Two-Tunnel Transtibial Repair of Radial Meniscus Tears Produces Comparable Results to Inside-Out Repair of Vertical Meniscus Tears

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Background: Radial meniscus tears disrupt the circumferential fibers and thereby compromise meniscus integrity. Historically, radial tears were often treated with meniscectomy because of an incomplete understanding of the biomechanical consequences of these tears, limited information regarding the biomechanical performance of repair, and the technical difficulty associated with repair. There is a paucity of studies on the outcomes of the repair of radial meniscus tears.

Purpose/Hypothesis: The purpose was to determine the outcomes of 2-tunnel transtibial repair of radial meniscus tears and compare these results to the outcomes of patients who underwent the repair of vertical meniscus tears with a minimum of 2-year follow-up. The hypothesis was that radial and vertical meniscus tear repair outcomes were comparable.

Study Design: Cohort study; Level of evidence, 3.

Methods: Patients who underwent 2-tunnel transtibial pullout repair for a radial meniscus tear were included in this study and compared with patients who underwent inside-out repair for a vertical meniscus tear. Subjective questionnaires were administered preoperatively and at a minimum of 2-year follow-up, including the Lysholm score, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the Short Form–12 (SF-12) physical component summary (PCS), the Tegner activity scale, and patient satisfaction. Analysis of covariance was used to compare postoperative outcome scores between the meniscus repair groups while accounting for baseline scores. Adjusted mean effects relative to the radial repair group were reported with 95% CIs.

Results: Twenty-seven patients who underwent 2-tunnel transtibial pullout repair for radial meniscus tears and 33 patients who underwent inside-out repair for vertical meniscus tears were available for follow-up at a mean of 3.5 years (range, 2.0-5.4 years). No preoperative outcome score significantly differed between the groups. There were no significant group differences for any of the 2-year postoperative outcome scores. Relative to the vertical repair group, the radial repair group exhibited an adjusted mean of –0.2 (95% CI, –5.4 to 4.9), –0.6 (95% CI, –6.6 to 5.5), and 5.1 (95% CI, –3.9 to 14.0) points on the SF-12 PCS, WOMAC, and Lysholm scores, respectively.

Conclusion: The 2-tunnel transtibial pullout technique for the repair of radial meniscus tears produces similar clinical outcomes when compared with the repair of vertical meniscus tears at a mean 3.5 years' follow-up.

Keywords: meniscus repair; radial tear; vertical tear; 2-tunnel repair; transtibial; clinical outcomes

Complete radial meniscus tears constitute a unique subset of meniscus injuries, resulting in disruption of the circumferential fibers[2] and compromising their ability to withstand hoop stresses.[10,12,22,23] This results in decreased contact area and increased tibiofemoral contact pressure, which can lead to the onset of an accelerated joint degenerative process.[15] The proportion of radial tears has been recently reported to be 10% to 23% of meniscus tear patterns in the adult population, greater than previously reported.[5,16] Radial meniscus tears are common in active patients and are frequently associated with anterior cruciate ligament (ACL) and multiligament knee injuries.[4]

Traditionally, radial tears were addressed by means of partial or total meniscectomy because they were considered to be unrepairable.[11] However, meniscectomy for a complete radial meniscus tear is associated with long-term biomechanical consequences and an accelerated degenerative process of the knee.[2,13,18] Importantly, a subset of these patients may ultimately undergo meniscus

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546517704425

transplantation to improve symptoms and to attempt to preserve the joint.[19] With an increased emphasis on the detrimental long-term effects of meniscectomy, meniscus preservation is paramount whenever possible. This concept was reinforced by a recent systematic review that reported improved patient outcomes with the repair of radial meniscus tears when compared with meniscectomy at longer term follow-up.[19]

Existing techniques to address radial meniscus tears include all-inside horizontal mattress repair, transtibial pullout repair, and inside-out repair with either single, double, or crossed horizontal mattress sutures.[19] Repair strength is an important factor because of the effects on healing potential and postoperative rehabilitation protocols.[5] A recent biomechanical study compared a 2-tunnel transtibial pullout repair technique to a standard horizontal repair technique and reported improved performance with cyclic loading with the former.[3] In this regard, this technique has been reported to produce durable results in a case report at early follow-up.[11]

While there is debate over whether the repair of complete radial tears will result in adequate biomechanical performance and healing, few debate the benefits of repairing vertical meniscus tears because of the reported excellent outcomes for this tear pattern.[20] Patients undergoing vertical tear repair therefore represent a relevant comparison group for those undergoing radial tear repair. Given the paucity of reported outcomes of radial meniscus tear repair techniques, the purpose of this study was to compare the outcomes for patients who underwent 2-tunnel transtibial pullout repair of a radial meniscus tear versus patients who underwent inside-out repair of a vertical meniscus tear at a minimum 2 years of follow-up. The hypothesis was that outcomes for radial tear repair were comparable with those for vertical tear repair.

METHODS

This was an institutional review board–approved study. All patient data were queried from a prospectively collected data registry. Patients aged $\geq$16 years (with radiographically closed physes) who underwent treatment of a meniscus tear by a single surgeon (R.F.L.) between 2010 and 2014 were included. The primary study group included patients who underwent 2-tunnel transtibial pullout repair for a radial meniscus tear.[19] The comparison group included patients with vertical meniscus tears treated with inside-out repair.[14] Patients were excluded from this study if they had a meniscus root tear or underwent previous surgical treatment of the same meniscus.

Demographic data were documented at the initial clinical evaluation. Patients were categorized into 2 cohorts: 2-tunnel transtibial pullout repair of radial meniscus tears and inside-out repair of vertical meniscus tears. All patients in the radial repair group had complete radial meniscus tears confirmed on preoperative magnetic resonance imaging (MRI). Preoperatively, and at a minimum of 2 years after surgery, patients were administered a subjective questionnaire, which included the following clinical outcome measures: Lysholm score, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Short Form–12 (SF-12) physical component summary (PCS), Tegner activity scale, and patient satisfaction with outcomes. Patient satisfaction was measured on a 1-to-10 scale, with 1 being very unsatisfied and 10 being very satisfied.

Surgical Technique: 2-Tunnel Transtibial Radial Meniscus Tear Repair

Conventional surgical treatments of radial meniscus tears include all-inside horizontal mattress repair and inside-out repair with various suture configurations. Studies have shown an unacceptably low rate of meniscus healing, especially in the central white-white zone of the meniscus.[5] To address this, James et al[11] reported a novel technique for the repair of a medial meniscus midbody tear.

Once the radial tear was identified through standard anteromedial and anterolateral arthroscopic portals, adhesions along the meniscocapsular junction were released to mobilize the meniscus and allow for an anatomic repair. The anterior and posterior segments of the tear were lightly debrided with a shaver. A single 2.4-mm tunnel was drilled from the anterior tibia to the posterior aspect of the radial tear location using an aiming guide and a sheathed drill (Smith & Nephew). If the desired location was achieved for the first tunnel, the sheath was left in place, and a 5-mm parallel offset drill guide (Smith & Nephew) was used to position the second tunnel (usually, the most posterior tunnel was created first). Next, a No. 2 nonabsorbable suture (Ultrabraid; Smith & Nephew) was first passed through the peripheral corner of the anterior and posterior meniscus segments using a self-capturing suture-passing device (Firstpass; Smith & Nephew). A ringed grasper was used to shuttle the sutures in a crossed fashion through the tibial tunnels (ie, the anterior sutures were passed through the posterior tunnel, and the posterior sutures were passed through the anterior tunnel). Finally, the sutures were tied over a button on the anteromedial tibial cortex for medial meniscus tears and on the anterolateral cortex for lateral meniscus tears, with the knee in 90° of flexion. Inside-out horizontal mattress sutures were then placed into the radial tear using standard

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One or more of the authors has declared the following potential conflict of interest or source of funding: R.F.L. reports personal fees from Athrex, Smith & Nephew, and Ossur; grants from Southern and Eastern Norway Regional Health Authority and the National Institutes of Health (R13 grants for biologics), outside the submitted work; patents pending with Ossur and Smith & Nephew; and patents with royalties paid from Ossur, Smith & Nephew, and Arthrex.

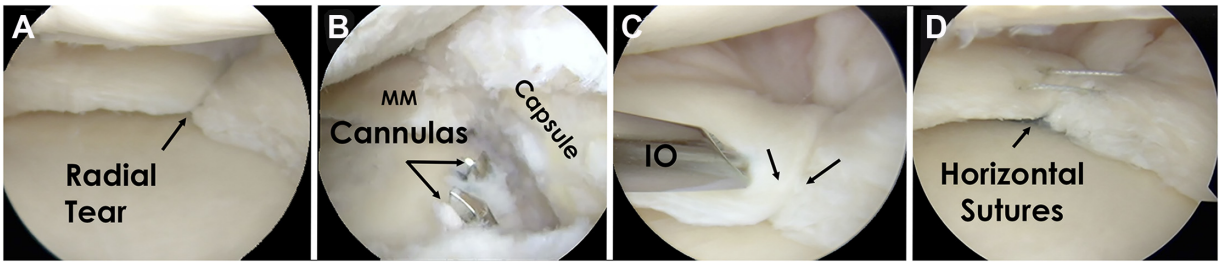

Figure 1. (A) Arthroscopic visualization of a medial meniscus radial tear. (B) Arthroscopic view of the transtibial placement of a cannula, which allows for the passage of sutures. (C) Arthroscopic view depicting inside-out repair of a medial meniscus radial tear. (D) Arthroscopic view showing horizontal sutures spanning a radial tear: tension is pulled to ensure complete repair of the tear. IO, inside-out suture passer; MM, medial meniscus.

2-0 nonabsorbable meniscus sutures to reinforce the transtibial technique. A marrow venting procedure (MVP) (microfracture within the intercondylar notch to allow the release of marrow elements and support healing)[7] was performed at completion of the repair in patients without concomitant intra-articular ligament reconstruction (Figures 1 and 2).

Surgical Technique: Inside-Out Vertical Meniscus Tear Repair

Standard medial and lateral arthroscopic portals were created adjacent to the patellar tendon, and diagnostic arthroscopic surgery was performed to assess for concurrent injuries.[21] Once the vertical tear was identified, a meniscus rasp was utilized to lightly debride the tear edges. For medial tears, a vertical incision was centered over the joint line, and dissection was made through the sartorius fascia; the interval anterior to the medial gastrocnemius was developed, and a retracting device was inserted to protect the posterior structures and allow needle capture. For lateral tears, the incision was centered over the posterior aspect of the iliotibial band, and the iliotibial band was split; the interval between the fibular collateral ligament (FCL) and lateral gastrocnemius was developed, and a retractor was inserted.

Dual meniscus repair needles loaded with 2-0 nonabsorbable sutures (FiberWire; Arthrex) were utilized and passed through the meniscus using a mechanical insertion device (Smith & Nephew). Vertical mattress sutures were placed either above or below the meniscus and tied sequentially with the knee in 90° of flexion. The number of sutures needed depended on the size and complexity of the tear.

Postoperative Rehabilitation Protocol

The postoperative protocol was dictated by concurrent pathological findings. Nonweightbearing was prescribed for the first 6 weeks. Passive range of motion was restricted from 0° to 90° of flexion for the first 2 weeks and then was progressed as tolerated by the patient. After this initial phase, partial protected weightbearing and cycling on a stationary bicycle were introduced. An unloader brace was utilized to protect the repair once the weightbearing phase commenced for 4 months postoperatively. Deep squatting, leg lifting, and sitting cross-legged were prohibited for 4 months postoperatively. After 4 months, the patient was allowed to resume unlimited low-impact activities.

Statistical Analysis

Assuming 2-tailed testing, an alpha of .05 (Bonferroni correction for 2 comparisons), and an independent-samples t test, 27 patients per group was sufficient to detect an effect size of $d = 0.78$ with 80% statistical power. First, the 2 patient groups were compared on the basis of potentially confounding covariates including demographics, details of the injury, and baseline outcome scores. Independent t tests and Fisher exact tests were used to assess these associations. To address the primary purpose of this study, minimum 2-year outcome scores were compared between the vertical and radial repair groups while accounting for baseline scores using analysis of covariance (ANCOVA). Group effects with 95% CIs were reported to facilitate the precision of estimates. All graphs and analyses were completed with the statistical package R (R Development Core Team).

RESULTS

Demographics

An initial database query yielded 70 patients (40 patients with a vertical tear, 30 patients with a radial tear) who were at least 2 years from surgery. The mean final follow-up for all patients was 3.5 years (range, 2.0-5.4 years). Complete follow-up was available for 60 of the 70 eligible patients (86%). This study included 60 knees in 60 patients (37 male, 23 female), with a mean age of 35.1 years (range, 18-67 years). The total patient cohort was divided into 2 groups: 27 patients (16 medial meniscus, 11 lateral meniscus) in the 2-tunnel transtibial pullout radial tear repair group and 33 patients (24 medial meniscus, 9 lateral meniscus) in the inside-out vertical tear repair group. The rate of medial and lateral meniscus tears was not significantly different between the 2 groups ($P = .270$). There was no significant difference in meniscus tear laterality between the radial and vertical repair groups ($P = .271$). Demographic variables, summarized for each group, are listed in Table 1. There were no

TABLE 1
Demographics and Characteristics by Repair Group[a]

	Radial Repair Group (n = 27)	Vertical Repair Group (n = 33)	*P* Value
Patient demographics			
Sex			.287 (FET)
Male	19 (70)	18 (55)	
Female	8 (30)	15 (45)	
Age, median (range), y	34 (18-67)	28 (18-63)	.208 (*t* test)
Knee			.068 (FET)
Left	16 (59)	11 (33)	
Right	11 (41)	22 (67)	
Injury characteristics			
Concomitant ligament			
Anterior cruciate ligament	17 (63)	30 (91)	.012 (FET)
Posterior cruciate ligament	1 (4)	1 (3)	>.999 (FET)
Medial collateral ligament	5 (19)	10 (30)	.375 (FET)
Fibular collateral ligament	1 (4)	9 (27)	.017 (FET)
Severe chondral defect (Outerbridge grade 3 or 4)			
Medial plateau or condyle	5 (19)	2 (6)	.227 (FET)
Lateral plateau or condyle	1 (4)	2 (6)	>.999 (FET)
Baseline outcome scores			
SF-12 PCS, mean ± SD	37 ± 9	37 ± 10	.766 (*t* test)
WOMAC, mean ± SD	37 ± 21	40 ± 24	.510 (*t* test)
Lysholm, mean ± SD	47 ± 22	46 ± 22	.780 (*t* test)
Tegner, median (range)	1 (0-9)	2 (0-10)	.271 (MWUT)

[a]Data are presented as n (%) unless otherwise indicated. FET, Fisher exact test; MWUT, Mann-Whitney *U* test; SF-12 PCS, Short Form–12 physical component summary; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

significant differences in sex or age between the 2 groups (P = .287 or .208, respectively). The mean follow-up was 3.5 years (range, 2.0-5.4 years).

Injury Pattern

Sixty-three percent of patients in the radial repair group had concurrent ACL tears, while 91% of patients in the vertical repair group had concurrent ACL tears (P = .012). The vertical repair group had a nonsignificantly higher rate of medial collateral ligament tears (P = .375) and a significantly higher rate of FCL tears (P = .017) than the radial repair group (Table 1). The occurrence of severe chondral defects, defined as Outerbridge grade 3 or 4, was not significantly different between the 2 groups in either the medial (P = .227) or lateral (P >.999) compartment of the knee. Preoperative and postoperative meniscus tear repair MRI results are displayed in Figure 3.

Baseline Outcome Scores

Despite differences in the ligamentous injury pattern, there were no significant differences in any baseline outcome score between the 2 groups (all $P > .250$). Baseline outcome scores are summarized in Table 1.

Patient-Reported Outcomes

A follow-up rate of at least 80% was obtained in both study groups. Postoperative outcome scores are summarized for both groups in Table 2. ANCOVA models, built to compare mean outcomes between the radial repair group and vertical repair group while adjusting for baseline scores, found no significant differences between the groups for any outcome score (all $P > .300$). Adjusted effects relative to the radial repair group are displayed along with their 95% CIs in Figure 4.

Significant improvements from baseline in all outcome scores (all $P < .001$) were observed for both the radial and vertical repair groups. The mean WOMAC score improved by 30.3 points at postoperative follow-up, the mean Lysholm score improved by 37.6 points at postoperative follow-up, and the mean SF-12 PCS score improved by 15.0 points at postoperative follow-up. The median Tegner score improved from 2 at baseline to 6 postoperatively. The preoperative to postoperative improvement in the WOMAC and SF-12 PCS scores was greater than the minimal clinically important difference (MCID) for each outcome score.[25]

Reoperations

Reoperation data for both the radial and vertical repair groups are reported in Table 3. The rate of reoperations was not significantly different between the groups (P = .97).

DISCUSSION

The most important finding of this study was that patients treated with 2-tunnel repair of radial meniscus tears had excellent outcomes that were comparable with the outcomes of the repair of vertical meniscus tears at a mean of 3.5 years (range, 2.0-5.4 years). These findings,

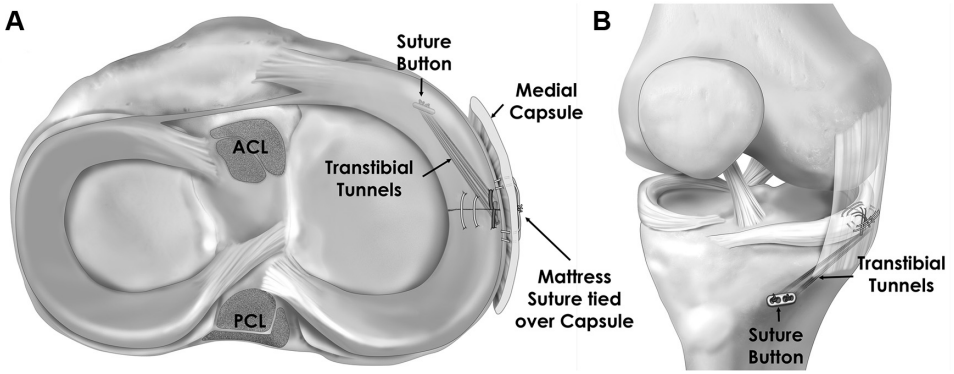

Figure 2. (A) Superior and (B) anteromedial views of 2-tunnel transtibial repair of a radial meniscus tear demonstrating the criss-cross transtibial tunnel technique in a left knee. ACL, anterior cruciate ligament; PCL, posterior cruciate ligament. (Reprinted with permission from Bhatia S, Civitarese DM, Turnbull TL, et al. A novel repair method for radial tears of the medial meniscus: biomechanical comparison of transtibial 2-tunnel and double horizontal mattress suture techniques under cyclic loading. *Am J Sports Med*. 2016;44(3):639-645.)

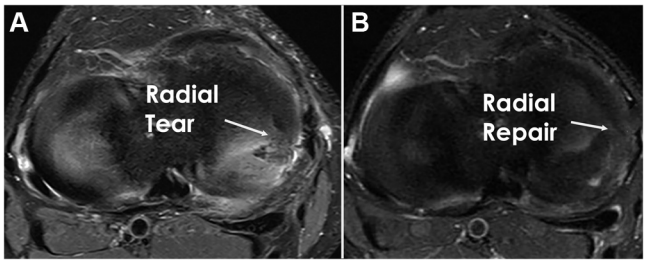

Figure 3. (A) Preoperative fat-suppressed magnetic resonance imaging (MRI) of a right knee consistent with a radial medial meniscus tear. (B) Postoperative fat-suppressed MRI of a right knee showing the repair of a radial tear in the medial meniscus.

combined with established biomechanical evidence of the deleterious effects of meniscectomy, support the repair of radial meniscus tears with similar consideration to that given for the repair of vertical meniscus tears.

The preoperative to postoperative improvement in the WOMAC, Lysholm, and SF-12 PCS scores was greater than the MCID reported in the literature for each outcome score (WOMAC: 11.5; Lysholm: 10.1; SF-12 PCS: 4.5). The 95% CI for the mean difference in the SF-12 PCS score between the radial and vertical repair groups constituted the lower bound to upper bound, which lies entirely within ±1 MCID (WOMAC: 11.5; SF-12 PCS: 4.5), as defined by Wright.[25] Therefore, we conclude with 95% confidence that these 2 patient groups achieve clinically equivalent SF-12 PCS and WOMAC scores.

Limited clinical literature exists for the outcomes of radial meniscus tear repair, and results are mostly limited to small case series. Foad[8] demonstrated that radial tears might have a self-limited ability to heal, indicating that the repair of radial tears that extend into the vascular zone of the meniscus is advocated. van Trommel et al[24] reported on 5 patients with complete radial lateral meniscus tears that were treated with inside-out horizontal suture repair

TABLE 2
Postoperative Outcome Scores by Repair Group[a]

	Median (Q1-Q3)
Radial repair group	
SF-12 PCS	55 (48-57)
WOMAC	4 (1-13)
Lysholm	91 (74-96)
Tegner	6 (5-7)
Vertical repair group	
SF-12 PCS	56 (46-58)
WOMAC	7 (1-12)
Lysholm	83 (73-95)
Tegner	6 (4-6)

[a]Q1, 1st quartile; Q3, 3rd quartile; SF-12 PCS, Short Form–12 physical component summary; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

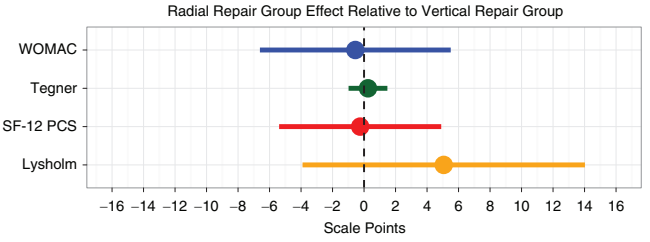

Figure 4. Adjusted effects of the radial repair group compared with the vertical repair group are displayed along with their 95% CIs. SF-12 PCS, Short Form12 physical component summary; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

over a fibrin clot. All 5 patients underwent second-look arthroscopic surgery within 3 to 6 months postoperatively to evaluate the integrity of the meniscus repair; 2 underwent partial meniscectomy of the repaired meniscus for incomplete healing. Three of 5 patients were available for

TABLE 3
Reoperations by Repair Group[a]

	Additional Surgery	Indication for Surgery
Radial repair group		
Patient 1	Revision ACL reconstruction	Reinjury
Patient 2	Revision ACL reconstruction	Planned staged revision ACL reconstruction after tunnel bone grafting
Patient 3	Inside-out repair of same meniscus that underwent prior radial repair	Sports-related reinjury
Patient 4	Microfracture of MFC, removal of loose bodies, and lysis of adhesions	Delamination of MFC
Vertical repair group		
Patient 1	Revision ACL reconstruction	Sports-related injury
Patient 2	Re-revision PCL reconstruction	Persistent instability after 2 prior PCL reconstructions at outside hospital
Patient 3	Revision MCL reconstruction	Chronic instability after traumatic fall
Patient 4	Contralateral partial meniscectomy	Persistent pain
Patient 5	ORIF of patellar fracture	Traumatic fall

[a]ACL, anterior cruciate ligament; MCL, medial collateral ligament; MFC, medial femoral condyle; ORIF, open reduction internal fixation; PCL, posterior cruciate ligament.

follow-up at an average of 71 months; all 3 were asymptomatic, and MRI demonstrated healing consistent with the early postoperative second-look procedure. Anderson et al[1] reported on 8 patients with radial lateral meniscus tears that were treated with inside-out horizontal suture repair. The mean Lysholm, International Knee Documentation Committee, and Tegner scores were 86.9, 81.6, and 5.8, respectively, at a mean follow-up of 70.5 months. Choi et al[6] studied outcomes at a mean of 36.3 months after all-inside repair of radial tears and reported mean postoperative Lysholm and Tegner scores of 94.7 and 5.7, respectively. Haklar et al[9] studied outcomes after inside-out horizontal suture repair of radial tears. This study reported a mean postoperative Lysholm score of 94.2 at a mean of 31 months' follow-up.[9] While these studies used different surgical techniques, they further support the findings of good midterm to long-term outcomes after the repair of radial meniscus tears.

Recent studies have evaluated the biomechanical properties of radial meniscus tear repair. Bhatia et al[3] performed a study comparing knees with complete radial tears of the medial meniscus. A matched-pair experiment was performed comparing inside-out horizontal suture repair and 2-tunnel transtibial repair. Specimens were cyclically loaded (N = 1000) with loads between 5 and 20 N. The 2-tunnel repair group had significantly stronger ultimate load failure (median, 196 N) than the horizontal suture repair group (median, 106 N). Additionally, this study reported that the 2-tunnel repair group had decreased gapping for all cyclic testing states.[3] In another biomechanical study, Matsubara et al[17] exposed 40 knees with complete radial meniscus tears to between 5 and 30 N of cyclical force. Twenty of the knees were repaired with a cross-suture technique, while the remaining 20 knees were repaired using a horizontal suture technique. After cyclical loads, the cross-suture group had significantly better ultimate failure loads.[17]

We recognize some limitations of this study. First, this was a retrospective evaluation of prospectively collected data. Second, although 2-year outcomes were obtained, it is relatively an early outcomes study in patients undergoing meniscus repair because the effects of meniscectomy may not be appreciated for several years. Third, this study compares the results from the repair of 2 different types of meniscus tears rather than 2 different techniques for the same type of tear. Finally, this study does not include postoperative radiographic analysis for degenerative joint changes or an MRI evaluation of repair success. However, this study demonstrates excellent early results with low failure rates.

CONCLUSION

Two-tunnel repair of radial meniscus tears yielded significantly improved clinical outcomes. Additionally, repair performance in this challenging and controversial treatment group was similar to outcomes for the well-accepted repair of vertical meniscus tears. Two-tunnel repair of radial meniscus tears should be considered a viable treatment option for this injury pattern and is supported by early clinical outcomes and biomechanical testing.

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