear forces of the TSF across the table at the maximum compressive load of 800 N. This single point of restraint was implemented to provide some anteroposterior translational stability to the specimen, which was devoid of stabilizing musculature, and to preserve presumed cruciate ligament integrity under the full 800-N load.

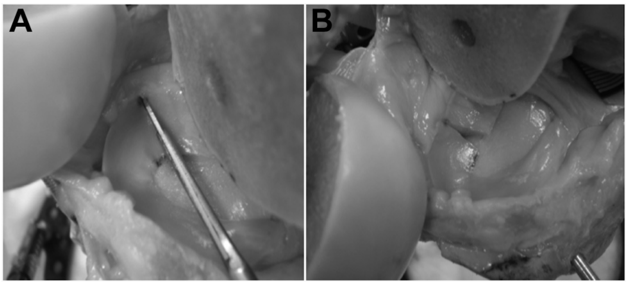

Figure 2. (A) Creation of a radially oriented defect in the posterolateral aspect of the lateral meniscus. (B) Complete (100%) radial tear.

Radially oriented defects were created 4 mm posterior to the posterior junction of the popliteal fossa of the lateral meniscus using a No. 15 blade (Figure 2). Each specimen underwent 6 sequential testing conditions: (1) intact lateral meniscus, (2) 50% radial width section representing a tear extending into the red-white region of the meniscus, (3) 75% radial width section representing a tear extending into the red-red region, (4) 100% radial width section representing a complete radial tear, (5) meniscal repair, and (6) total meniscectomy. One specimen from each paired set of knees was randomly chosen to receive either an inside-out repair using nonabsorbable 2-0 sutures (FiberWire, Arthrex Inc, Naples, Florida) or an all-inside repair (Meniscal Cinch, Arthrex Inc). The contralateral knee specimen received the alternate repair construct. The selections of which repair construct to perform first and whether this was performed on either a left or right knee were arbitrary. Overall, there were 5 all-inside repairs (3 left knees, 2 right knees) and 5 inside-out repairs (2 left knees, 3 right knees). All of the repairs were performed with 2 horizontal mattress sutures: one crossing the tear on the superior surface of the meniscus and a second in the same configuration on the inferior surface. During the repair phase of the pilot study, specimens were manually cycled 50 times without load to verify the structural integrity of both repair constructs in the cadaveric model.

Each pressure sensor measured an area of 28 × 33 mm and provided contact area and pressure measurement from 2288 sensels (sensing elements). Per the manufacturer's guidelines (Tekscan Inc, Boston, Massachusetts), contact area was defined as the sensor area containing only the loaded transducer sensels. This corresponded to the area of contact between the femur and the tibia through the meniscus. There was anatomic variability between specimens with regard to the amount of lateral meniscus that could be visualized given the constraints of the size of the pressure sensor. However, care was taken to place the sensors in a position that accommodated the greatest area of meniscus visualized during preloading and then fixed in place before testing of the intact specimen. All results, for both medial and lateral joint compartments, were compared against this fixed sensor area, normalizing any variability in relative contact area that could be related to the specific size of the lateral meniscus. The results data were normalized to that of the intact condition under the maximum load.

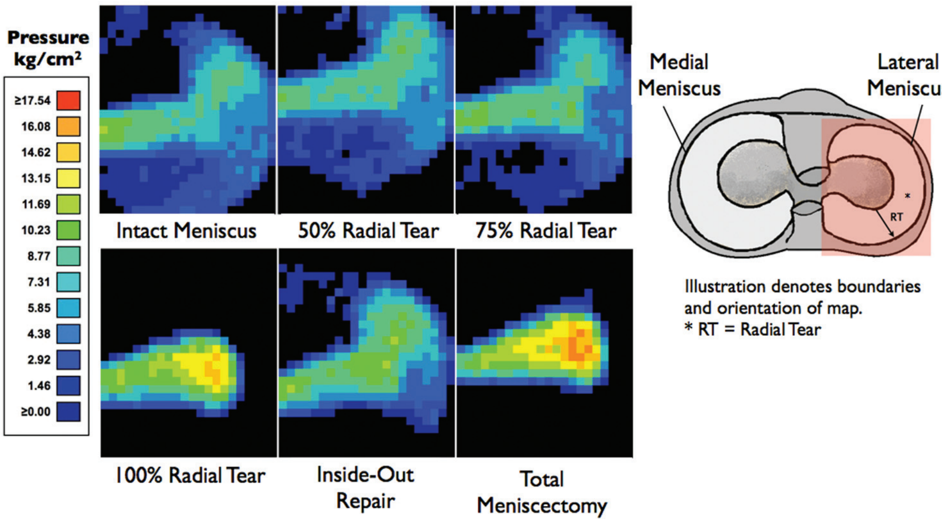

Illustration denotes boundaries and orientation of map.
* RT = Radial Tear

Figure 3. Sequential contact pressure maps of the lateral compartment for specimen 5. Increases in pressure or changes in pressure distribution denoted by color changes. (See legend for pressure range.)

Testing

Before each loading trial, a preload of 20 N was applied for 2 minutes so that the specimen's meniscal fibers were slightly conditioned to loading. The specimen was then loaded at a rate of approximately 13 N/s until a maximum load of 800 N was reached; 800 N was chosen as a result of a limitation of the TSF. During pilot studies, a load of 1000 N resulted in noticeable visible deformation of the 2 Schanz pins used in the TSF for fixation of the tibia. A load of 800 N fell comfortably below this value, did not induce visible pin deformation, and represented the body weight of a 70-kg person. This load was held for 60 seconds to ensure stabilization of pressure transmission across the joint. Rest time after loading was at least 2 minutes to aid tissue recovery. Using I-Scan software (Tekscan Inc), instantaneous recordings of 10-second duration were created (Figure 3). For each test condition, knees were tested first at 0° of flexion and then at 60° of flexion (corresponding to the extremes of range experienced during gait). The femoral jig was fixed and immobile within the materials testing machine throughout all testing, whereas the TSF was attached to the tibia but was free to rotate and translate in a medial-lateral or anterior-posterior plane. After the specimen was tested at 0° of flexion, full load was removed, and the femur was rotated about the distal fixation point of the femoral jig and fixed at 60° of flexion. Two trials were performed per flexion angle for each meniscal testing condition to confirm the reproducibility of results. Prior publications with K-Scan sensors[14,18] suggest that measurements taken with this device are reproducible with 2 data sets. Relative difference in contact pressure between data sets was no greater than 0.7 kg/cm^2 and for contact area was no greater than 0.09 inches^2. Between each serial sectioning test condition (eg, 50% radial tear), the specimen was allowed to rest for at least 10 minutes. During this time period, the specimen was removed from the materials testing machine and the femur jig, while remaining attached to the TSF. The osteotomy site was reopened, exposing the meniscus to create the serial radial incision or repair. The exposed specimen was moistened with saline solution to prevent desiccation of the meniscus. The osteotomy was closed, taking care to ensure that the distal femur was fixed and stable. The specimen was reinserted into the femur jig and the tibia, affixed to the TSF, and fastened to the base of the materials testing machine in the position of natural seating previously determined during initial testing of the intact state. For each specimen, contact pressure, peak contact force, and contact area for both lateral and medial compartments were recorded, with the reported data for each meniscal condition per specimen representing the average of the 2 repeated trials.

Data Analysis

Data were analyzed using a 2-factor repeated-measures ANOVA with within-subject factors of repair type and test condition (eg, intact, 75% tear, meniscectomy). The Tukey-Kramer post hoc test for multiple comparisons was used when significant differences among the experimental conditions were detected. In an attempt to minimize the effects of anatomic variations between specimens, all data were normalized to that of the intact state. The threshold for statistical significance was a *P* value of less than .05.

RESULTS

Contact Pressure and Peak Force

A summary of normalized mean tibiofemoral contact pressure (CP) data across radial sectioning conditions as well as after repair and total meniscectomy for both the lateral and medial compartments is provided in Figure 4A and

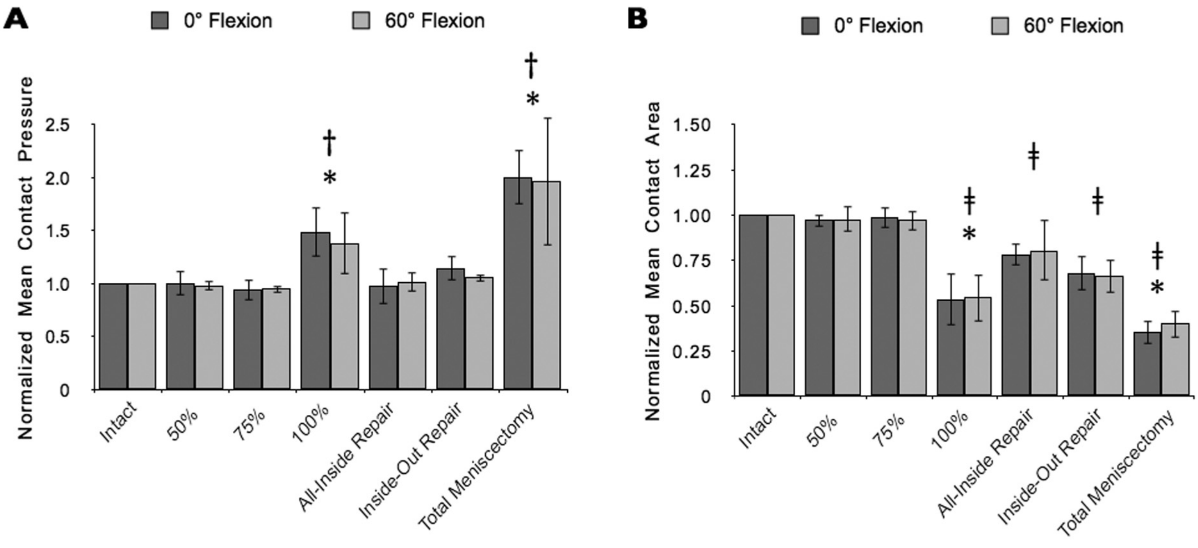

Figure 4. Normalized mean contact pressure (A) and contact area (B) across the lateral compartment in extension (0° of flexion) and 60° of flexion. *A significant difference existed between 100% radial tears and total meniscectomy ($P < .001$). †100% radial tears and total meniscectomy were significantly different from the intact state ($P < .001$). ‡100% radial tears, all-inside repair, inside-out repair, and total meniscectomy were significantly different with respect to the intact state ($P < .001$).

Figure 5A. In 0° of flexion, there was no significant increase in CP for 50% (P = .7649) and 75% (P = .3619) radial tears versus the intact state. Complete radial tears (100% sectioning), however, produced a significant increase in CP, averaging 49% greater than in the intact meniscus ($P < .0001$). No significant difference in lateral CP was detected between the 2 repair constructs (P = .4000), and both repairs demonstrated decreased lateral CP relative to the complete radial tear state, which was not significantly different from the intact state (P = .2595). Lateral CP after total meniscectomy was significantly greater than after complete radial tears ($P <$ .0001) and overall demonstrated a 100% increase in CP compared with the intact state. Results for CP in 60° of knee flexion were similar to those seen in 0° of flexion (Figure 4A). The medial side showed no significant difference in normalized CP between all testing conditions for 0° and 60° of flexion ($P \geq .2580$) (Figure 5A).

Trends in peak contact force (PF) for both the medial and lateral compartments were similar to those seen with CP. In 0° of flexion, no significant difference was noted between the intact state and tears extending through 50% (P = .9611) and 75% (P = .6366) of the radial width of the lateral meniscus. Statistically significant differences were seen after complete radial transection (P = .0008) and after total lateral meniscectomy (P = .0001) compared with the intact state. With regard to repair, no statistically significant differences were noted across all test conditions for either repair construct (P = .1037 when compared with the intact state), and no significant difference in lateral PF was detected between the 2 repair constructs (P = .1377). However, PF values for both repairs were consistently lower than those recorded for 100% radial tears and total meniscectomy, which is consistent with trends seen in CP. Results for PF in 60° of knee flexion were similar to those seen in 0° of flexion.

Contact Area

Normalized results for lateral and medial compartment contact areas are presented for all testing conditions in Figure 4B and Figure 5B. Lateral contact area (CA) did not significantly change after 50% (P = .3832) and 75% sectioning (P = .6269) compared with the intact state. However, a significant decrease in CA (47% in 0° of flexion) was seen after complete radial tears compared with the intact state ($P < .0001$). Meniscal repair produced an increase in CA compared with complete tears; however, CA after either meniscal repair was still significantly less (22% in 0° of flexion) than that of the intact meniscus ($P < .0001$). No significant difference in CA was noted between the repair types (P = .7659). Postmeniscectomy CA was significantly smaller than after complete radial tears (P = .0023). Results for CA in 60° of knee flexion were similar to those in 0° of flexion (Figure 5A). The medial side showed no significant difference in normalized CA between all testing conditions for 0° and 60° of flexion ($P \geq .0650$) (Figure 5B).

DISCUSSION

The purpose of this study was to evaluate knee contact pressures with sequential sectioning of the lateral meniscus as well as inside-out and all-inside repair techniques for complete radial tears. Results demonstrated a significant increase in lateral compartment contact pressure as well as a significant decrease in contact area after complete

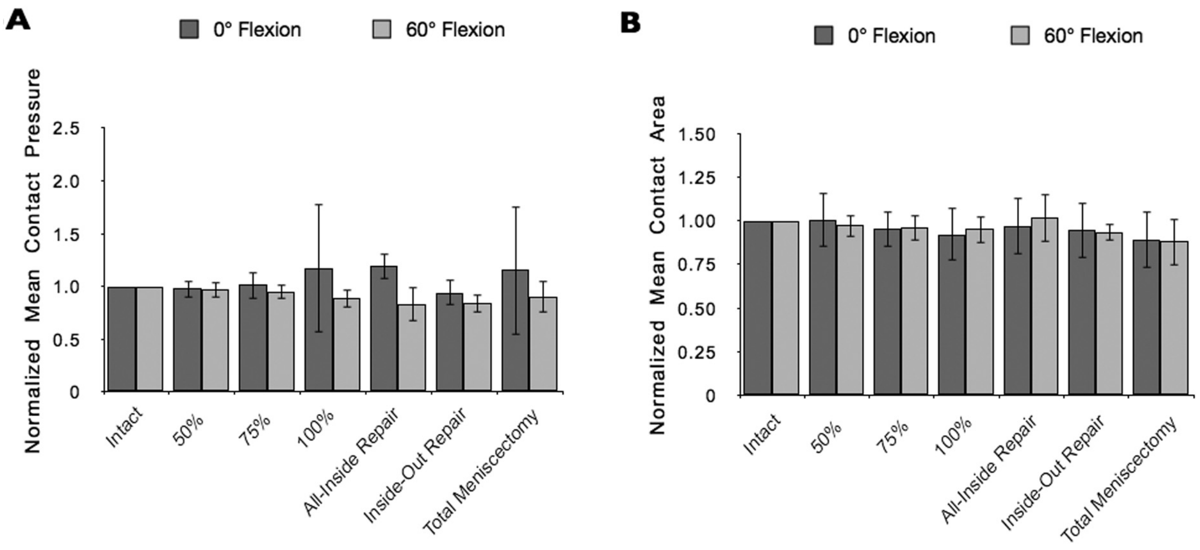

Figure 5. Normalized mean contact pressure (A) and mean contact area (B) across the medial compartment in extension (0° of flexion) and 60° of flexion. *All labeled conditions (intact to total meniscectomy) refer to testing conditions on the lateral meniscus. No significant difference exists between the tested states across the medial compartment during serial sectioning of the lateral meniscus.

radial tears in a static human cadaveric model at 0° and 60° of flexion. Interestingly, lesser degrees (ie, up to 75%) of radial tears were shown to exhibit similar contact pressure profiles to those of the intact meniscus in our 2 conditions. These findings reinforce the importance of peripheral meniscal fibers and are in agreement with the observations of Bedi et al,[7] who demonstrated that there was no significant difference in peak contact pressure between the intact medial meniscus and radial tears up to 90% of the radial width ($P < .095$).

There are limited biomechanical data on the effect of a complete lateral radial tear.[26] Shrive et al,[26] in human cadaveric and porcine models, noted similar load transmission in meniscectomized knees and those with complete radial tears of both menisci, although they utilized a testing protocol in which the collateral ligaments were sectioned and independent testing of radial tears of the lateral meniscus was not included. Furthermore, Marzo et al[20] and Allaire et al[2] demonstrated significant increases in contact pressures resulting from simulated posterior root avulsion of the medial meniscus, with results from Allaire et al,[2] demonstrating equivalence to meniscectomy. Similarly, Paletta et al[23] found no significant difference in peak pressures between meniscectomy and those after transection of the anterior and posterior horns of the lateral meniscus.

The current study did demonstrate statistically significant differences after complete radial tears, but these changes were not equivalent to those accompanying total meniscectomy. Complete radial tears produced significantly smaller changes in normalized contact pressure (mean, 43% vs 99%), peak force (mean, 29% vs 40%), and contact area (mean, 47% vs 63%) compared with total meniscectomy. Numerous studies have demonstrated the effects of total meniscectomy,[4,5,15,18] and our results are in agreement with the consistently observed decrease in contact area and increase in pressure transmission. Paletta et al[23] and Fukabayashi and Kurosawa[12] reported large increases in peak force (100% to 335%) after lateral meniscectomy; however, results in the study by Dienst et al[9] were more consistent with our own (34%-46%). Decrease in contact area in our study was similar to that seen by Paletta et al[23] and Fukabayashi and Kurosawa[12] (45% to 50% vs 60% to 65%, respectively). However, details of testing conditions are fairly variable across these comparable studies. It is possible that each study's variations in load transmission, use of different pressure-sensing materials, types of specimens tested (human vs porcine), and intrinsic anatomic variability between human cadaveric specimens could make direct comparison of their results with the results of our study difficult. There was no significant change across all joint-loading variables in the contralateral medial compartment. This result was consistent with what has been reported in the contralateral hemijoint in a similar study by Marzo and Gurske-DePerio.[20]

Meniscal repair of a complete radial tear demonstrated greater contact area (12% to 26%, depending on the specific repair technique) compared with a complete radial tear; however, contact area after repair remained significantly less (20% to 34%) than for the intact meniscus. This was most likely because the repair construct improves, but cannot replicate, the load sharing that an intact meniscus provides through its radial fibers. With regard to contact pressures, each of the repair states was not significantly different than the intact state and was significantly less than the complete tear or meniscectomized state. Relatively few other studies have examined the biomechanical effects of meniscal repair. Allaire et al[2] and Marzo and Gurske-DePerio[20] noted that repair of root avulsion demonstrated restoration of load transmission equal to the intact meniscus. Bedi et al[7] noted no significant difference after inside-out meniscal repair compared with the intact medial meniscus and radial tears involving up to 90% of the radial width. In our study, contact pressure and peak force decreased after both inside-out and all-inside repair techniques, and contact pressures after both repair techniques were not significantly different from the intact state at time zero. There was no demonstrable difference between the 2 meniscal repair techniques for any of the measured parameters.

Further discussion of our method of specimen fixation is warranted. The TSF was used instead of the more common practice of potting using PMMA cement or resin.[9,19,29] During early stages of pilot testing within our laboratory, the tibia and fibula were cemented into a polyvinyl chloride (PVC) pipe using PMMA, with effort taken to ensure that the tibial plateau remained parallel to the materials testing machine platform. However, using this method, it was exceedingly difficult to verify appropriate weight distribution across the tibial plateau until placement of the Tekscan sensors before testing of the intact state. A malaligned specimen at this junction in testing would have required repotting of the specimen after osteotomy and sensor placement. Removal of the PMMA cement would have placed a specimen at considerable risk for fracture, rendering it unusable for testing. Use of the TSF minimized the potential for excessive overloading of either compartment of the knee during initial fixation of the tibia and allowed for translational and rotational adjustments, if needed, of alignment of the tibial plateau following placement within the testing apparatus and prior to compressive loading of the specimen.

Limitations

Our study is not without limitations. The protocol employed a static loading model that was adapted from widely accepted experimental techniques[2,9,12,15,18,20,23] and has previously demonstrated reproducible and reliable results.[27] However, this approach has 2 important limitations. In vivo, the pressure and contact area of the lateral compartment vary with knee position/loading, and each repair construct would only be clinically functional if it remained secure throughout dynamic loading. The effects of dynamic loading were not tested in the current study. However, prior investigations on the effect of cycling a meniscal repair have noted a nonlinear relationship with gap formation occurring in the early cycles of testing.[21,33] Therefore, to compensate for this phenomenon, each knee/repair construct was manually cycled 50 times before testing. The static loading conditions were then chosen based on previous published work.[2,9,12,15,18,20,23] The authors acknowledge the shortcomings associated with nondynamic conditions but also believe that the testing protocol employed did allow for a well-controlled analysis of the contribution from the lateral meniscus on the contact pressure profile of the knee at 0° and 60° of flexion.

Another limitation was that our methods of specimen fixation used an approximately equal load distribution across both medial and lateral compartments, which slightly differs from other studies[27] and does not represent true anatomic alignment of the knee, of which there is preferential loading across the medial compartment (60% of load distribution). We do not believe this would significantly alter the results of our study because each specimen was subjected to all test conditions in this standardized alignment configured for the intact specimen, and all results were normalized to this intact state.

The Tekscan sensors were chosen for data collection because of advantages in reproducibility, dynamic measurement, and reusability compared with Fujifilm (Tokyo, Japan). The limitations of Tekscan include the finite thickness of the sensor, which may affect contact pressure and area measurements; decreased sensor durability under severe loads; and the inability to customize the sensor shape to the desired specifications. The rectangular shape of the Tekscan sensor resulted in an additional limitation because the coronary ligaments of the menisci were cut to facilitate accurate placement of the sensors. This was also standardized across all testing conditions and would most likely not influence the results reported. While we acknowledge these potential limitations, they conform to those described in previous biomechanical knee studies.[18,20]

One clinical limitation was that we tested all conditions in a cadaveric model. Inherent to any cadaveric study, the effects of healing and rehabilitation after repair cannot be measured, and clinical outcomes of radial tears and repair could not be considered. Additionally, our protocol standardized the location of radial transection, limiting it to the posterior segment of the lateral meniscus. Thus, we cannot confidently extrapolate our results to the scenario of radial tears of the anterior segment or midbody of the lateral meniscus.

Clinical Implications

Although a complete radial tear was not equivalent to total meniscectomy in any of the parameters measured, increases in pressure transmission were demonstrated with greater than a 75% tear. Furthermore, repair of a complete radial tear using an all-inside or inside-out construct did improve the time zero biomechanical contact pressure profile but did not return the contact area to the intact state. These findings are clinically important because the detrimental effect of elevated pressure on cartilage is well established.[10,24] If repair of a complete radial tear at time zero in a cadaveric model improves pressures, further investigation in a clinical model is warranted. This is supported by the clinical fact that Yagishita et al[31] observed healing in many lateral meniscal tears on second-look arthroscopy (78% to 94%) but identified no evidence of healing in the 3 complete lateral radial tears left in situ at the time of ACL reconstruction. Interestingly, Shelbourne et al[25] analyzed a cohort of ACL reconstructions with and without posterior lateral meniscus root tears at a minimum of 5 years' follow-up and found that the patients with meniscal tears had a trend toward worse functional scores and significantly decreased lateral joint space. Certainly, at time zero, our data provide a biomechanical rationale for repair of complete radial meniscal tears. Long-term clinical results of repair remain to be demonstrated; however, at short-term second-look arthroscopy, both van Trommel et al[28] and Yoo et al[32] noted some degree of healing of the lateral meniscus after repair of complete radial tears. Yoo et al[32] had complete healing in all cases, but even with the addition of fibrin clot, van Trommel et al[28] reported that 40% (2/5) had incomplete healing treated with partial meniscectomy.

Overall, both inside-out and all-inside repairs of a complete radial tear showed significant improvements in contact pressures of the lateral compartment at time zero in a static cadaveric knee model. This supports the clinical findings that an intact meniscus is superior[25] and encourages further clinical investigation into the repair of radial tears.[28,31] Additionally, the minimal contact pressure changes seen with less than a 75% tear suggest that the clinical maintenance of the peripheral fibers may be important, and the ideal management of noncomplete tears could be different than that of complete tears. Future studies will include the evaluation of the effect of partial lateral meniscectomy on knee biomechanics and the clinical outcomes of posterior lateral meniscal radial repair.

ACKNOWLEDGMENT

The authors thank James Kercher, MD, for his guidance with specimen testing and repair.

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