A Contact Pressure Analysis Comparing an All-Inside and Inside-Out Surgical Repair Technique for Bucket-Handle Medial Meniscus Tears

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Purpose: To directly compare effectiveness of the inside-out and all-inside medial meniscal repair techniques in restoring native contact area and contact pressure across the medial tibial plateau at multiple knee flexion angles. **Methods:** Twelve male, nonpaired ($n = 12$), fresh-frozen human cadaveric knees underwent a series of 5 consecutive states: (1) intact medial meniscus, (2) MCL tear and repair, (3) simulated bucket-handle longitudinal tear of the medial meniscus, (4) inside-out meniscal repair, and (5) all-inside meniscal repair. Knees were loaded with a 1,000-N axial compressive force at 5 knee flexion angles (0°, 30°, 45°, 60°, 90°), and contact area, mean contact pressure, and peak contact pressure were calculated using thin film pressure sensors. **Results:** No significant differences were observed between the inside-out and all-inside repair techniques at any flexion angle for contact area, mean contact pressure, and peak contact pressure (all $P > .791$). Compared with the torn meniscus state, inside-out and all-inside repair techniques resulted in increased contact area at all flexion angles (all $P < .005$ and all $P < .037$, respectively), decreased mean contact pressure at all flexion angles (all $P < .007$ and all $P < .001$, respectively) except for 0° ($P = .097$ and $P = .39$, respectively), and decreased peak contact pressure at all flexion angles (all $P < .001$, all $P < .001$, respectively) except for 0° ($P = .080$ and $P = .544$, respectively). However, there were significant differences in contact area and peak contact pressure between the intact state and inside-out technique at angles ≥45° (all $P < .014$ and all $P < .032$, respectively). Additionally, there were significant differences between the intact state and all-inside technique in contact area at 60° and 90° and peak contact pressure at 90° (both $P < .005$ and $P = .004$, respectively). Median values of intact contact area, mean contact pressure, and peak contact pressure over the tested flexion angles ranged from 498 to 561 mm^2, 786 to 997 N/mm^2, and 1,990 to 2,215 N/mm^2, respectively. **Conclusions:** Contact area, mean contact pressure, and peak contact pressure were not significantly different between the all-inside and inside-out repair techniques at any tested flexion angle. Both techniques adequately restored native meniscus biomechanics near an intact level. **Clinical Relevance:** An all-inside repair technique provided similar, native-state-restoring contact mechanics compared with an inside-out repair technique for the treatment of displaced bucket-handle tears of the medial meniscus. Thus, both techniques may adequately decrease the likelihood of cartilage degeneration.

See commentary on page 1849

Meniscal tears have been reported to be the most commonly treated knee injury, accounting for more than half of all knee arthroscopies.[1] Historically, a meniscectomy was performed in the event of a meniscal tear; however, the resulting negative effects of decreased meniscus function, such as decreased contact area and increased contact pressure within the knee, have become better understood in recent years.[2-5] Studies have shown that meniscectomies increase axial stress across the knee joint,[2,5] which often results in loss of articular cartilage.[3,4] Recent studies have shown that surgical repair of radial and vertical meniscal tears can restore contact pressures within the knee to near intact levels[6] for the medial[7] and lateral[8] compartments. The utility of meniscal repairs has

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been shown in vitro; correspondingly, there has been an evolution of meniscus repair techniques that have improved surgeons' ability to visualize and repair the damaged meniscus while minimizing operative morbidity.

The inside-out repair has been considered the gold standard for longitudinal meniscal tears because of the technique's ability to preserve the structural integrity and biomechanical function of the meniscus.[9-11] However, the disadvantages of this repair technique include increased operative time and increased risk of injury to the hamstring tendons and the posterior neurovascular structures of the knee.[11-13] To minimize the risks associated with the inside-out technique, all-inside meniscus repair devices have been developed,[11-14] eliminating the need for long needle passage and suture tying behind the knee.[15]

Although studies have shown that surgical repair of radial and vertical meniscal tears can restore joint contact pressures and contact areas,[5-8,16] to the authors' knowledge, none have assessed displaced bucket-handle tears of the medial meniscus at multiple flexion angles. Furthermore, there is a paucity of literature comparing the effectiveness of an inside-out versus all-inside repair technique in restoring the contact pressure of a torn meniscus. Therefore, the purpose of this study was to directly compare effectiveness of the inside-out and all-inside medial meniscal repair techniques in restoring native contact area and contact pressure across the medial tibial plateau at multiple knee flexion angles. The all-inside surgical technique was hypothesized to restore native knee contact pressures in the same proportion as the inside-out technique through repair of simulated bucket-handle longitudinal medial meniscus tears in cadaveric knees.

Methods

Specimen Preparation

Twelve male nonpaired (n = 12), fresh-frozen human cadaveric knees (mean age 57 ± 7 years, [range: 41-65]) that met the following inclusion criteria were used in the study: no history of prior injury, anatomic abnormalities, ligament instability, or disease. Extensive pilot testing was performed prior to study commencement to ensure the defined methods and testing protocol were adequate. Thus, there were no exclusions from the final group of 12 specimens that were sequentially tested. The cadaveric specimens used in this study were donated to a tissue bank for medical research and then purchased by our institution. Specimens were stored at −20°C and thawed at room temperature for 24 hours prior to dissection and testing. The skin and subcutaneous adipose tissue was removed, followed by careful resection of the muscle, tendon, and patella, retaining the interosseous membrane, collateral and cruciate ligaments, and meniscal tissues.

An 11-mm tunnel was drilled through the femur along the transverse axis at the level of the femoral epicondyles, without damaging the collateral ligaments. The knee was placed in a custom fixture, which facilitated distinct flexion angle adjustments, and a steel rod was inserted through the tunnel to secure the knee. A 7-mm tunnel was drilled through the femur parallel and 7.5 cm proximal to the first tunnel, and a steel rod was inserted. The rod inserted through the 11-mm tunnel acted as a pivot point and load-bearing site, whereas the rod inserted through the 7-mm proximal tunnel was used to adjust and maintain the angle of knee flexion. For potting alignment preparation, each knee was secured in the fixture at 45° of knee flexion, and the tibia and fibula were transected approximately 15 cm distal to the joint line and potted in a cylindrical mold filled with PMMA (Poly Methyl Methacrylate; Fricke Dental, Streamwood, IL). Incisions were made in the anterior and posterior meniscotibial ligaments of both menisci, avoiding the meniscal roots, to allow for insertion of pressure mapping sensors (Model 4000; Tekscan, South Boston, MA) on top of the tibial plateau articular cartilage and underneath the medial and lateral menisci.[17-20] The sensor used is made up of 572 sensels (27.9 mm × 33.0 mm; 62.0 sensels/cm^2) with a pressure range of 10.3 MPa. The Tekscan I-Scan system has a linearity of <±3%, repeatability of <±3.5%, and overall accuracy of ± 10%. Prior to insertion, the pressure sensors were calibrated according to manufacturer specifications, and suture tags were passed through the sensor tabs to aid sensor placement. The sensors were carefully inserted from anterior to posterior such that the border of each sensor was aligned adjacent to the posterior rim of the tibial plateau and then fastened securely by tying the suture tags around the tibia and fibula to maintain standardized and proper placement throughout testing (Fig 1). Placement of the pressure sensors was assessed prior, throughout, and after testing by 2 observers; no adjustments were needed as sensor placement remained consistent throughout all states of testing.

Testing States

Each knee was tested in a series of 5 consecutive states: (1) intact medial meniscus, (2) MCL tear and repair, (3) simulated bucket-handle longitudinal tear of the medial meniscus, (4) inside-out meniscal repair, and (5) all-inside meniscal repair. The MCL tear and repair (state 2) was necessary because the MCL was cut midsubstance and repaired during states 3 to 5 to guarantee proper sectioning and repair of the medial meniscus. The approximately 5-cm-long, simulated bucket-handle longitudinal tear (state 3) was created by an orthopedic surgeon (S.B.S.) with a no. 15 surgical blade at the

Fig 1. Anterosuperior photograph showing sensor placement under the menisci of a left knee.

junction of the middle and outer third of the meniscus. In all specimens, the tear was initiated posteriorly, approximately 1 cm from the posterior meniscal root, and then traveled from the posterior 1/3 into the middle 1/3 and then into the anterior 1/3 of the meniscus, depending on the size of the knee. Approximately 1-3 mm of peripheral meniscus rim remained attached to the capsule. The torn meniscus was positioned lateral to the medial femoral condyle, simulating the "bucket-handle" displacement common in injury,[21] and was maintained in that position for the duration of testing in the torn state. Then the meniscus tear was anatomically reduced and an inside-out repair was performed (Meniscal Mender II; Smith & Nephew, Andover, MA). After the inside-out meniscal repair state was analyzed, the repair sutures were carefully removed and a subsequent repair was performed using an all-inside technique (FasT-Fix 360; Smith & Nephew). It should be noted that the inside-out repair was performed using an outside-in repair device; however, meticulous specimen preparation allowed for an adequate adaptation of the device for an inside-out technique.

Meniscus Repair Techniques

Inside-out Technique

Four vertical mattress sutures were placed in all specimens. The meniscal mender needles were passed between the medial femoral condyle and medial tibial plateau, each suture placed approximately 1 cm apart. Both curved and straight needles were utilized, based on optimizing individual repairs. The initial needle passed through the central meniscus, reducing it, then into the rim meniscus/capsule. Then, the suture was passed through the needle and captured out the back of the capsule. The needle was then removed. A second pass was then performed through the rim/capsule and a looped nitinol wire fed through the needle was then used to pass the other suture limb. Each suture was tied using multiple half-hitches over the capsule with appropriate tension. The needle passes were 5-7 mm apart. Sutures were placed within approximately 5 mm of the posterior and anterior extent of the simulated tear, with the remaining sutures slightly more than 1 cm apart. Sutures were placed only on the top (femoral side) of each meniscus.

All-inside Technique

Four vertical mattress sutures were placed in all specimens. The initial stitch traversed the peripheral meniscus/capsule, then the second passed the central (inner) meniscus, reducing it, and then through the peripheral meniscus/capsule. The needle passes were 5-7 mm apart. The sliding knot advanced down the suture limb with a knot pusher using an appropriate amount of tension, securing the tear, and then the suture was cut leaving a 2-mm tail. Sutures were placed within approximately 5 mm of the posterior and anterior extent of the simulated tear, with the remaining sutures slightly more than 1 cm apart. Sutures were placed only on the top (femoral side) of each meniscus.

Biomechanical Testing

Each knee specimen was tested by applying a constant, 1,000-N axial compressive load[17-20] for 30 seconds using a dynamic testing machine (Instron ElectroPuls E10000; Instron Systems, Norwood, MA) at 5 randomized flexion angles (0°, 30°, 45°, 60°, and 90°). The potted tibia and fibula were rigidly held in a custom "pivot table" fixture[17-20] that allowed control of rotation, translation, and varus-valgus angulation. The femur was mounted to the testing machine actuator with the previously described fixture, which preliminarily ensured proper placement of the femoral tunnels (Fig 2). The pivot table allowed equal load to be distributed to the medial and lateral compartments throughout testing by visualizing the center of load on the contact pressure sensor live feed and manually adjusting the table accordingly. Equal load distribution established that recorded changes in contact pressure readings were a result of testing condition changes and not changes in the load distribution itself with regard to the medial and lateral compartments of the tibial plateau.

Data Processing

Despite the accurate and repeatable application of a 1,000-N axial compressive load, there was a steady linear decline of 1.5% per test iteration in the total

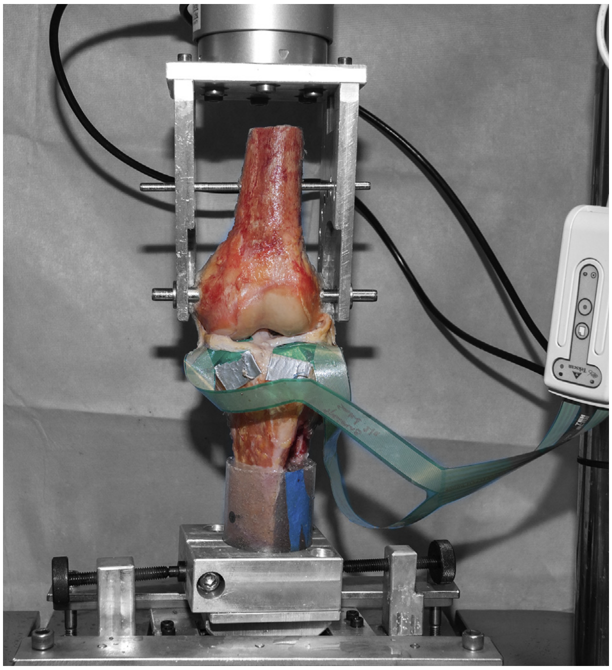

Fig 2. Photograph of the testing setup for a left knee specimen showing the femoral fixture inclusive of a pivot pin (inferior pin) and flexion angle selector pin (superior pin) and tibial pivot table with varus/valgus alignment control knobs. The interosseous membrane, collateral and cruciate ligaments, and meniscal tissues were left intact, and the sensors were placed between the tibial plateau articular cartilage and the medial and lateral menisci.

load measured by the Tekscan sensor throughout the testing process for each specimen. To avoid convolution of this observation and experimental condition comparisons, a slight data adjustment was used to de-trend this decline in the same manner reported previously.[17,19,20,22] All biomechanical variables (contact area, mean contact pressure, and peak contact pressure) were computed from the medial compartment pressure sensor output data via a custom script (Matlab; MathWorks, Natick, MA). Note that peak contact pressure was defined and calculated as the average contact pressure among the 90th percentile (top 10%) of contacted sensels (pixel-shaped sensing elements) for each condition.

Statistical Analysis

Linear mixed-effects models were used to compare contact area, mean contact pressure, and peak contact pressure between knee states at each flexion angle while accounting for the repeated measures nature of the study design. Residual diagnostics were performed to ensure a quality model fit and that model assumptions were met. Tukey post hoc comparisons were used to make pairwise comparisons between groups. The statistical software R was used for all plots and analyses (R [R Foundation for Statistical Computing], with the packages *nlme* and *ggplot2*).[23-25]

For the 5 testing states, 7 clinically relevant comparisons were analyzed at each flexion angle for contact area, mean contact pressure, and peak contact pressure. These included the intact state compared with the (1) repaired MCL, (2) simulated bucket-handle meniscus tear, (3) inside-out repair technique, and (4) all-inside repair technique. Additionally, the simulated bucket-handle meniscus tear was compared with both the (5) inside-out repair technique and (6) all-inside repair technique. The last comparison (7) was made between the inside-out and all-inside repair technique.

Results

The repaired MCL state was not significantly different from the intact state across all tested flexion angles for contact area (all $P > .631$), mean contact pressure (all $P > .933$), and peak contact pressure (all $P > .583$).

Contact Area

Mean contact area for each state and flexion angle are presented in Figure 3 and Table 1. The intact state showed significantly greater contact area compared with the simulated meniscal tear state across all tested flexion angles (all $P < .001$). The inside-out repair group was not significantly different from the intact state at 0° and 30° (both $P > .433$), whereas the all-inside repair group was not significantly different from the intact state from 0° to 45° (all $P > .162$). However, both the inside-out (all $P < .005$) and all-inside techniques (all $P < .037$) significantly increased the contact area across the tibial plateau at all flexion angles when compared with the simulated meniscal tear state. Lastly, no significant difference was observed between the inside-out and all-inside techniques (among all flexion angles, all $P > .791$).

Mean Contact Pressure

Mean contact pressure for each state and flexion angle are presented in Figure 4 and Table 2. The simulated meniscal tear state showed significantly greater mean contact pressure compared with the intact state across all tested flexion angles (all $P < .009$) and increased with increasing flexion angle. The inside-out and all-inside repair techniques were not significantly different from the intact state for all tested flexion angles (all $P > .121$ and all $P > .208$, respectively). However, both the inside-out (all $P < .007$) and all-inside (all $P < .001$) techniques significantly decreased the contact pressure at all flexion angles other than 0° ($P = .097$ and $P = .390$, respectively) when compared with the simulated meniscal tear state. No significant difference was observed between the

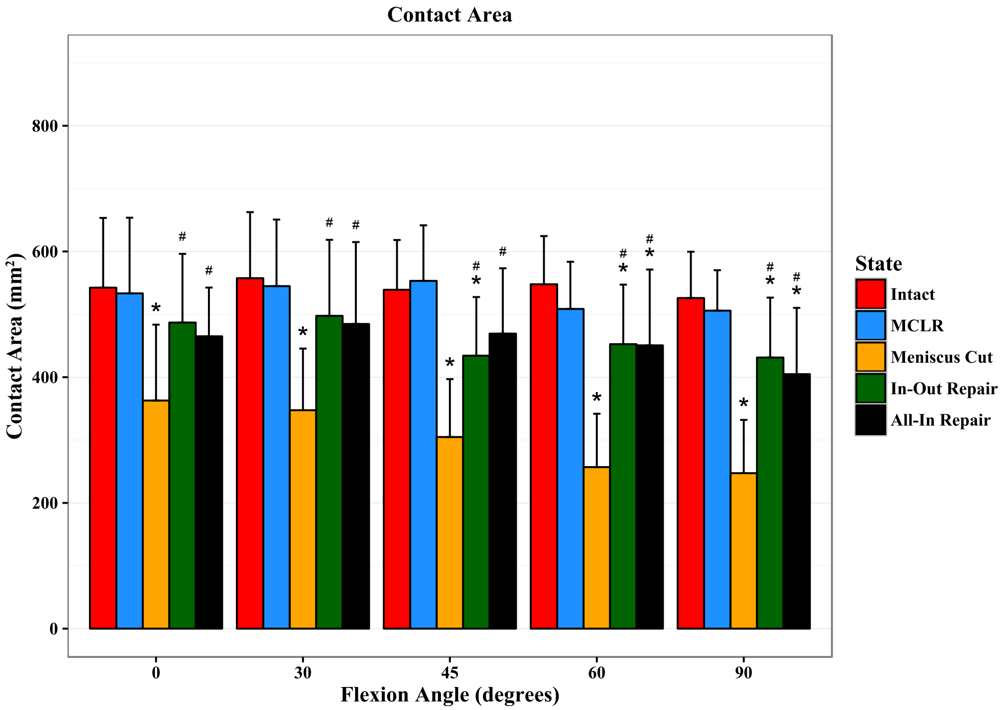

Fig 3. Mean contact area (mm^2) for each flexion angle and testing state: Intact, baseline measurement; MCLR, cut and repaired MCL; Meniscus Cut, simulated bucket-handle meniscus tear; In-Out Repair, first repair technique; All-In Repair, second repair technique. $^*P < .05$ compared with Intact state; $^\# P < .05$ compared with Meniscus Cut state. (MCL, medial collateral ligament.)

inside-out and all-inside techniques at any tested flexion angle (all $P > .895$).

Peak Contact Pressure

Peak contact pressure for each state and flexion angle is presented in Figure 5 and Table 3. The simulated meniscal tear state showed significantly greater peak contact pressure across the tibial plateau when compared with the intact state (all $P < .033$). The inside-out repair technique was not significantly different from the intact state at 0° and 30° (both $P > .522$), and the all-inside repair group was not significantly different from the intact state from 0° to 60° (all $P > .095$). Nevertheless, both the inside-out (all $P < .001$) and all-inside (all $P < .001$) techniques significantly decreased the peak contact pressure in the specimens compared with the simulated meniscal torn state at all flexion angles other than 0° ($P = .080$ and $P = .544$, respectively). Lastly, there was no significant difference between the inside-out and all-inside techniques at any tested flexion angle (all $P > .847$).

Discussion

The most important finding in this study was that there was no significant difference in contact area, mean contact pressure, or peak contact pressure between the all-inside and inside-out repair techniques at any tested flexion angle. Furthermore, both techniques restored contact area, mean contact pressure, and peak contact pressure near intact levels for most flexion angles. This current investigation was undertaken to determine if an all-inside meniscus repair technique compared favorably with the traditional inside-out technique with respect to the ability to restore intact contact biomechanics to the knee (medial compartment) after a displaced simulated bucket-handle medial meniscal tear. The results indicated an all-inside repair provided similar, native-state-restoring contact mechanics compared with an inside-out medial meniscus repair technique.

In the current study, the inside-out and all-inside repair techniques were successful at restoring contact

Table 1. Mean Contact Area ± SD (mm^2) for Each Testing State and Knee Flexion Angle

State*	0°	30°	45°	60°	90°
Intact	542.5 ± 110.9	557.5 ± 105.1	539.1 ± 79.1	547.8 ± 76.7	525.9 ± 73.7
MCLR	533.3 ± 120.4	544.9 ± 105.9	553.2 ± 88.4	508.6 ± 75.1	505.9 ± 64.3
Meniscus Cut	362.9 ± 120.7	347.4 ± 98.1	304.8 ± 92.1	257.0 ± 84.9	247.3 ± 84.7
In-Out Repair	487.0 ± 109.3	497.6 ± 121.0	434.3 ± 93.2	452.6 ± 94.7	431.3 ± 95.3
All-In Repair	465.1 ± 77.5	484.7 ± 130.3	469.4 ± 103.9	450.7 ± 120.6	404.8 ± 105.5

MCLR, cut and repaired medial collateral ligament; SD, standard deviation.

*n = 12 for all conditions tested.

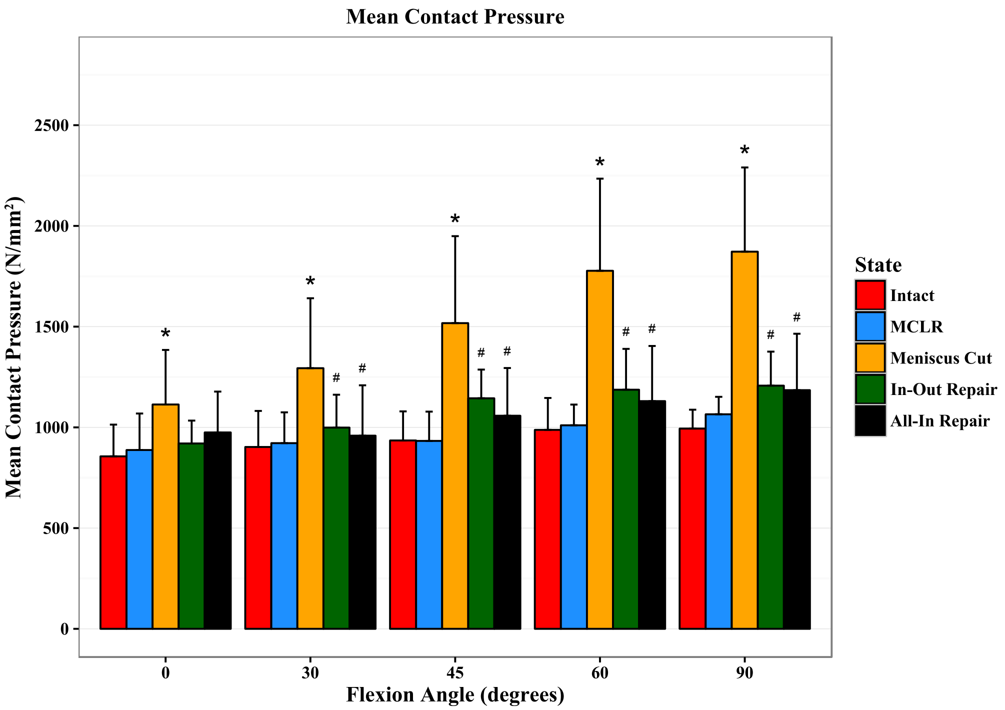

Fig 4. Mean contact pressure (N/mm^2) for each flexion angle and testing state: Intact, baseline measurement; MCLR, cut and repaired MCL; Meniscus Cut, simulated bucket-handle meniscus tear; In-Out Repair, first repair technique; All-In Repair, second repair technique. $^{*}P < .05$ compared with Intact state; $^{\#}P < .05$ compared with Meniscus Cut state. (MCL, medial collateral ligament.)

area, mean contact pressure, and peak contact pressure near that of the intact meniscus at most tested flexion angles in this uniaxial testing model. However, there were significant differences in contact area between the intact state and the repair techniques at deeper knee flexion angles (for inside-out ≥45°, $P < .014$; and for all-inside ≥60°, $P < .005$). Furthermore, there were significant differences observed in the peak contact pressure between the intact state and the repair techniques at deeper flexion angles (for inside-out ≥45°, $P < .0317$; all-inside at 90°, $P = .004$). Despite this, at all flexion angles, both techniques significantly increased contact area and significantly decreased mean contact pressure and peak contact pressure when compared with the simulated meniscus tear, indicating improved contact mechanics of the meniscus when using either technique. If joint contact pressures after a meniscus tear repair are improved and/or returned to a near normal state, then the potential for the future development of articular cartilage thinning, deterioration, and osteoarthritis may be minimized.

Although relative success has been reported for the inside-out meniscal repair,[9-11] this technique is technically demanding and requires more assistance and time in the operating room. Therefore, there has been a push for the development of all-inside techniques that decrease the surgical risk of damaging neurovascular structures, need for posterolateral and/or posteromedial incisions, technical demand, and the need for surgical assistance, thus reducing operative time.[26] However, reported disadvantages of all-inside devices include the potential for chondral damage, implant breakage or migration, foreign body reactions, and higher costs.[27] Therefore, further clinical research of all-inside repairs is warranted.

The current study adds to the body of published literature that has reported related biomechanical properties, for example, meniscal displacement after cyclic loading and load-to-failure when comparing the inside-out technique to the various all-inside techniques.[28,29] The present study reveals that both the inside-out and all-inside techniques are equivalent in

Table 2. Mean Contact Pressure ± SD (N/mm^2) for Each Testing State and Knee Flexion Angle

State*	0°	30°	45°	60°	90°
Intact	856.2 ± 157.5	902.6 ± 179.0	935.0 ± 144.4	987.6 ± 158.3	994.0 ± 93.7
MCLR	887.5 ± 181.3	921.7 ± 153.0	932.7 ± 145.4	1,010.3 ± 102.8	1,064.9 ± 86.6
Meniscus Cut	1,113.6 ± 270.7	1,293.8 ± 347.2	1,517.4 ± 431.7	1,777.2 ± 457.3	1,872.1 ± 418.0
In-Out Repair	920.1 ± 113.5	999.0 ± 163.0	1,144.4 ± 142.4	1,186.9 ± 202.7	1,207.1 ± 168.8
All-In Repair	974.9 ± 202.7	958.8 ± 250.0	1,057.8 ± 236.8	1,130.3 ± 273.7	1,184.8 ± 280.0

MCLR, cut and repaired medial collateral ligament; SD, standard deviation.
*n = 12 for all conditions tested.

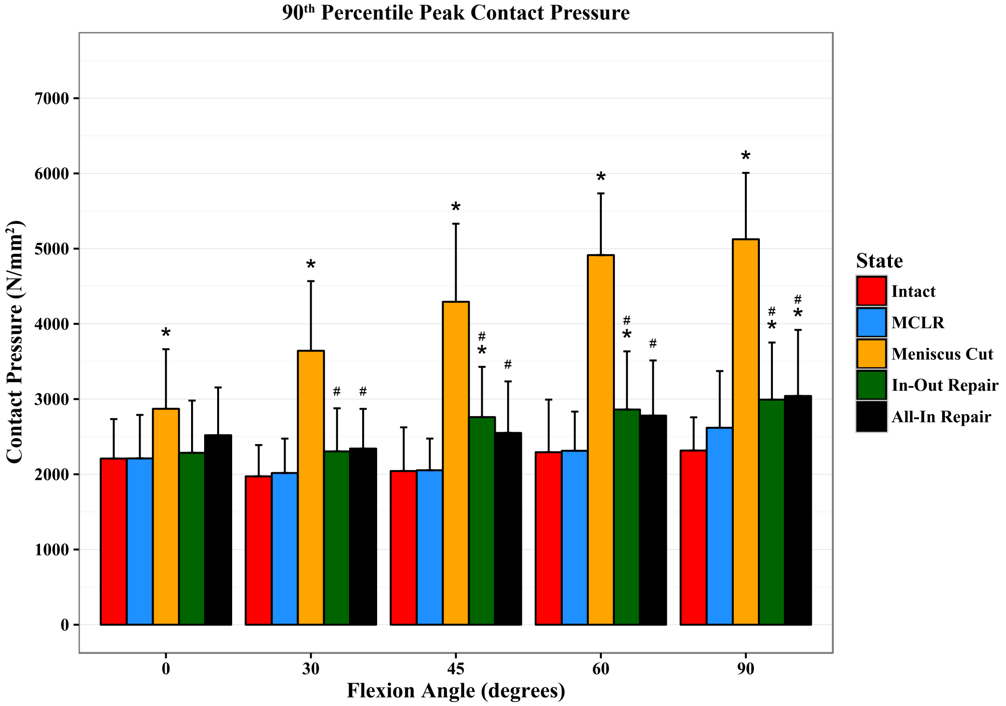

Fig 5. Peak contact pressure (N/mm^2) for each flexion angle and testing state: Intact, baseline measurement; MCLR, cut and repaired MCL; Meniscus Cut, simulated bucket-handle meniscus tear; In-Out Repair, first repair technique; All-In Repair, second repair technique. $^*P < .05$ compared with Intact state; $^\#P < .05$ compared with Meniscus Cut state. (MCL, medial collateral ligament.)

restoring near-native tibiofemoral contact pressure and contact area. Moreover, other recent studies have found comparable structural healing and functional outcomes between repair techniques.[30-32] Additionally, Fillingham et al.[33] recently published a review of 27 studies comparing modern all-inside devices with the inside-out repair and found no significant differences in clinical or anatomic failure rates (clinical failure 10% vs 11%, respectively; anatomical failure 16% vs 13%, respectively).

Several studies have assessed the biomechanical changes between an intact, torn, repaired, and excised meniscus.[5-8,16] Two studies have analyzed the effects of a horizontal cleavage tear (HCT) of the medial meniscus.[5,16] Koh et al.[5] found no significant difference ($P > .05$) in contact area or peak pressure between the HCT state and the intact state at the tested flexion angles (0° and 60°). In contrast, Beamer et al.[16] found that an HCT significantly increased ($P < .03$) contact pressure (70% increase) and reduced contact area compared with the intact state at all tested flexion angles (0°, 10°, and 20°). Both studies found no statistically significant difference between the repaired HCT and intact state ($P > .05$) for contact pressure and contact area, though both did find a significant difference in contact pressure (increased) and contact area (decreased) between the complete meniscectomy (excised inferior and superior leaf) and the intact state.

Other studies have assessed the effects of radial and vertical tears of the meniscus. Ode et al.[8] found that a full radial tear of the lateral meniscus resulted in significant differences in contact pressure and contact area (at 0° and 60°) between both the intact state and the total meniscectomy state ($P < .001$). Although our current study reported that both the inside-out and all-inside techniques adequately restored intact contact area and contact pressure, Ode et al. found that repaired menisci resulted in significantly decreased contact area compared with the intact state ($P < .001$) at both tested flexion angles. In a similar vein, Muriuki

Table 3. Peak Contact Pressure ± SD (N/mm^2) for Each Testing State and Knee Flexion Angle

State*	0°	30°	45°	60°	90°
Intact	2,209.6 ± 524.4	1,972.6 ± 415.8	2,043.5 ± 580.7	2,293.3 ± 699.7	2,316.2 ± 441.2
MCLR	2,211.3 ± 578.0	2,017.4 ± 457.1	2,053.6 ± 421.2	2,312.6 ± 520.9	2,618.5 ± 754.1
Meniscus Cut	2,870.9 ± 792.0	3,642.6 ± 925.6	4,293.7 ± 1,037.9	4,914.2 ± 820.3	5,124.8 ± 882.7
In-Out Repair	2,285.6 ± 694.3	2,304.4 ± 573.0	2,760.4 ± 667.8	2,861.3 ± 773.0	2,992.8 ± 759.1
All-In Repair	2,519.6 ± 634.8	2,342.0 ± 527.6	2,550.1 ± 684.6	2,780.6 ± 733.0	3,041.4 ± 878.1

MCLR, cut and repaired medial collateral ligament; SD, standard deviation.
*n = 12 for all conditions tested.

et al.[7] assessed the biomechanical effects of radial and vertical tears while using the most similar testing protocol (1,000 N axial load applied at 0°, 30°, 60°, and 90° of knee flexion) to that of the present study. They found that radial split tears caused insignificant changes in tibiofemoral contact pressure and contact area; conversely, vertical tears of the medial meniscus caused increased contact pressure and reduced contact area similar to that of a medial meniscectomy. And, in agreement with the current study, they observed increased contact pressure and decreased contact area with increasing flexion angle. Lastly, they reported that repair of the vertical medial meniscal tear using an inside-out technique returned contact pressure and contact area near the intact state, except for contact area at 90° in the medial compartment. Similarly, in our study, repairs failed to restore contact pressure to an intact level at angles $\geq 45°$ for the inside-out technique and at angles $\geq 60°$ for the all-inside technique.

Although the previously described studies have assessed the altered tibiofemoral contact pressures and contact areas for horizontal, radial, and vertical tears and repairs of the meniscus, the current study specifically analyzed displaced simulated bucket-handle tears of the medial meniscus. Nonetheless, a common theme was observed across studies such that meniscal tears caused increased contact pressure and decreased contact area across the tibiofemoral joint with increasing flexion angle. Furthermore, the results of these studies indicate that repairing meniscal tears can decrease contact pressure and increase contact area compared with the torn state and restore them to near intact values.

Limitations

The current study had limitations inherent to the biomechanical, cadaveric study design. The model is representative of the immediate postoperative period and does not take into account healing of the meniscus. Application of a uniaxial compressive force at a fixed flexion angle was a simplification of the forces and shear forces experienced by the joint during functional activities. However, the custom fixture allowed varus and valgus adjustment to better re-create distributed, in vivo loading forces. Furthermore, the testing protocol and custom fixture was similar to those used in other biomechanical studies assessing the biomechanics of meniscal tears and repairs. Vedi et al.[34] have shown that the medial meniscus moves from anterior to posterior and medial to lateral with increasing angles of knee flexion; therefore, the results of the current study must be interpreted in the context of an in vitro, static, uniaxial loading protocol and are therefore not directly transferable to a dynamic, in vivo setting. No a priori power calculation was made; however, the sample size was determined based on previous, similar biomechanical studies. Cutting and repairing the MCL to allow for repeatable meniscus tears and repairs could have altered the biomechanics of the knee; however, there was no significant difference in contact area, mean contact pressure, or peak contact pressure between the MCL cut state and the intact state at any tested flexion angle. Although there are several all-inside repair devices available, the current study only assessed a single device, thus not allowing generalization of the results to other repair devices. The all-inside meniscus repair was performed sequentially on an already-repaired and tested meniscus (inside-out repair); however, the suture imprint on the meniscus was minimal, and sequential testing allowed for stronger statistical comparisons. Lastly, the current investigation only studied a model of displaced bucket-handle tears of the medial meniscus and cannot be generalized to other tear patterns of the medial and lateral menisci.

Conclusions

Contact area, mean contact pressure, and peak contact pressure were not significantly different between the all-inside and inside-out repair techniques at any tested flexion angle. Both techniques adequately restored native meniscus biomechanics near an intact level.

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