Midterm Outcomes of Posterior Medial Meniscus Root Tear Repair

A Systematic Review

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Background: Whereas there has been growing interest in surgical repair of posterior medial meniscus root tears (PMMRTs), our understanding of the medium- and long-term results of this procedure is still evolving.

Purpose: To report midterm clinical outcomes from PMMRT repairs.

Study Design: Systematic review.

Methods: A literature review for this systematic analysis was performed in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. We identified studies that reported the results of arthroscopic repair of PMMRTs. Functional and imaging outcomes were reviewed and summarized.

Results: In total, 28 studies with a total of 994 patients (83% female) with an overall mean age of 57.1 were included in this review. Clinical outcomes (Lysholm, International Knee Documentation Committee, Hospital for Special Surgery, and Tegner scores) were improved at final follow-up in all studies. Of patients, 49% had radiographic progression of at least 1 grade in the Kellgren-Lawrence scale at a mean follow-up of 4.0 years in 11 studies. Cartilage degeneration had progressed at least 1 grade on magnetic resonance imaging scans in 23% of patients at a mean follow-up of 31.6 months in 4 studies.

Conclusion: PMMRT repairs provide a functional benefit with consistent improvements in clinical outcome scores. There is some evidence that PMMRT repair slows the progression of osteoarthritis but does not prevent it at midterm follow-up.

Keywords: knee; general; meniscus; imaging; magnetic resonance; clinical assessment/grading scales; economic and decision analysis

Meniscus roots serve a critical role in maintaining meniscal function and converting axial tibiofemoral loads into hoop stresses across the meniscus.[3,42] Meniscus root tears are defined as bony or soft tissue root avulsion injuries or radial tears within 1 cm of meniscus root attachment.[12,44,45,50,51] Root tears are generally placed into 2 clinical categories: traumatic tears, which are most often lateral and occur in younger patients, and degenerative tears, which are more often medial and result from chronic low-energy injury, most commonly in older adults.[10,32,33,42,50]

Because meniscus root tears are often degenerative and occur without a specific inciting event, clinical suspicion is required to make the diagnosis. Patients typically have posterior or midline knee pain or have mechanical symptoms, such as popping or clicking in the knee with movement. T2-weighted magnetic resonance imaging (MRI) is the modality of choice for diagnosing meniscus root tears. In diagnosing meniscus root tears, 3 interpretive signs may be detected on MRI: (1) radial tears, best detected in the axial view; (2) the truncation sign (a vertical linear defect), best detected on coronal series; and (3) the ghost sign (increased signal intensity on the meniscus root of the medial meniscus), best viewed in sagittal series.[12,29,42] While variable results have been found regarding the optimal imaging series, Choi et al[13] emphasized the use of

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coronal, axial, and sagittal imaging in diagnosing root tears, with reported axial plane sensitivity, specificity, positive predictive value, and negative predictive values of 93.3%, 100%, 100%, and 93.8%, respectively.[5,22] Regardless of the imaging modality of choice, a thorough history and physical examination in combination with MRI findings have the potential to limit false reports.[53]

The load-bearing function of the menisci allows for a significant increase in load-bearing area and capability at the tibiofemoral junction.[3] Meniscus root tears result in meniscal extrusion and loss of hoop stresses and meniscal function, leading to supraphysiologic stress being placed on the articular cartilage of the knee.[2,19,42,50] In previous biomechanical studies, a posterior root tear of the medial meniscus caused a 25% increase in peak contact pressures as compared with the unaltered condition ($P < .001$); these results were similar to those of a total meniscectomy.[2,42] A repair of the posterior root tear restored the peak contact pressures back to control levels and restored the ability of the medial meniscus to absorb hoop stress.[2,51]

Owing to the poor prognosis of meniscus root tears, there has been growing interest in surgical repair of posterior medial meniscus root tears (PMMRTs).[14,25,50,54] Two methods of repair have been described for tears of the posterior medial root: the transtibial pullout repair (TPR) and the suture anchor repair (SAR).[7,25,35,39,41] There is still a relative lack of information on midterm outcomes of this procedure, particularly with regard to whether root repair slows the development of knee osteoarthritis. The purpose of this review was to systematically analyze the short- and midterm results (patient-reported outcomes and radiographic progression of arthritis) in studies that have characterized patients undergoing arthroscopic repair of PMMRTs.

METHODS

Literature Search

The published literature was searched for outcomes of arthroscopic PMMRT repair following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The search strategies were implemented in PubMed, Ovid Medline, Embase, Scopus, Cochrane Central Register of Controlled Trials, and ClinicalTrials.gov and were established using a combination of standardized terms and keywords including but not limited to the following: (meniscus OR meniscal OR knee joint cartilage) AND (repair OR fixation OR transosseous anchor suture) AND (root OR posterior horn OR radial tear) AND (patient outcome assessment OR treatment outcome OR musculoskeletal disease assessment OR follow-up OR retrospective). The search was limited to the English language, and conference abstracts were excluded from the search. All searches were from database inception and were completed in June 2020. There were a total of 978 results, including 579 duplicates, resulting in 399 unique citations.

The following inclusion criteria were used: English-language studies that reported the functional, radiographic, and/or second-look arthroscopic outcomes of PMMRT repair. Exclusion criteria included the following: non–English language studies; studies on anterior meniscus root or lateral meniscal tears, posterior meniscal horn tears without root disruption, PMMRTs treated using surgical procedures other than TPR or SAR, or PMMRT repairs with concomitant ligament reconstruction or cartilage restoration procedures; radiological studies; epidemiological studies; systematic reviews; and in vitro or animal studies.

Three reviewers (P.C., L.R., P.W.) reviewed the title and abstract of each article for relevance according to the defined inclusion/exclusion criteria. If an abstract was not available, a full-text copy of the article was obtained and reviewed using the same criteria. The full text of each relevant article was obtained and reviewed by the same 3 reviewers for inclusion in the systematic review. Any disagreement on eligibility was resolved through discussion by the reviewers. The reference list of each eligible article was also screened to identify additional relevant articles not found in the electronic database search.

Data Extraction

The data from each study meeting the inclusion criteria were extracted regarding the study characteristics, patient characteristics, surgical technique, rehabilitation, and outcome measures. Outcomes of interest included pre- and postoperative functional scores, Kellgren-Lawrence (K-L) osteoarthritis progression and mean joint space narrowing evaluated via radiograph, progression of cartilage degeneration, pre- and postoperative mean medial meniscal extrusion and number of patients with reduced medial meniscal extrusion based on MRI findings, and healing status based on MRI or second-look arthroscopy findings. Descriptive statistics were used to report study characteristics, patient characteristics, and outcomes. Several studies compared multiple procedures or stratified data by patient characteristics or outcomes. Unless specified, each subgroup was included as an independent data point.

Quality Assessment

The modified Coleman Methodology Score[21] was used to assess the methodological quality of each included study. Additionally, all studies were evaluated for level of evidence according to the Oxford Centre for Evidence-Based Medicine.[56]

RESULTS

Literature Search and Quality Assessment

The PRISMA search returned 399 articles; 27 met inclusion criteria. One additional article was identified during

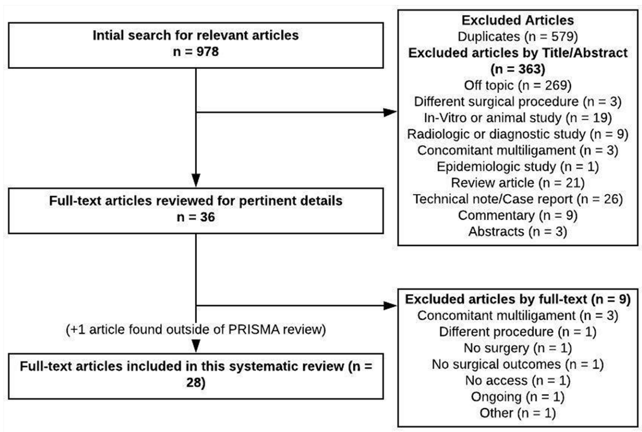

Figure 1. Flowchart of search results in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

the literature review, resulting in 28 articles included in this systematic review (Figure 1). All studies had a level of evidence of 3 or 4. The modified Coleman Methodology Score was 67.4 ± 7.10 (mean ± SD; range, 49-80) (Appendix Table A1, available in the online version of this article). In general, the quality of studies was above average to good.

Patient Characteristics

In total, 994 patients were enrolled across all studies. Cohorts ranged from 6 to 91 patients, with a mean of 27 per study. The overall mean age was 57.1 years, and 827 (83%) were female.

Surgical Technique and Rehabilitation

Surgical repair has become the standard of treatment for meniscus root tears to restore joint kinematics and slow the progression of osteoarthritis.[15,25,50,54] Currently, there are 2 established methods of repair for meniscus root tears: TPR and SAR.[7,25,35,38] TPR is a transosseous method that contains a variety of techniques. In general, it involves passing sutures through the meniscus root; guiding them through tunnels drilled in the proximal tibia; and then tying them off on a button, post, or bone bridge on the anterior tibia.[1,41,50] SAR describes a technically challenging all-inside technique that utilizes 2 sutures and 1 suture anchor to restore joint kinematics. For a PMMRT repair, a high posteromedial portal is used to place a suture anchor at the anatomic footprint of the meniscus root, and 2 vertical sutures are used to reattach the meniscus root.[25,34,35,50]

With the large number of studies included in this systematic review, there was a variety of techniques used in the repair of PMMRT in terms of portals, which suture anchor was used during SAR, and how tibial tunnels were created and their number during TPR.

Postoperative rehabilitation varied among the studies. In 20 studies, the knee was immobilized in a long cylinder leg cast/knee brace in full extension for the first 2 to 3 weeks.[‖] Immediate toe-touch weightbearing was allowed in 7 studies,[17,18,20,35,37,46,55] while immediate partial weightbearing was allowed in 2 studies.[19,39] Two studies allowed partial weightbearing at 2 weeks[27,28]; 2 studies, at 4 weeks[24,48]; and 6 studies, at 6 weeks.[9,15,35,38,46,47] Sixteen studies progressed patients to full weightbearing at 6 weeks[¶] and 5 at 8 weeks.[11,35,38,47,48] Four studies did not permit deep flexion and deep squat until 3 months,[30,49,52,55] 1 study allowed deep flexion at 4 months,[31] while 2 did not permit it until 6 months.[38,47] Seven studies permitted return to sport after 6 months.[11,19,37,38,46,48,52] Three studies requested that patients permanently avoid deep knee flexion.[17,18,20]

Functional Outcome Scores

The functional outcome scores in this study included Tegner activity rating (7 studies[4,19,26-28,35,46]), Lysholm score (24 studies[#]), International Knee Documentation Committee (IKDC) subjective knee form score (17 studies[**]), and Hospital for Special Surgery (HSS) score (5 studies[11,38,47,48,52]) (Table 1). Mean Lysholm scores increased from 53.4 to 84.1 (available for 90% of total cohort). For IKDC scores, the mean increased from 42.3 to 71.4 (63%). Mean Tegner activity rating improved from 2.8 to 3.8 after surgery (16%). Mean HSS scores increased from 57.6 to 91.8 (15%).

Radiographic Analysis

Conventional radiographs were used to evaluate patients in 15 of the 28 studies.[††] Only 10 studies provided information on the number of patients experiencing K-L grade progression,[‡‡] covering 40% of patients across all studies (Table 2). Among these patients, 49% saw progression of at least 1 K-L grade at a mean follow-up of 4.0 years (Figure 2). Eight of these studies reported mean joint space narrowing (2 did not[43,47]), resulting in 32% of total patients being evaluated. The mean joint space narrowing for these patients was 0.64 mm at a mean follow-up of 4.5 years.

Total Knee Arthroplasty

Just 6 studies[4,9,18-20,39] provided information on progression to total knee arthroplasty (Table 3). Within these studies, 11 of 232 patients progressed to total knee arthroplasty (5%) at a mean follow-up of 76.0 months.

[‖]References 9, 11, 15, 17-20, 26-28, 30, 31, 36-38, 47-49, 52, 55.
[¶]References 4, 17-20, 26-28, 30, 31, 36, 37, 46, 49, 52, 55.
[#]References 1, 11, 15, 17-20, 24, 26-28, 30, 31, 35, 37-39, 43, 46-49, 52, 55.
[**]References 1, 4, 15, 17-19, 26-28, 30, 31, 37-39, 43, 46, 48.
[††]References 1, 4, 9, 15-17, 19, 20, 37-39, 43, 46-48.
[‡‡]References 9, 15-17, 19, 37-39, 43, 46, 48

TABLE 1
Mean Follow-up and Functional Outcome Scores[a]

Study	Surgical Technique	No. (%)[b]	Follow-up, mo	Lysholm		HSS		IKDC SKF		Tegner Activity	
				PRE	POST	PRE	POST	PRE	POST	PRE	POST
Chung[18]	TPR	37 (100)	125.9	52.3	77.1[c]			41.0	63.7[c]		
Hiranaka[31]	TPR, TSS	41 (100)	12.0	63.6	84.7[c]			41.0	63.2[c]		
	TPR, MMA	27 (100)		55.6	85.6[c]			32.7	63.1[c]		
Hiranaka[30]	TPR	25 (100)	15.0	63.4	87.4[c]			45.6	70.5[c]		
Kwon[43]	TPR, MTG	24 (100)	25.7	60.3	76.1[c]			45.6	63.6[c]		
	TPR, LTG	27 (100)	23.0	65.2	80.3[c]			60.2	80.0[c]		
Ulku[55]	TPR, TLS	20 (100)	44.6	55.8	88.8[c]						
	TPR, TSS	21 (100)		56.7	87.6[c]						
Furumatsu[28]	TPR: FasT-Fix	17 (100)	12.0	56.8	85.9[c]			31.5	59.4[c]	1.4	3.0
	TPR: F-MMA	21 (100)	12.0	61.3	86.4[c]			38.3	67.2[c]	1.9	3.0
Kim[37]	TPR	21 (100)	39.2	51.7	80.9[c]			39.7	75.2[c]		
Chung[20]	TPR	91 (100)	84.8	51.8	83.0[c]						
Chung[16]	TPR, ≤60 y	25 (100)	71.3	53.0	86.0[c]			41.2	75.7[c]		
	TPR, >60 y	22 (100)		51.1	82.9[c]			39.4	72.6[c]		
Furumatsu[26]	TPR	20 (100)	12.0	60.0	86.5[c]			37.9	64.4[c]	2.0	3.0[c]
Lee[48]	TPR	56 (100)	40.6	48.7	81.5[c]	62.7	93.4[c]	38.5	64.9[c]		
Chung[17]	TPR: INC EXT	23 (100)	67.2	50.3	81.0[c]			39.1	71.1[c]		
	TPR: RED EXT	16 (100)	67.2	53.9	88.1[c]			42.5	79.0[c]		
Eun[24]	SAR	6 (100)	21.6	48.6	87.6						
Ahn[1]	TPR	25 (100)	17.4	57.3	73.4[c]			37.3	59.2[c]		
Chung[15]	TPR	40 (100)	71.1	52.1	83.8[c]			40.1	73.3[c]		
Chung[19]	TPR	37 (100)	72.0	52.3	84.3[c]			40.1	73.7[c]	2.7	3.6[c]
Cho[11]	TPR	13 (100)	7.1	34.7	75.6[c]	33.5	82.2[c]				
Lee[46]	TPR: MMA	25 (100)	24.1	57.4	87.6[c]			44.1	78.4[c]	4.4	4.9[c]
	TPR: TSS	25 (100)	25.9	56.1	85.4[c]			43.5	77.7[c]	4.3	4.7[c]
Moon[49]	TPR	51 (100)	33.0	48.3	83.2[c]						
Jung[35]	SAR	13 (100)	30.8	69.1	90.3[c]					1.9	3.9[c]
Kim[38]	TPR	22 (100)	22.9	54.3	92.5[c]	55.3	91.7[c]	57.3	91.8[c]		
	SAR	23 (100)	26.8	55.4	93.2[c]	54.7	93.8[c]	58.5	93.4[c]		
Kim[39]	TPR	30 (100)	48.5	56.8	85.1[c]			42.6	77.2[c]		
Seo[52]	TPR	11 (100)	13.4	56.1	83.0[c]	64.1	87.4[c]				
Lee[47]	TPR	21 (100)	31.8	57.0	93.1[c]	61.1	93.8[c]				
Total		899 (90)	44.0	53.4	84.1						
		146 (15)	29.5			57.6	91.8				
		629 (63)	42.3					42.3	71.4		
		158 (16)	31.7							2.8	3.8

[a]Blank cells indicate *not applicable*. F-MMA, FasT-Fix (Smith & Nephew) modified Mason-Allen technique; HSS, Hospital for Special Surgery; IKDC SKF, International Knee Documentation Committee subjective knee form; INC EXT, increased extrusion; LTG, lateral tunnel group; MMA, Modified Mason Allen; MTG, medial tunnel group; POST, postoperative; PRE, preoperative; RED EXT, reduced extrusion; SAR, suture anchor repair; TLS, 2 modified loop stitch; TPR, transtibial pullout repair; TSS, 2 simple stitch.
[b]No. of patients (% of study group).
[c]Statistically significant.

MRI Analysis

Follow-up MRI was used to evaluate patients in 13 of the 28 studies,[§§] covering 44% of patients overall (Table 4). Four studies investigated cartilage degeneration[38,39,46,49] as assessed using Outerbridge scores. Of the 142 patients evaluated for cartilage degeneration, 33 (23%) progressed at least 1 grade at a mean follow-up of 31.6 months.

Ten studies compared pre- and postsurgical mean medial meniscal extrusion,[‖‖] evaluating 297 patients (30% of all). Medial meniscal extrusion decreased from a mean 3.77 mm to 3.69 mm at a mean follow-up of 47.8 months. Three studies demonstrated statistically significant decreases in extrusion,[24,38,55] while 1 showed statistically significant increases in extrusion.[49] Chung et al[17] stratified their analysis based on patients seeing increased or decreased extrusion. Mean change for the combined

[§§]References 15, 17, 20, 24, 27, 35-39, 46, 49, 55.

[‖‖]References 15-17, 24, 35, 36, 38, 39, 49, 55.

TABLE 2
Radiographic Results[a]

Study	Surgical Technique	No. (%)[b]	Mean Follow-up, mo	Progression of K-L Grade ≥1, No. (%)	Mean Joint Space Narrowing, mm
Kwon[43]	TPR, MTG	24 (100)	25.7	8 (33)[c]	
	TPR, LTG	27 (100)	23.0	12 (44)[c]	
Brophy[9]	TPR	9 (41)	24.0	6 (67)[d]	
Kim[37]	TPR	21 (100)	39.2	11 (52)[c]	0.6[e]
Chung[16]	TPR, ≤60 y	25 (100)	71.3	17 (68)[c]	0.9[e]
	TPR, >60 y	22 (100)	71.3	18 (82)[c]	0.9[e]
Lee[48]	TPR	56 (100)	40.6	23 (41)[c]	0.35[e]
Chung[17]	TPR: INC EXT	23 (100)	67.2	20 (87)[c]	1.1[e]
	TPR: RED EXT	16 (100)		8 (50)[c]	0.6[e]
Chung[15]	TPR	40 (100)	71.1	28 (70)[c]	0.8[e]
Chung[19]	TPR	37 (100)	72.0	25 (68)[e]	0.8[e]
Lee[46]	TPR: MMA	25 (100)	24.1	2 (8)[c]	0.3[e]
	TPR: TSS	25 (100)	25.9	7 (28)[c]	0.8[e]
Kim[39]	TPR	30 (100)	48.5	9 (30)[c]	0.16[c]
Lee[47]	TPR	21 (100)	31.8	1 (5)[c]	
Total		401 (40)	48.4	195 (49)	
		320 (32)	54.0		0.64

[a]Blank cells indicate *not applicable.* INC EXT, increased extrusion; K-L, Kellgren-Lawrence; LTG, lateral tunnel group; MMA, modified Mason-Allen technique; MTG, medial tunnel group; RED EXT, reduced extrusion; TPR, transtibial pullout repair; TSS, 2 simple stitch.
[b]No. of patients (% of study group).
[c]No *P* value reported.
[d]Not statistically significant.
[e]Statistically significant.

groups was from 3.75 to 4.44 mm, but the methodology made it difficult to interpret the significance of this finding. Six studies provided information on the number of patients experiencing reduced extrusion.[15-17,36,39,49] In these studies, 101 of 206 (49%) saw reduced medial meniscal extrusion postoperatively.

Healing Rates

Healing status was evaluated in 19 of the 28 studies (Table 5). Healing status was determined via second-look arthroscopy in 11 studies,[¶¶] while MRI was used in 8 studies.[15-17,35,38,39,46,49] Overall, 631 patients (64%) had their healing status evaluated. Because of the different categorization criteria used, it is difficult to provide an overall summary of the results. In sum, 422 patients were evaluated qualitatively. Of these, 244 (58%) demonstrated good or complete healing; 150 (36%), incomplete, partial, lax, or scar tissue healing; and 28 (7%), retear or failed healing at a mean follow-up of 38.1 months. Five studies[26-28,30,31] used a quantitative scoring system (0-10, with 10 being a perfect score)[26] rather than a qualitative assessment, evaluating 209 patients. The mean score was 6.4 at a mean follow-up of 12.4 months.

DISCUSSION

There is a growing body of evidence that repairs of PMMRT provide a functional benefit with consistent improvements in clinical outcome scores. There is some evidence that PMMRT repair can slow the progression of, but not prevent, osteoarthritis at combined midterm follow-up. The evidence in terms of healing and extrusion is less clear, with mixed results in the literature.

[¶¶]References 11, 26-28, 30, 31, 37, 43, 47, 48, 52.

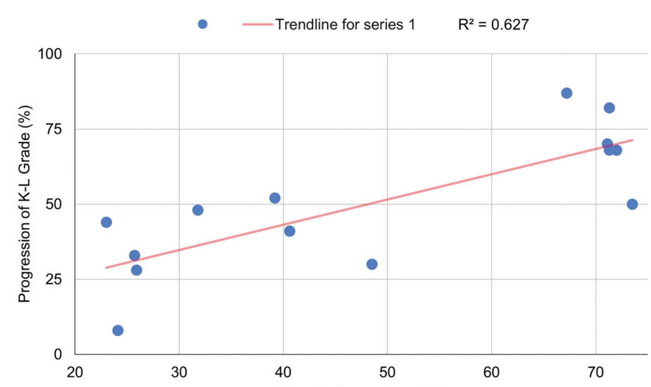

Figure 2. The relationship between the number of patients seeing progression of at least 1 K-L grade (%) and mean follow-up (months) after undergoing posterior medial meniscus root tear repair. All studies with a mean follow-up >5 years showed a K-L progression rate >50%. K-L, Kellgren-Lawrence.

PMMRT repair provides a consistent clinical benefit. Of 24 studies, 23 reported that Lysholm scores demonstrated significant improvements, and the mean change of 30.7 compares favorably with the minimal clinically important

TABLE 3
Progression to TKA[a]

Study	Surgical Technique	No. (%)[b]	Mean Follow-up, mo	Progression to TKA, No. (%)[b]
Chung[18]	TPR	37 (100)	125.9	8 (22)
Bernard[4]	TPR	15 (100)	40.0	0 (0)
Brophy[9]	TPR	22 (100)	24.0	2 (9)
Chung[20]	TPR	91 (100)	84.8	1 (1)
Chung[19]	TPR	37 (100)	72.0	0 (0)
Kim[39]	TPR	30 (100)	48.5	0 (0)
Total		232 (23)	76.0	11 (5)

[a]TKA, total knee arthroplasty; TPR, transtibial pullout repair.
[b]No. of patients (% of study group).

TABLE 4
Results of Magnetic Resonance Imaging[a]

Study	Surgical Technique	No. (%)[b]	Mean Follow-up, mo	Cartilage Degeneration ≥1 Grade, No. (%)	Mean MME, mm		Reduced MME, No. (%)[b]
					PRE	POST	
Ulku[55]	TPR, TLS	20 (100)	44.6		3.6	2.1[c]	
	TPR, TSS	21 (100)	44.6		3.5	2.9[c]	
Kamatsuki[36]	TPR	23 (100)	3.0		4.2	4.3[d]	15 (65)
Chung[16]	TPR, ≤60 y	24 (96)	71.3		4.0	4.4[d]	17 (40)
	TPR, >60 y	19 (86)	71.3		3.6	4.2[d]	
Chung[17]	TPR: INC EXT	23 (100)	67.2		3.5	5.1[c]	0 (0)
	TPR: RED EXT	16 (100)	67.2		4.1	3.5[c]	16 (100)
Eun[24]	SAR	6 (100)	21.6		4.1	2.0[c]	
Chung[15]	TPR	40 (100)	71.1		3.9	4.2[d]	19 (48)
Lee[46]	TPR: MMA	25 (100)	24.1	6 (24)			
	TPR: TSS	25 (100)	25.9	12 (48)			
Moon[49]	TPR	31 (61)	33.0	3 (10)	3.6	5.0[c]	8 (26)
Jung[35]	SAR	13 (100)	30.8		3.9	3.5	
Kim[38]	TPR	17 (77)	22.9	4 (24)	4.3	2.1[c]	
	SAR	14 (61)	26.8	2 (14)	4.1	2.2[c]	
Kim[39]	TPR	30 (100)	48.5	6 (20)	3.1	2.94[d]	26 (87)
Total		142 (14)	31.6	33 (23)			
		297 (30)	47.8		3.77	3.69	
		206 (21)	53.8				101 (49)

[a]Blank cells indicate *not applicable*. INC EXT, increased extrusion; MMA, modified Mason-Allen technique; MME, medial meniscal extrusion; POST, postoperative; PRE, preoperative; RED EXT, reduced extrusion; SAR, suture anchor repair; TPR, transtibial pullout repair; TLS, 2 modified loop stitch ; TSS, 2 modified loop stitch.
[b]No. of patients (% of study group).
[c]Statistically significant.
[d]Not statistically significant.

difference (MCID)[23] of 10.1. Similarly, significant improvements were found in 5 of 5 studies investigating HSS scores, with a mean improvement of 34.2 points, far greater than the MCID[23] of 8.72. Statistically significant improvements were found in 16 of 16 studies evaluating IKDC scores, and the mean change of 29.2 is substantially higher than the MCID[23] of 3.19 to 16.17. Tegner activity ratings demonstrated lower relative improvements, increasing from a mean 2.8 to 3.8 on a 10-point scale, which is not a high level of activity. These results may have been influenced by the relatively older age of patients (mean, 57.1 years) at which point high-impact activity and competitive sport would be expected to decline. However, the 1-point change is equivalent to the MCID of 1 for Tegner scores.[8]

Roughly half of patients (49%) saw an increase of at least 1 degree in K-L grade. However, this compares favorably with the rate of progression with meniscectomy, which ranged from 58% to 100% (mean, 76%).[19,37,47] PMMRT repair clearly does not prevent osteoarthritis. Only 1 study[19] of the 11 reporting K-L grade progression recorded a *P* value that was statistically significant. However, 8 studies[15-17,19,37,43,46,48] performed Fisher exact tests on K-L grade distribution pre- and postoperatively. Five

TABLE 5
Healing Status[a]

Study	Surgical Technique	Method	No. (%)[b]	Mean Follow-up, mo	Healing Status, No. (%)[b]
Furumatsu[27]	TPR: poor healing	Arthroscopy	35 (100)	12.0	5.1[c]
	TPR: good healing	Arthroscopy	23 (100)	12.0	7.8[c]
Hiranaka[31]	TPR: TSS	Arthroscopy	41 (100)	12.0	6.1[c]
	TPR: MMA	Arthroscopy	27 (100)	12.0	6.5[c]
Hiranaka[30]	TPR	Arthroscopy	25 (100)	15.0	7[c]
Kwon[43]	TPR: MTG	Arthroscopy	24 (100)	25.7	Complete, 21 (88); partial, 1 (4); failed, 2 (8)
	TPR: LTG	Arthroscopy	27 (100)	23.0	Complete, 26 (96); partial, 0 (0); failed, 1 (4)
Furumatsu[28]	TPR: FasT-Fix	Arthroscopy	17 (100)	12.0	6[c]
	TPR: F-MMA	Arthroscopy	21 (100)	12.0	7.2[c]
Kim[37]	TPR	Arthroscopy	30 (100)	16.6	Complete, 2 (7); partial, 21 (70); failed, 7 (23)[d]
Chung[16]	TPR: ≤60 y	MRI	24 (96)	71.3	Complete, 12 (50); partial, 12 (50); failed, 0 (0)
	TPR: >60 y	MRI	19 (86)	71.3	Complete, 10 (53); partial, 9 (47); failed, 0 (0)
Furumatsu[26]	TPR	Arthroscopy	20 (100)	12.0	6.5[c]
Lee[48]	TPR	Arthroscopy	33 (59)	16.4	Complete, 23 (70); partial, 0 (0); failed, 10 (30)
Chung[17]	TPR: INC EXT	MRI	23 (100)	67.2	Complete, 13 (57); partial, 10 (43); failed, 0 (0)
	TPR: RED EXT	MRI	16 (100)	73.5	Complete, 9 (56); partial, 7 (44); failed, 0 (0)
Chung[15]	TPR	MRI	40 (100)	71.1	Complete, 18 (45); partial, 22 (55); failed, 0 (0)
Cho[11]	TPR	Arthroscopy	13 (100)	7.1	Complete, 4 (31); partial, 8 (62); failed, 1 (8)
Lee[46]	TPR: MMA	MRI	25 (100)	24.1	Complete, 15 (60); partial, 9 (36); failed, 1 (4)
	TPR: TSS	MRI	25 (100)	25.9	Complete, 8 (32); partial, 16 (64); failed, 1 (4)
Moon[49]	TPR	MRI	31 (61)	33.0	Complete, 28 (90); partial, 3 (10); failed, 0 (0)
Jung[35]	SAR	MRI	10 (77)	30.8	Complete, 5 (50); partial, 4 (40); failed, 1 (10)
Kim[38]	TPR	MRI	17 (77)	22.9	Complete, 11 (65); partial, 6 (35); failed, 0 (0)
	SAR	MRI	14 (61)	26.8	Complete, 12 (86); partial, 2 (14); failed, 0 (0)
Kim[39]	TPR	MRI	30 (100)	48.5	Complete, 17 (57); partial, 11 (37); failed, 2 (7)
Seo[52]	TPR	Arthroscopy	11 (100)	13.4	Complete, 0 (0); partial, 9 (82); failed, 2 (18)
Lee[47]	TPR	Arthroscopy	10 (48)	14.0	Complete, 10 (100); partial, 0 (0); failed, 0 (0)
Total		Arthroscopy	148 (15)	18.0	Complete, 86 (58); partial, 39 (26); failed, 23 (16)
			209 (21)	12.4	6.4[c]
		MRI	274 (28)	49.0	Complete, 158 (58); partial, 111 (41); failed, 5 (2)
		Combined[e]	422 (42)	38.1	Complete, 244 (58); partial, 150 (36); failed, 28 (7)

[a]F-MMA, FasT-Fix (Smith & Nephew) modified Mason-Allen technique; INC EXT, increased extrusion; LTG, lateral tunnel group; MMA, modified Mason-Allen technique; MRI, magnetic resonance imaging; MTG, medial tunnel group; RED EXT, reduced extrusion; SAR, suture anchor repair; TLS, 2 modified loop stitch; TPR, transtibial pullout repair; TSS, 2 simple stitch.
[b]No. of patients (% of study group).
[c]Novel quantitative healing score: mean value reported.
[d]Case study of lax healing group.
[e]Qualitative assessment only.

studies[15,16,37,43,48] demonstrated statistically significant changes. Of the 8 studies reporting mean joint space narrowing, 6 showed a statistically significant decrease postoperatively.[15,17,19,37,46,48]

Rates of K-L progression were correlated directly with time to follow-up. All studies with a mean follow-up >5 years showed that K-L progressed in >50% of patients. MRI follow-up studies showed that approximately 1 in 4 patients had progression of at least 1 grade on the Outerbridge score at a mean follow-up of just over 2.5 years. Given the shorter follow-up and the study and patient heterogenicity, this does not appear to contradict the radiographic results. Current data suggest that, at best, PMMRT repair delays osteoarthritis progression slightly, a finding supported by Bernard et al,[4] who found a delta K-L grade of 0.1 for TPR repair as compared with 1.0 for nonoperative management and 1.1 for meniscectomy at a mean of 49 months. Overall, however, the confounding variables and lack of a control group make it impossible to draw firm conclusions about the effect of PMMRT on progression of osteoarthritis.

Although meniscal extrusion decreased by an average change of 0.08 mm, the data were too heterogeneous to analyze for statistical significance. Additionally, the clinical relevance of a 0.08-mm change is unclear, particularly because this may fall within measurement error. Furthermore, meniscal extrusion was reduced in 49% of patients, with reduction rates ranging from 0% to 100%. While reduction of meniscal extrusion is considered important to restoring the biomechanical function of the medial meniscus,[2,5,17,42,50] functional score results suggest that reduction in extrusion may not be absolutely necessary to see clinical benefit from PMMRT. However, reduced rates of reduction in extrusion were correlated with increasing rates of K-L grade osteoarthritis progression within the 3 studies that reported both sets of data.[15,17,39] More research is needed to determine the effect of this procedure on meniscal extrusion and its clinical significance.

Just 58% of patients who were evaluated qualitatively demonstrated complete healing. The studies that rated healing using the scale proposed by Furumatsu et al[26] reported an overall mean of 6.40 (range, 0-10). Furumatsu et al[27] defined good healing status as a score $\geq$7; moderate healing, as 4 to 6; and poor healing, as $\leq$3. Despite the relatively low rates of complete repair, the effect on clinical outcomes is unclear. Two studies[27,52] did not find an association between healing status and functional outcomes, while 3 other studies[11,15,48] found improved clinical outcomes for complete healing relative to partial healing.

This systematic review was subject to several limitations. Only a subset of studies was evaluated for osteoarthritis progression (49%), reduction of medial meniscal extrusion (21%), and healing (42% qualitatively, 21% quantitatively). Just 3 studies[24,35,38] investigating SAR repairs met the inclusion criteria. Perhaps most importantly, this study was limited by the lack of studies with level of evidence of 1 and 2. There was potential for selection bias, as the included studies primarily focused on subacute and chronic PMMRTs, which occur mostly in middle-aged women.[6] This injury pattern is different from that of traumatic PMMRTs, which are commonly accompanied by ligamentous injuries in younger and more active patients.[40] Patient age may have influenced the healing potential of a PMMRT. The length of follow-up was relatively short, and longer-term studies are needed to draw definitive conclusions regarding this procedure. The combination of rest and supervised physical therapy and strengthening after surgery may be as important as the surgery itself (or more so). Finally, patient selection, surgical techniques, and rehabilitation protocols were heterogeneous, making cross-study analysis difficult and a meta-analysis inappropriate.

CONCLUSION

Despite some limitations, there is strong evidence that PMMRT repairs provide benefit in the short and intermediate time frame with good to excellent clinical results. Healing of the meniscus root and changes in medial meniscal extrusion are unpredictable. There appears to be some short-term chondroprotective benefit of root repair, although this diminishes over time. Further research is needed, particularly higher-level prospective studies, to better understand the optimal indications, techniques, and outcomes from this increasingly common surgery.

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