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Effects of Medial Meniscus Posterior Horn Avulsion and Repair on Tibiofemoral Contact Area and Peak Contact Pressure With Clinical Implications

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Background: Avulsion of the posterior horn attachment of the medial meniscus can compromise load-bearing ability, produce meniscus extrusion, and result in tibiofemoral joint-space narrowing, articular cartilage damage, and osteoarthritis.

Hypothesis: Avulsion of the posterior horn of the medial meniscus will increase peak contact pressure and decrease contact area in the medial compartment of the knee, and posterior horn repair will restore contact area and peak contact pressures to values of the control knee.

Study Design: Controlled laboratory study.

Methods: Eight fresh-frozen human cadaveric knees had tibiofemoral peak contact pressures and contact area measured in the control state. The posterior horn of the medial meniscus was avulsed from its insertion and knees were retested. The meniscal avulsion was repaired by suture through a transosseous tunnel and the knees were tested a third time.

Results: Avulsion of the posterior horn attachment of the medial meniscus resulted in a significant increase in medial joint peak contact pressure (from 3841 kPa to 5084 kPa) and a significant decrease in contact area (from 594 mm^2 to 474 mm^2). Repair of the avulsion resulted in restoration of the loading profiles to values equal to the control knee, with values of 3551 kPa for peak pressure and 592 mm^2 for contact area.

Conclusion: Posterior horn medial meniscal root avulsion leads to deleterious alteration of the loading profiles of the medial joint compartment and results in loss of hoop stress resistance, meniscus extrusion, abnormal loading of the joint, and early knee medial-compartment degenerative changes.

Clinical Relevance: The repair technique described restores the ability of the medial meniscus to absorb hoop stress and eliminate joint-space narrowing, possibly decreasing the risk of degenerative disease.

Keywords: meniscus avulsion; meniscus extrusion; arthritis; meniscus repair

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Avulsion of the posterior horn of the medial meniscus is a described entity that produces meniscus extrusion,[7,11,22,23,25,27,30] articular cartilage loss and osteophyte formation,[22] and medial joint-space narrowing.[1,14,16,18,22,32] Meniscus extrusion prevents the meniscus from resisting hoop stresses and shielding the adjacent articular cartilage from axial load.[2,6,21] Over time, the joint-space narrowing produced by meniscus extrusion can lead to symptomatic knee osteoarthritis.[6] A previous publication by the senior author (J.M.M.) described an anatomic arthroscopic-assisted transosseous procedure to repair posterior horn meniscal avulsions.[23] The purpose of this study is to examine the relationship of medial meniscal avulsion and subsequent repair on tibiofemoral peak contact pressure and contact area, and to comment on the clinical implications.

MATERIALS AND METHODS

Approval for use of cadaveric specimens was granted from the Institutional Review Board at our institution. Eleven unaltered fresh-frozen cadaveric knees were harvested from the Department of Anatomy Laboratory. The knees

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were transected across the femur and tibia to isolate the knee joint and the knees were stripped of muscle, tendon, and patella, retaining the cruciate and collateral ligaments. An anterior capsulectomy was performed to grossly inspect the joint for any signs of meniscal or articular cartilage injury and to allow for biomechanical testing with a Tekscan knee sensor (Tekscan, South Boston, Massachusetts). The meniscofemoral and meniscotibial (coronary) ligaments were incised to allow placement of the sensor beneath the medial meniscus and on top of the flat tibial plateau for better conformity. Any knee with gross findings of arthritis or meniscal injury was eliminated. Anteroposterior radiographs were taken and any knee with radiographic signs of arthritis (joint-space narrowing, flattening of the condyles, osteophytes) or chondrocalcinosis was eliminated.

A transverse 10-mm drill hole was made in the distal tibia, and the medullary canal of the tibia was reamed. A threaded rod was placed through the tibial drill hole, and it was potted in methylmethacrylate. The femoral medullary canal was also reamed and potted in methylmethacrylate cement. A drill hole was made through the femur in the sagittal plane to allow unconstrained varus/valgus rotation during load testing. A custom stainless steel rod was inserted through the femoral hole and attached to the model 858 Mini Bionix load machine (MTS Systems Corp, Eden Prairie, Minnesota).

The tibiofemoral joint surface was oriented parallel to the floor with the knee held in full extension and measured goniometrically at 0°, allowing for varus/valgus angulations but otherwise constrained. To be consistent with prior studies, and to simulate load during normal gait (2.5 times body weight of the average 70-kg individual), an 1800-N load was applied axially through the knee and the Tekscan 410-N knee sensor recorded contact area and peak contact pressure (Figure 1).[21,26] Knees were calibrated using an 1800-N load and that calibration file was applied to the Tekscan data. The control knee contact area and peak contact pressure of medial tibiofemoral articulations were recorded over 3 trials. A longitudinal posterior capsular incision was made over the lateral aspect of the medial femoral condyle. The posterior cruciate ligament (PCL) and posterior horn of the medial meniscus were identified and were intact in all knees. The posterior horn of the medial meniscus was then incised directly at its tibial insertion just medial to the PCL insertion into the tibia to simulate a posterior horn of the medial meniscal avulsion. It was observed that the meniscus became unstable and mobile. The knee was then reexamined using the same 1800-N load over 3 trials, recording medial tibiofemoral contact area and peak contact pressure. It was routinely observed that the meniscus would slowly extrude from the joint when the knee was loaded. The posterior horn medial meniscal avulsion was then repaired according to a technique recently described and reported.[23] A 0.62-mm Kirschner wire was driven from the posterior horn attachment site under direct visualization to the anterior medial tibia. A 7-mm cannulated drill bit was then used to drill the transosseous tunnel in antegrade fashion (Figure 2). Three No. 2 FiberWire sutures (Arthrex, Naples, Florida) were passed through the posterior horn of the medial meniscus; the first was a horizontal suture at 1 cm from the avulsed end of the meniscus, and the second and third were vertical sutures just medial to the first. The 6 ends of the FiberWire were then passed through the bone tunnel using a free-wire loop and tied over a metallic washer flush to the anterior tibial cortex. The knee was then reexamined using the same 1800-N load, again recording contact area and peak contact pressure. Medial and lateral contact area and peak contact pressure were recorded for each knee in control, avulsed meniscus, and repaired meniscus groups.

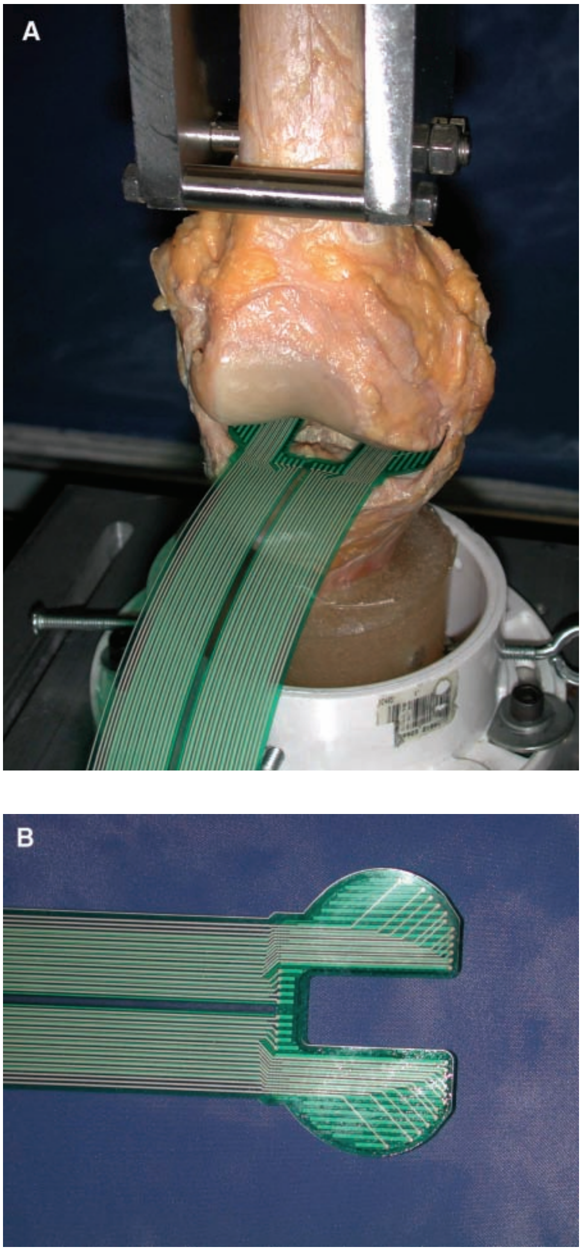

Figure 1. A, Tekscan sensor in a knee specimen mounted in the custom testing jig. B, close-up view of Tekscan sensor.

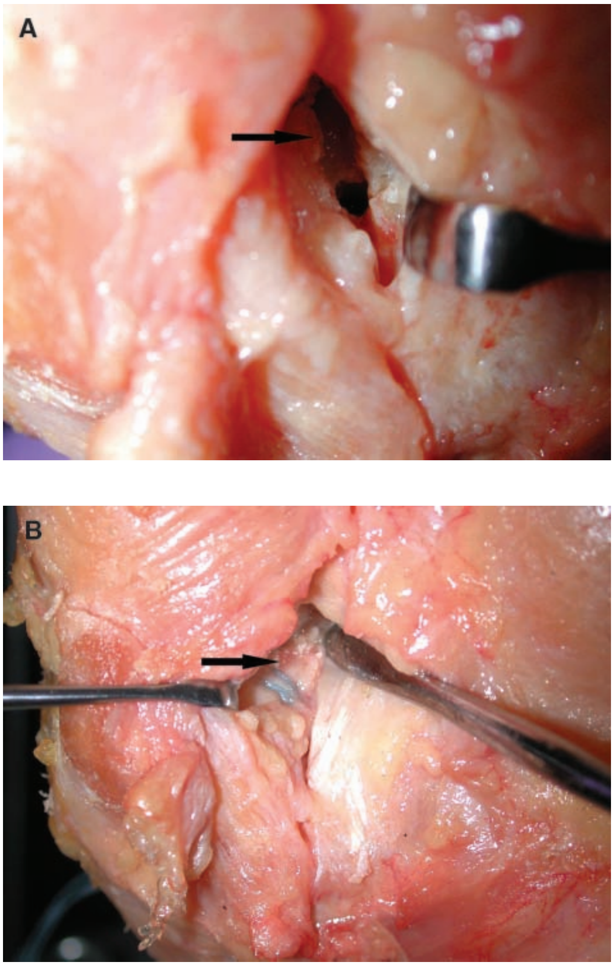

Figure 2. A, the posterior horn of the medial meniscus has been avulsed, and a 7-mm drill hole has been placed anatomically at the posterior root attachment site. B, sutures have been passed in the meniscus and the attachment secured into the drill hole with transosseous sutures.

TABLE 1
Pairwise Comparison of Medial Contact Area and Peak Contact Pressure From a Cadaveric Control Knee Compared With an Avulsed Medial Meniscus and a Meniscus Repaired by a Transosseous Suture Technique[a]

	Control vs Avulsed	Avulsed vs Repaired	Repaired vs Control
Contact area (mm^2)	C: 594 ± 59 A: 474 ± 79 *P* = .005[b]	A: 474 ± 79 R: 592 ± 80 *P* = .015[b]	R: 592 ± 80 C: 594 ± 59 *P* = .959
Peak contact pressure (kPa)	C: 3841 ± 1240 A: 5084 ± 1087 *P* = .006[b]	A: 5084 ± 1087 R: 3551 ± 1305 *P* = .018[b]	R: 3551 ± 1305 C: 3841 ± 1240 *P* = .424

[a] C, control knee; A, avulsed meniscus: R, repaired meniscus.
[b] Statistical significance ($P < .05$)

TABLE 2
Pairwise Comparison of Lateral Contact Area and Peak Contact Pressure From a Cadaveric Control Knee Compared With an Avulsed Medial Meniscus and a Meniscus Repaired by a Transosseous Suture Technique[a]

	Control vs Avulsed	Avulsed vs Repaired	Repaired vs Control
Contact) area (mm^2	C: 571 ± 80 A: 581 ± 76 *P* = .674	A: 581 ± 76 R: 592 ± 114 *P* = .824	R: 592 ± 114 C: 571 ± 80 *P* = .655
Peak contact pressure (kPa)	C: 5081 ± 769 A: 5228 ± 1155 *P* = .628	A: 5228 ± 1155 R: 5330 ± 282 *P* = .795	R: 5330 ± 282 C: 5081 ± 769 *P* = .405

[a] C, control knee; A, avulsed meniscus: R, repaired meniscus.

Descriptive statistics are provided as mean ± standard deviation. Comparisons between groups were calculated with a 1-way analysis of variance. Tukey's post hoc analysis was completed for all significant analysis of variance results to determine significant pairwise comparisons. A probability value of ≤.05 was considered statistically significant in all tests performed. All statistical analyses were performed with SPSS software (version 15.0, SPSS Inc, Chicago, Illinois).

RESULTS

A total of 11 knees were tested as described. Two knees were eliminated from the analysis because they became unstable during axial loads. These specimens were acquired after they had been used for a study of patellofemoral mechanics and the proximal fibula had been excised, rendering the lateral and posterolateral aspects too unstable to withstand loading. One knee was eliminated when the femur fractured under loading conditions as a control knee. For the remaining 8 knees, summary data for the mean peak contact pressure and mean contact area measured in the medial and lateral compartments are presented in Tables 1 and 2, respectively. When avulsion of the posterior horn of the medial meniscus was simulated by incision, peak contact pressure in the medial compartment increased from 3841 kPa to 5084 kPa (*P* = .006), and contact area decreased from 594 mm^2 to 474 mm^2 (*P* = .005). We also noted a consistent pattern of loading on a more posterior location of the medial tibiofemoral joint and no change in location of the loading pattern on the lateral tibiofemoral joint (Figure 3). Repair of the meniscus by a transosseous suture method restored the loading profile values to equal the control knee, with peak contact pressure of 3551 kPa and contact area of 592 mm^2. When the posterior horn of the medial meniscus was avulsed, peak contact pressure and contact area in the lateral compartment did not change.

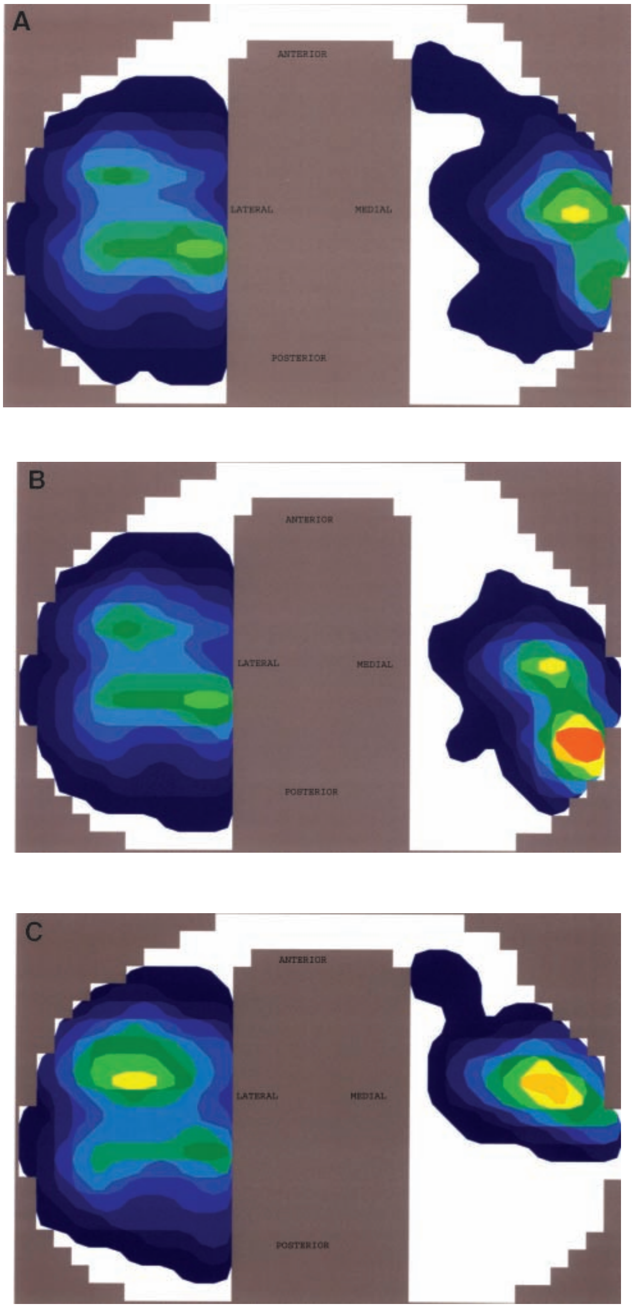

Figure 3. Representative Tekscan images of the 3 test conditions: A, control knee; B, avulsed meniscus; and C, repaired meniscus. Note the increased contact pressure and decreased contact area on the sensor from a knee with an avulsed meniscus, and the posterior location of the loading pattern when compared with either the control knee or the repaired meniscus.

DISCUSSION

The menisci are integral parts of the complex biomechanics of the knee and function in part to protect the adjacent articular surfaces from axial loads.[3,19,36] The knee menisci serve to increase the congruity of the convex femur to the relatively flat tibia and play an important role in joint lubrication, load distribution, joint stability, and proprioception. During weightbearing, the circumferential collagen bundles of the menisci bear and contain hoop strain, allowing even distribution of axial load across the joint and effectively protecting the articular cartilage.[17] The wedge shape of the meniscus gives it a tendency to extrude from between the femoral and tibial condyles, but because most of the collagen fibers are oriented circumferentially, they give the meniscus great tensile stiffness. The medial meniscus, especially its posterior horn and posterior root attachment site, is the most likely to sustain acute and chronic-type injuries.[8,11,34] The anterior and posterior root attachments of the menisci are critical for maintaining normal meniscus positioning, preventing extrusion, and preserving meniscus function.[3] There is good evidence of the deleterious biomechanical effect of meniscus loss, with 50% to 200% increases in medial contact pressure in totally meniscectomized versus normal knees.[4,9,13,20] Others have noted a correlation between the amount of meniscus resection and the onset and severity of osteoarthritis.[12,15,36] It makes sense that our values fall somewhat below a total meniscectomy knee because the meniscus remains in the knee, albeit in an abnormal position. Our study may underestimate the changes that result from this condition chronically because the results are an average of 3 trials at time zero of the condition.

Radial tears at or near the posterior horn root attachment may be more common than is clinically appreciated.[7,30] Bin et al[7] examined 345 consecutive medial meniscal tears at arthroscopy and found that 28% of all medial meniscal tears were at this location. Of those for whom MRI was available, meniscus extrusion was present in 79% of patients with complete medial meniscal root tears, 64% with partial medial meniscal root tears, and 50% with a degenerative medial meniscal root. Meniscus extrusion is an important sign that there may be injury at the meniscal origin root and is defined as more than 3 mm measured from the outer margin of the meniscus to the outer articular margin of the medial tibial plateau on midcoronal MRI scans.[8,16,28] A study by Costa et al[11] showed that in knees with minor meniscus extrusion (<3 mm), there were meniscal root tears in only 3%, compared with 42% when the extrusion was greater than 3 mm. In many studies, meniscus extrusion has been shown to be associated with joint-space narrowing, sclerosis, and other signs of degenerative arthritis.[1,10,11,14,18,32] Lerer et al,[22] on the basis of analysis of 205 MRI scans, were able to make a particularly strong correlation between medial meniscus extrusion and degenerative joint disease. It seems, then, that surgical efforts designed to repair, restore, or replace meniscal tissue should be pursued to avoid articular cartilage damage.

We could not find a published study of the biomechanical consequences of medial meniscal root detachment or medial meniscus extrusion. Comparison with a study of tibiofemoral contact mechanics after serial meniscectomies shows that loss of hoop stress by segmental meniscectomy gave results equal to a total meniscectomy.[21] Meniscus transplant studies have shown that when the posterior horn is not attached, contact areas and peak pressures fall somewhere between the intact knee and the total meniscectomy knee.[9,26] These experimental studies seem to support the results of our posterior horn meniscal avulsion model in which meniscal tissue is not removed, which apparently is not as biomechanically deleterious as a subtotal or total meniscectomy. Our study shows a 24.4% increase in medial peak pressure and a 20.2% decrease in medial contact area (Table 1), which supports the first part of our hypothesis.

There are a few clinical case reports in the literature that document posterior horn root avulsion injury.[5,16,25,27,31] In all cases, the treatment described was to resect meniscal tissue adjacent to the attachment site to prevent mechanical symptoms and pain. It is interesting to note that in 2 of these studies, the authors describe partial-thickness chondral wear and/or extensive cartilage fissuring of the medial surfaces. This is our experience also and would seem to indicate a fairly rapid decline in the health of the articular cartilage of these knees and, we think, early osteoarthritis. Most reports of medial meniscal avulsion from the posterior horn attachment site stated that a repair was not performed because of degeneration of the meniscal tissue, need for a posterior arthrotomy, or just "not technically possible."[16,25,27] Raustol et al[29] described repair of a traumatically induced medial meniscal ossicle by using a long pin and sutures passed through a posteromedial accessory arthroscopy portal in a transosseous fashion. West et al[35] reported a technique to repair lateral meniscal avulsions when associated with anterior cruciate ligament tears. Our past clinical experience with cases of medial meniscal avulsion led us to devise and report a similar repair technique to restore the posterior horn medial meniscus attachment site.[23] This was in an attempt to restore the attachment, decrease or eliminate meniscus extrusion, and reestablish the ability of the meniscus to absorb hoop stress. We theorized that this would give the patient the best chance of avoiding subsequent joint degeneration. The landmarks for the posterior horn attachment of the medial meniscus are the PCL, the medial tibial spine, and the articular margin of the posteromedial tibial plateau.[24,33] Two patients with posterior horn root avulsions of the medial meniscus and meniscus extrusion underwent arthroscopic primary repairs of the posterior horn of the medial meniscus using sutures through a transosseous tunnel and realized excellent short-term results. The current study was designed to provide laboratory biomechanical evidence of the procedure's ability to return hoop stress resistance and to provide basic science evidence to support the early clinical success of the operation. Repair of the meniscus in our experiment did restore the loading profile to that of the control knee (Table1), supporting the second part of our hypothesis.

We speculate that cyclic loading, like what occurs clinically in patients who continue to walk on knees after this injury, would further adversely affect the knee. These conditions are the subject of further testing in our laboratory. We recognize that the repair technique described allows the meniscus to be tucked into the transosseous tunnel by several millimeters. This most likely decreased the circumference of the meniscus, bringing the meniscus in greater contact with the femoral condyle, and decreased peak pressure on the joint surface. One could speculate that these would be desirable results of the repair but may adversely affect the long-term viability of the repair. Further studies in our laboratory did not show any desirable biomechanical effect of repairing the posterior horn of the medial meniscus using a smaller and/or less deep bone tunnel (data not reported in this article). Another study will evaluate creation of the tunnel at a more medial location than the anatomic attachment site. Either of these modifications may allow the meniscus to sit more anatomically on the tibial condyle and avoid decreasing the radius of curvature of the meniscus. Admittedly, the lack of cyclic loading is a weakness in this study, but we think that cyclic loading would reveal an even greater negative effect in the avulsed knees. It is hoped that cyclic loading would not have a negative effect on the repair knees, but that is a distinct possibility. The protocols in this study tested the knees in full extension only, and with muscle forces eliminated. Knee flexion angle was fixed to simplify the testing apparatus and sequences, and with the knowledge that other studies have shown a consistent pattern of change in loading profiles across all flexion angles.[21] Although both represent potential limitations of this study, they conform to protocols of other published biomechanical knee studies. Cutting of the coronary ligaments in our experiment was done to allow the test film to lie flat on the tibial plateau. We found in pilot testing that other positions of the film, such as on top of the meniscus, led to slippage of the film and inconsistent data collection. Transecting these ligaments may have rendered the control knee meniscus more unstable and thus altered contact area and pressure. The effect, though, would be to decrease the contact area and increase the contact pressure, tending to minimize the potential difference between the control knee and the meniscal avulsion knee. Finally, we did not find it surprising that the lateral joint-loading profiles did not change, theorizing that as the medial meniscus extruded, the knee went into varus and effectively neutralized the potential effect of medial meniscus functional loss.

SUMMARY

The posterior horn attachment of the medial meniscus is critical for maintaining its anatomic and biomechanical integrity. Avulsion injury or degenerative tear at this site can cause the meniscus to extrude from the joint, lose the ability to absorb hoop stress, and biomechanically overload the medial joint articular surface. Primary repair of the posterior horn of the medial meniscus has been described and has met with good short-term clinical follow-up in a limited number of cases. This laboratory study supports the ability of this technique to restore the hoop stress resistance of the meniscus, with contact pressures and contact areas similar to the control knee under physiologic loading conditions.

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