Minimum 2-Year Clinical Outcomes of Medial Meniscus Root Tears in Relation to Coronal Alignment

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Background: The effect of coronal plane alignment on the outcomes of repairs of the medial meniscus root remains unclear.

Hypothesis: Increased preoperative varus alignment is associated with higher failure rates and lower patient-reported outcomes (PROs) after isolated repair of the medial meniscus root.

Study Design: Case series; Level of evidence, 4.

Methods: Patients aged 18 years or older who underwent arthroscopy-assisted repair of the medial posterior meniscus root over a 7-year period were included. The mechanical axis of the knee was measured preoperatively. Osteoarthritis was assessed radiographically preoperatively and at the final follow-up according to the Kellgren-Lawrence grading scale. Failure was defined as any patient having to undergo revision root repair, partial meniscectomy of the previously repaired meniscus, debridement, lysis of adhesions, or conversion to arthroplasty.

Results: A total of 53 patients (29 women, 24 men) with a mean age of 51.3 years were included in the follow-up analysis. The mean time of follow-up after surgery was 3.3 years (range, 22-77 months). Significant improvements were observed in all PROs analyzed. Decreased varus as measured by alignment percentage was correlated with baseline Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Pain (P = .023) and WOMAC Stiffness (P = .022). Alignment percentage was also significantly negatively correlated with postoperative WOMAC Stiffness (P = .005) and positively correlated with Lysholm (P = .003) and International Knee Documentation Committee (P = .009) scores. Higher baseline Kellgren-Lawrence grade was correlated with worse postoperative PROs ($P < .05$), except 12-Item Short Form Health Survey Mental Component Summary and satisfaction. Eight patients who underwent a concomitant high tibial osteotomy (HTO) achieved lower PROs in all scales analyzed, regardless of their alignment. When excluding patients who underwent HTO, postoperative Lysholm score (P = .004) and postoperative WOMAC Stiffness (p = 0.014) were inferior among the patients with $>5°$ of varus.

Conclusion: Lower extremity alignment closest to neutral correlated with improved PROs. Patients who underwent a concurrent HTO had worse PROs than those who did not undergo HTO.

Keywords: meniscus; root; repair; alignment

Tears of the meniscus root are significant injuries that compromise the ability of the menisci to absorb axial loads and distribute hoop stresses. Previous biomechanical studies have demonstrated how tears of the meniscus root alter the tibiofemoral contact pressures in a similar manner to that of a complete meniscectomy, and that successful root repair has the ability to restore the pressures back to native levels.[2,15,18,20] Unrecognized tears of the meniscus root or failed root repairs can lead to accelerated cartilage degeneration and early osteoarthritis.[4,7,11,12] With an increased understanding and recognition of tears of the meniscus root, there has been an emphasis on the technical factors of root repairs to restore knee joint biomechanics as well as to evaluate factors to increase the chances for successful repair.

A systematic review evaluating the transtibial technique for repairs of the medial meniscus root has demonstrated complete healing rates in 62%, partial healing in 34%, and repair failure in 3% based on magnetic resonance imaging and second-look arthroscopy criteria.[9] However, the authors did not evaluate patient or surgical factors leading to incomplete or failed healing. Moon et al[19] found that both varus alignment of $>5°$ and preoperative Outerbridge grades 3 and 4 were independent risk factors for poor clinical outcomes. LaPrade et al[16] did not find a significant difference in alignment when comparing failures versus nonfailures. However, the analysis included repairs of

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both the medial and the lateral meniscus root without an independent focus on each root tear type with consideration of all alignments. Additionally, the medial meniscus anatomically does not have the stabilizing feature of the meniscofemoral ligaments that exist on the lateral side. As such, from a pathophysiologic standpoint, they may not behave the same. Currently, no definitive consensus exists on the tolerable amount of preoperative varus alignment when considering repairs of the medial meniscus root.

The purpose of this study was to evaluate preoperative patient factors, including long-standing alignment assessed on radiographic exam, that may increase risk for failed repairs of the medial meniscus root when performed in isolation. It was hypothesized that increased preoperative varus alignment, particularly values >5°, would lead to higher failure rates and lower patient-reported outcomes (PROs) after isolated repair of the medial meniscus root.

METHODS

After approval by the institutional review board at Vail Health Hospital, a retrospective study was performed on prospectively collected data. Inclusion criteria were patients aged 18 years or older at the time of surgery, with available preoperative long-leg alignment radiographs, who had undergone arthroscopy-assisted repair of the medial posterior meniscus root using transtibial bone tunnels between June 2011 and May 2018 by 2 orthopaedic sports medicine surgeons within the same practice (R.F.L. and M.T.P.).

Exclusion criteria included meniscal repair in a region other than the medial posterior root attachment, any lateral meniscal repair, or any concomitant ligamentous or cartilage restoration procedures. All patients were identified from a data registry consisting of prospectively collected data in a consecutive series. No distinction was made between traumatic or degenerative-type tears. Tears of the meniscus root were defined as complete avulsion of the root or a complete radial tear of the posterior horn of the meniscus within 9 mm of the root attachment, as previously described.[14] Indication for this procedure was an avulsion of the medial meniscus root or root tear equivalent (complete radial tear within 9 mm of the meniscus root attachment) in a symptomatic patient with no or mild-to-moderate (Kellgren-Lawrence 0-2) medial compartment degenerative changes.

The mechanical axis of the knee was measured preoperatively by using long-leg standing radiographs to assess knee alignment before repair of the meniscus root. This was performed as previously described[16] and reported as a percentage, with 0% as the mechanical axis falling on the medial border of the tibial plateau and 100% falling on the lateral border. Additionally, the amount of knee varus/valgus measured in degrees was reported as the angle between the intersection of a line from the center of the hip to the center of the femoral condyle and a line from the center of the ankle to the center of the tibial spines. Two reviewers (T.J.R. and J.J.R.) performed the measurements independently to assess interrater agreement.

Patients voluntarily completed subjective questionnaires preoperatively and at a minimum of 2 years postoperatively. This included the Lysholm score, Tegner activity scale, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), 12-Item Short Form Health Survey (SF-12) Physical Component Summary (PCS) and Mental Component Summary (MCS), International Knee Documentation Committee (IKDC) questionnaire, and patient satisfaction with outcome. Patient satisfaction with outcome was rated on a 10-point scale, with 1 equal to highly unsatisfied and 10 equal to highly satisfied. All patients were administered a questionnaire on a tablet computer at the time of the office visit or via email. The degree and progression of osteoarthritis were assessed radiographically preoperatively and at the final follow-up according to the Kellgren-Lawrence grading scale. Failure was defined as any patient having to undergo revision root repair, partial meniscectomy of the previously repaired meniscus, debridement, lysis of adhesions, or conversion to arthroplasty after the index surgery. Failures were identified via responses on the remote follow-up questionnaires, or via chart review.

Surgical Techniques

Repair of the Meniscus Root. An anatomic transtibial double-tunnel pullout repair of the meniscus root was performed as previously described and the sutures through the root were secured over a surgical cortical fixation device

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on the anterior tibia.[16] After diagnostic arthroscopy, the root tear was identified and the tibial attachment site was decorticated with the use of a curette and arthroscopic shaver. Two transtibial tunnels were drilled from the anteromedial tibia to the root attachment site, and sutures were passed through the meniscus root with a suture passer. The sutures were passed through the tibial tunnels and secured to the anteromedial tibia with a cortical button.

High Tibial Osteotomy

Two variations on the high tibial osteotomy (HTO) were performed: 1 with plate fixation and the other with a polyetheretherketone (PEEK) wedge (iBalance; Arthrex). Briefly, each HTO was performed utilizing an anteromedial incision with elevation of the sartorial fascia and distal tibial medial collateral ligament origin as a single sleeve. Posteriorly, subperiosteal dissection of the tibia was performed to allow for digital palpation of the proximal tibia. For the freehand technique, 2 Kirshner wires were placed fluoroscopically from the anteromedial tibia approximately 5 cm distal to the joint line with a trajectory toward the fibular head, and an oscillating saw was used to complete the osteotomy with a sagittal-oriented, 1-cm lateral hinge, as well as completion of the posterior cortex medial to the hinge. The osteotomy was then slowly distracted to the desired correction and fixed with a posteriorly placed wedged osteotomy plate (Puddu plate; Arthrex). With the knee in full extension, hyperextension of the osteotomy was performed to minimize the anterior osteotomy gap and an anteromedial Richards staple (Smith & Nephew) was placed for additional stabilization.[6]

For the PEEK implant, an anterior-to-posterior hinge pin was placed that allowed for assembly of a cutting jig. After completion of the osteotomy and distraction to the predetermined medial opening, the appropriate sized PEEK wedge was placed into the osteotomy and fixed with 4 corresponding PEEK screws.[3]

Rehabilitation

Two primary rehabilitation protocols were utilized for this patient cohort, depending on the treating surgeon. The first, as previously described,[16] involved nonweightbearing for 6 weeks with 0° to 90° range of motion initiated on postoperative day 1 and advancing as tolerated after 2 weeks. The second protocol involved toe-touch weightbearing with 0° to 90° range of motion for 6 weeks. For patients undergoing HTOs, both surgeons' protocols entailed nonweightbearing for 8 weeks. All patients focused on endurance and strength exercises starting at 8 to 10 weeks postoperatively and gradually progressed to normal activities, with an average return to full activities at 5 to 7 months postoperatively.

Statistical Analysis

Wilcoxon signed-rank and Mann-Whitney *U* tests were used to compare continuous variables between paired samples and independent groups, respectively. Spearman rho was calculated to assess the correlation between continuous covariates. Interrater measurement repeatability was assessed for varus-valgus alignment, measured both in degrees and as a percentage of the tibial plateau. In each case, a 2-way random-effects model was used to calculate the single-measure absolute agreement version of the intraclass correlation coefficient (ICC). Nonparametric 95% bias-corrected and accelerated confidence intervals, calculated using 1999 bootstrap resamples, were reported with each ICC estimate. To further assess the measurement reliability, Bland-Altman 95% limit of agreement analyses were performed. This tool aids in clinical interpretation by determining the average bias and spread (±2 SD) of the observed differences by 2 raters (T.J.R. and J.J.R.) in the units of the measurement. The ICC values were interpreted as follows: ICC < 0.50, poor agreement; $0.50 <$ ICC < 0.75, moderate agreement; $0.75 <$ ICC < 0.90, good agreement; and ICC > 0.90, excellent agreement.[13] Interrater measurement agreement for the ordinal Kellgren-Lawrence grade was assessed using a weighted Cohen kappa statistic with quadratic weighting.[20] Assuming a type 1 error rate of .05 and 2-tailed hypothesis testing for a nonzero correlation coefficient, 53 patients is sufficient to detect an effect size of rho = 0.365 with 80% statistical power. All statistical analyses were performed with the statistical package R Version 4.0.0 (R Development Core Team; with additional packages *psy*, *boot*, and *irr*).[5,8,10,21]

RESULTS

A total of 61 knees in 60 patients met the inclusion criteria for this study and all patients agreed to participate. Two knees (bilateral in a single patient) underwent total knee arthroplasty 6 months after the second index surgery; thus, subjective outcomes at 2 years were excluded from the analysis. Of the remaining 59 knees (in 59 patients), a minimum 22-month subjective follow-up was obtained for 53 knees (90%) (Figure 1). Among all 61 eligible knees, baseline subjective data were obtained for all but 2 patients. Final analysis was performed with the 53 patients (29 women, 24 men; mean age at time of surgery, of 51.3 years) for whom follow-up subjective data were successfully obtained. The mean time of follow-up postsurgery was 3.3 years (range, 22-77 months). No baseline covariates were statistically different between the included patients and the 6 patients lost to follow-up (Table 1). There was excellent interrater reliability for standing lower extremity alignment (ICC, 0.971; 95% CI, 0.908, 0.989). Fair interrater agreement was found for Kellgren-Lawrence grade (weighted kappa, 0.33).

Significant improvements were observed in all PROs analyzed (Table 2). Tegner and IKDC scores did not have enough baseline observations for preoperative analysis to be performed. Alignment percentage was significantly negatively correlated with baseline WOMAC Pain (rho = −0.32; P = .023) and WOMAC Stiffness (rho = −0.32; P = .022). Alignment percentage, measured preoperatively, was also significantly negatively correlated with postoperative WOMAC Stiffness (rho = −0.39; P = .005) and

TABLE 1
Comparison of Patients With Successfully Obtained Subjective Follow-up Versus Patients Who Were Lost to Follow-up[a]

	Total, n = 59	LTF, n = 6	FU, n = 53	*P* Value[b]
Age	54.9 (43.1-60.4)	52.5 (43.2-56.5)	54.9 (43.4-60.6)	.83
Sex				.69
Female	33 (55.9)	4 (66.7)	29 (54.7)	
Male	26 (44.1)	2 (33.3)	24 (45.3)	
Laterality				.39
Left	33 (55.9)	2 (33.3)	31 (58.5)	
Right	26 (44.1)	4 (66.7)	22 (41.5)	
Previous surgery				.19
No	57 (96.6)	5 (83.3)	52 (98.1)	
Yes	2 (3.4)	1 (16.7)	1 (1.9)	
HTO				.58
No	51 (86.4)	6 (100.0)	45 (84.9)	
Yes	8 (13.6)	0 (0.0)	8 (15.1)	
Alignment, %	33.5 (26.5-40.8)	33.0 (29.5-35.9)	33.5 (26.4-41.0)	.83
Alignment, deg	2.8 (1.6-5.0)	3.2 (2.5-4.1)	2.8 (1.5-5.1)	.69
Baseline Outerbridge grade				>.99
0	7 (11.9)	0 (0.0)	7 (13.2)	
1	16 (27.1)	2 (33.3)	14 (26.4)	
2	17 (28.8)	2 (33.3)	15 (28.3)	
3	11 (18.6)	1 (16.7)	10 (18.9)	
4	8 (13.6)	1 (16.7)	7 (13.2)	
Baseline KL grade				.43
0	29 (50.0)	2 (33.3)	27 (51.9)	
1	14 (24.1)	1 (16.7)	13 (25.0)	
2	13 (22.4)	3 (50.0)	10 (19.2)	
3	2 (3.4)	0 (0.0)	2 (3.8)	
Baseline SF-12 PCS	34.6 (28.7-43.8)	28.7 (25.4-34.9)	35.2 (29.2-44.2)	.22
Baseline SF-12 MCS	54.5 (45.5-59.5)	59.2 (54.7-66.9)	54.1 (42.2-58.9)	.08
Baseline WOMAC Pain	9.0 (7.0-11.0)	9.5 (7.2-13.2)	9.0 (6.5-10.5)	.67
Baseline WOMAC Stiffness	3.0 (2.0-4.0)	3.0 (3.0-3.8)	4.0 (2.0-4.5)	.75
Baseline WOMAC Physical Function	24.0 (14.0-35.0)	22.5 (19.2-34.8)	24.0 (13.5-34.5)	.81
Baseline WOMAC Total	35.0 (20.0-48.0)	35.0 (30.0-51.2)	35.0 (20.0-48.0)	.84
Baseline Lysholm	55.0 (44.0-71.0)	46.5 (35.8-57.2)	56.0 (44.0-71.5)	.46

[a]Data are presented as number (%) or median (1st quartile–3rd quartile). Diff, difference; FU, follow-up; HTO, high tibial osteotomy; KL, Kellgren-Lawrence; LTF, lost to follow-up; MCS, Mental Component Summary; PCS, Physical Component Summary; SF-12, 12-Item Short Form Health Survey; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
[b]*P* values correspond to the Wilcoxon rank-sum test or Fisher exact test.

positively correlated with Lysholm (rho = 0.41; P = .003) and IKDC (rho = 0.38; P = .009) scores. Tegner activity scale was the only postoperative PRO that was significantly different between men (median, 4; 25th percentile, 4; 75th percentile, 6) and women (median, 3; 25th percentile, 3; 75th percentile, 4) (P = .005), and the only postoperative PRO that was significantly associated with age at surgery (rho = −0.328; P = .024). Higher baseline Kellgren-Lawrence grade was correlated with worse postoperative PROs (Spearman correlation, each $P < .05$), except SF-12 MCS and satisfaction.

Patients who underwent HTO (n = 8) achieved significantly worse SF-12 PCS (P = .020), WOMAC Pain (P = .031), WOMAC Stiffness (P = .012), WOMAC Total (P = .014), Lysholm (P = .022), and IKDC (P = .038) scores than patients who did not undergo an HTO (n = 45) (see Appendix Table A1, available in the online version of this article). HTO patients did not significantly differ from non-HTO patients with respect to age (P = .180), sex (P = .720), previous surgery ($P > .999$), baseline Outerbridge grade (P = .730), length of follow-up (P = .350), or any baseline PRO score (all $P > .05$); however, HTO patients did exhibit higher baseline Kellgren-Lawrence grades (P = .05) and significantly different lower alignment percentages (P = .02).

Patients were further analyzed in subgroups of >5° or <5° in varus and whether or not they underwent an HTO (Table 3). Patients who underwent an HTO achieved lower PROs in all scales analyzed, regardless of their alignment. When excluding patients who underwent HTO, postoperative Lysholm (P = .004) and postoperative WOMAC Stiffness (P = .014) scores were inferior among the patients with < 5° of varus. None of the other PROs differed significantly depending on > 5° of varus alignment.

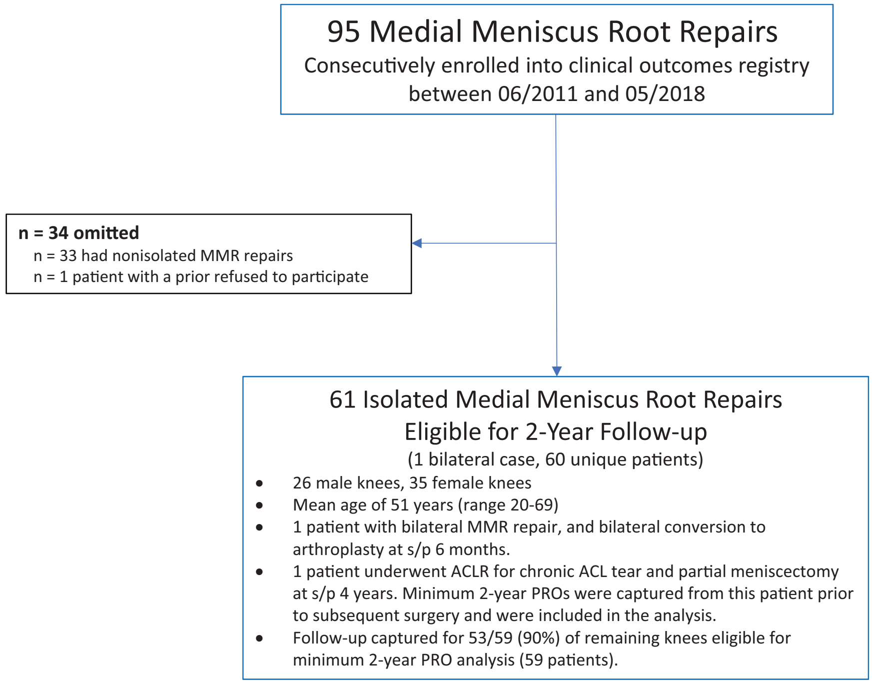

Figure 1. Flowchart of exclusion and inclusion criteria of the study cohort. *One patient had 2-year follow-up before revision surgery, which was used in outcome analysis. ACL, anterior cruciate ligament; ACLR, ACL reconstruction; MMR, medial meniscus root; PRO, patient-reported outcome; s/p, status-post index surgery.

TABLE 2
Outcome Measures from Pre- to Postoperatively After Arthroscopy-Assisted Repair of the Medial Posterior Meniscus Root Using Transtibial Bone Tunnels[a]

Outcome Measure	Preoperative	Postoperative	*P* Value
WOMAC Total	35 (19.5-48.0)	4 (1.5-13.0)	**<.001**
WOMAC Pain	9 (6.0-10.5)	1 (0.0-4.0)	**<.001**
WOMAC Stiffness	3 (2.0-4.0)	1 (0.0-2.0)	**<.001**
WOMAC Physical Function	24 (12.0-34.5)	2 (0.0-9.0)	**<.001**
Lysholm	55 (44.0-72.0)	88 (75.0-94.5)	**<.001**
SF-12 PCS	35.7 (29.3-44.3)	53.2 (44.8-57.0)	**<.001**
SF-12 MCS	54.1 (42.3-58.9)	57.5 (53.3-59.6)	**.008**
Satisfaction with outcome		10 (8.0-10.0)	—
Tegner[b]		4 (3-5)	—
IKDC[b]		82.8 (64.3-88.8)	—

[a]Data are presented as median (1st quartile–3rd quartile). Significant values appear in bold. Diff, difference; IKDC, International Knee Documentation Committee; MCS, Mental Component Summary; PCS, Physical Component Summary; SF-12, 12-Item Short Form Health Survey; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
[b]Not enough preoperative observations of Tegner and IKDC scores for robust pre- to postoperative comparison.

DISCUSSION

The main findings of this study were that PRO measures inversely correlated with increasing degrees of preoperative varus alignment after arthroscopic repair of the medial meniscus root. However, utilizing the cutoff value of 5° did not reliably predict patient outcomes, with the exception of the WOMAC Stiffness and Lysholm scales. The 5° cutoff was utilized because other authors have proposed this as a cutoff value.[18] Furthermore, patients who underwent concomitant HTO for alignment correction reported worse outcomes postoperatively, regardless of alignment. Last, increased preoperative Kellgren-Lawrence grade was associated with worse outcomes postoperatively.

In accordance with previously published literature, the current study demonstrated significant improvements in PROs after repair of the medial meniscus root. Only 1 patient who underwent a bilateral procedure went on to bilateral total knee arthroplasties, each performed 6 months after the primary repairs. Chung et al[7] used

TABLE 3
Postoperative Outcome Scores[a]

	<5° Varus, No HTO, n = 33	<5° Varus, HTO, n = 5	>5° Varus, No HTO, n = 11	>5° Varus, HTO, n = 3	*P* Value[b]
SF-12 PCS	55.1 (50.5-57.0)	38.8 (29.0-43.5)	54.2 (43.4-57.4)	45.6 (42.8-46.6)	.03
SF-12 MCS	57.5 (55.6-59.5)	51.4 (45.7-53.3)	58.7 (54.2-61.2)	58.4 (53.0-60.3)	.1
WOMAC Pain	0.0 (0.0-2.5)	3.0 (1.0-4.0)	0.0 (0.0-5.5)	5.0 (4.5-5.5)	.14
WOMAC Stiffness	0.0 (0.0-2.0)	2.0 (1.0-2.0)	2.0 (1.0-2.0)	3.0 (2.5-3.0)	.011
WOMAC Physical Function	2.0 (0.0-6.5)	8.0 (5.0-11.0)	2.0 (0.0-12.5)	2.0 (1.0-10.0)	.35
WOMAC Total	3.0 (1.0-9.5)	12.0 (12.0-14.0)	3.0 (1.5-20.5)	9.0 (9.0-17.0)	.25
IKDC	87.3 (71.2-90.8)	64.9 (51.9-71.0)	78.1 (58.6-88.5)	64.3 (63.1-70.7)	.077
Lysholm	91.0 (85.5-95.0)	79.0 (78.0-81.0)	80.0 (54.5-89.5)	74.0 (67.0-75.5)	.012
Tegner	4.0 (3.0-6.0)	3.0 (3.0-4.0)	3.0 (3.0-4.0)	5.0 (4.0-5.0)	.66
Satisfaction	10.0 (8.0-10.0)	9.0 (8.0-9.5)	10.0 (9.0-10.0)	8.0 (5.5-8.5)	.31

[a]Data are presented as median (1st quartile–3rd quartile) and are stratified by 4 groups defined post hoc: ≤5° varus alignment with no HTO, ≤5° varus alignment with HTO, >5° varus alignment with no HTO, and >5° varus alignment with HTO. HTO subgroup sample sizes are small, limiting the ability to conduct post hoc pairwise comparisons. Statistically significant evidence was found for differential postoperative SF-12 PCS, WOMAC Stiffness, and Lysholm scores among the 4 subgroups. Diff, difference; HTO, high tibial osteotomy; IKDC, International Knee Documentation Committee; MCS, Mental Component Summary; PCS, Physical Component Summary; SF-12, 12-Item Short Form Health Survey; WOMAC, Western Ontario and McMasters Universities Osteoarthritis Index.

[b]*P* values correspond to Kruskal-Wallis analysis of variance testing of the null hypothesis of equality of postoperative PROs among all 4 groups.

IKDC and Lysholm scores to compare partial meniscectomy and meniscal repair groups and found significant improvements in both scores with the PROs of the meniscal repair being superior. Ahn et al[1] compared patients who underwent root repair with patients treated nonoperatively for a tear of the medial meniscus root and demonstrated that patients treated with root repair had better PROs (Tegner, Lysholm activity, and IKDC scores). However, this report did not take into account lower extremity alignment as a variable.

There is limited literature that reports the analysis of outcomes in relation to mechanical alignment in the setting of repair of the medial meniscus root. Lee et al[17] demonstrated that simple debridement for root tears can lead to acceptable outcomes in patients with well-aligned knees. Without a comparison group, it is difficult to conclude whether it is the surgical repair and restoration of joint mechanics or the baseline knee alignment that leads to improved outcomes in these patients. Moon et al[19] found that varus alignment of >5° was an independent risk factor for poor clinical outcomes. On the other hand, LaPrade et al[16] did not find a significant difference in alignment for failures versus nonfailures. However, the latter analysis included repair of both the medial and the lateral meniscus root. Although the current study demonstrated that more neutral lower extremity alignments correlated with improved WOMAC Pain, WOMAC Stiffness, and Tegner scores, when analyzing the subpopulation of patients with >5° of malalignment, this group as a whole did not have significantly worse PRO measures than those with <5° of malalignment.

Although increased malalignment correlated with worse outcomes postoperatively, patients who underwent HTO to improve their alignment reported worse outcomes. This important finding may guide surgeons when consulting patients about expectations in the setting of a tear of the meniscus root and malalignment. Patients may be educated that their baseline alignment likely plays a large role in their outcome, but correcting their alignment may not improve their outcome. Those with varus malalignment and tears of the medial meniscus root should be counseled that uncertain and possible inferior outcomes are possible as a result. Future investigations should focus on the results of repair of the medial meniscus root in the setting of concomitant alignment procedures such as HTO.

Finally, this study continues to support previous literature that preoperative joint degeneration plays a large role in determining successful outcomes after repair of the meniscus root. Moon et al[19] found that preoperative Outerbridge grades 3 and 4 were independent risk factors for poor clinical outcomes. Similarly, Chung et al[7] reported that high-grade cartilage degeneration was a poor prognostic factor for medial meniscus posterior root tear fixation. The current study further supports the findings of these studies that varus alignment is a risk factor for failed repairs of the meniscus root.

Limitations

The authors recognize some limitations with this study. First, data were reviewed retrospectively; however, all data were collected prospectively. Additionally, postoperative imaging was not available to assess whether or not the repairs healed. Second, all surgeries were performed at a tertiary referral center, which may limit the generalizability of the results. Furthermore, long-standing lower extremity alignment was evaluated in the setting of all tears of the meniscus root, which is likely not a commonly performed practice withinthe field of orthopaedics. Third, the size of each comparison cohort may have limited the statistical power of the study; however, this study examined a consecutive series of patients treated by two surgeons at 1 institution. Moreover, there was a large difference in cohort size when analyzing those with >5 or <5° of varus. The 2 different postoperative protocols may have introduced a confounding variable within these groups. Last, there was no debridement cohort to serve as a comparison to determine if the outcomes could be attributed to alignment alone.

CONCLUSION

Repairs of the medial meniscus root led to significant improvements in PRO measures at a minimum 2-year follow-up, with only 3.3% undergoing conversion to arthroplasty. Lower extremity alignments closest to neutral correlated with improved PROs. Patients with >5° of varus who did not undergo HTO were also found to have worse PROs. Furthermore, patients who underwent a concurrent HTO had worse PROs than those who did not undergo an HTO.

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REFERENCES

1. Ahn JH, Jeong HJ, Lee YS, et al. Comparison between conservative treatment and arthroscopic pull-out repair of the medial meniscus root tear and analysis of prognostic factors for the determination of repair indication. *Arch Orthop Trauma Surg*. 2015;135(9):1265-1276.
2. Allaire R, Muriuki M, Gilbertson L, Harner CD. Biomechanical consequences of a tear of the posterior root of the medial meniscus: similar to total meniscectomy. *J Bone Joint Surg Am*. 2008;90(9):1922-1931.
3. Arthrex Inc. *iBalance HTO System for Medial High Tibial Opening Wedge Osteotomy*. Arthrex Inc; 2020.
4. Bhatia S, LaPrade CM, Ellman MB, LaPrade RF. Meniscal root tears: significance, diagnosis, and treatment. *Am J Sports Med*. 2014; 42(12):3016-3030.
5. Canty A, Ripley B. Boot:Bootstrap R (S-Plus) Functions. R package version 1.3-16. 2015.
6. Chahla J, Dean CS, Mitchell JJ, Moatshe G, Serra Cruz R, LaPrade RF. Medial opening wedge proximal tibial osteotomy. *Arthrosc Tech*. 2016;5(4):e919-e928.
7. Chung KS, Ha JK, Yeom CH, et al. Comparison of clinical and radiologic results between partial meniscectomy and refixation of medial meniscus posterior root tears: a minimum 5-year follow-up. *Arthroscopy*. 2015;31(10):1941-1950.
8. Falissard B (2012). Psy: various procedures used in psychometry. R package version 1.1. Accessed February 8, 2022. https://CRAN.R-proj ect.org/package=psy
9. Feucht MJ, Kuhle J, Bode G, et al. Arthroscopic transtibial pullout repair for posterior medial meniscus root tears: a systematic review of clinical, radiographic, and second-look arthroscopic results. *Arthroscopy*. 2015;31(9):1808-1816.
10. Gamer M, Lemon J, Fellows I, Singh P. Irr: various coefficients of interrater reliability and agreement. R package version 0.84.1. Accessed February 8, 2022. https://CRAN.R-project.org/package=irr
11. Kellgren JH, Lawrence JS. Radiological assessment of osteoarthrosis. *Ann Rheumat Dis*. 1957;16(4):494-502.
12. Kim JH, Chung JH, Lee DH, Lee YS, Kim JR, Ryu KJ. Arthroscopic suture anchor repair versus pullout suture repair in posterior root tear of the medial meniscus: a prospective comparison study. *Arthroscopy*. 2011;27:1644-1653.
13. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15(2):155-163. doi:10.1016/j.jcm.2016.02.012
14. LaPrade CM, James EW, Cram TR, Feagin JA, Engebretsen L, LaPrade RF. Meniscal root tears: a classification system based on tear morphology. *Am J Sports Med*. 2015;43(2):363-369. doi:10.1177/0363546514559684
15. LaPrade CM, Jansson KS, Dorman G, Smith SD, Wijdicks CA, LaPrade RF. Altered tibiofemoral contact mechanics due to lateral meniscus posterior horn root avulsions and radial tears can be restored with in situ pull-out suture repairs. *J Bone Joint Surg Am*. 2014;96(6):471-479.
16. LaPrade RF, Matheny LM, Moulton SG, James EW, Dean CS. Posterior meniscal root repairs: outcomes of an anatomic transtibial pull-out technique. *Am J Sports Med*. 2017;45(4):884-891. doi:10.1177/0363546516673996
17. Lee BS, Bin SI, Kim JM, Park MH, Lee SM, Bae KH. Partial meniscectomy for degenerative medial meniscal root tears shows favorable outcomes in well-aligned, nonarthritic knees. *Am J Sports Med*. 2019;47(3):606-611. doi:10.1177/0363546518819225
18. Marzo JM, Gurske-DePerio J. Effects of medial meniscus posterior horn avulsion and repair on tibiofemoral contact area and peak contact pressure with clinical implications. *Am J Sports Med*. 2009; 37(1):124-129.
19. Moon HK, Koh YG, Kim YC, Park YS, Jo SB, Kwon SK. Prognostic factors of arthroscopic pull-out repair for a posterior root tear of the medial meniscus. *Am J Sports Med*. 2012;40:1138-1143.
20. Padalecki JR, Jansson KS, Smith SD, et al. Biomechanical consequences of a complete radial tear adjacent to the medial meniscus posterior root attachment site: in-situ pullout repair restores derangement of joint mechanics. *Am J Sports Med*. 2014;42(3):699-707.
21. *R Core Team. R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing; 2020. Accessed February 8, 2022. https://www.R-project.org/