Medial Patellofemoral Ligament Reconstruction in Skeletally Immature Patients

A Systematic Review of Outcomes by Fixation Technique

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Background: Various medial patellofemoral ligament (MPFL) reconstruction techniques have been developed to minimize risks to the physis in skeletally immature patients.

Purpose: To examine outcomes of MPFL reconstruction (MPFLR) based on fixation technique in skeletally immature patients.

Study Design: Systematic review; Level of evidence, 4.

Methods: PubMed, Scopus, Ovid, Cochrane Library, and CINAHL databases were searched for the literature on outcomes of MPFLR in the pediatric population, utilizing various anatomic and nonanatomic techniques. Primary outcomes were postoperative redislocation rates, return-to-sports (RTS) rates, and patient-reported outcomes (PROs). Moreover, outcomes involving sequela of growth plate disturbance were collected.

Results: The final analysis included 17 studies—2 using sling-based techniques, 3 using surface-based techniques, 5 using soft tissue realignments, and 7 utilizing transosseous femoral fixations. Higher rates of postoperative redislocation were found in the sling-based (14.8%) and distal soft tissue realignment using semitendinosus tenodesis (38%) techniques, while lower rates were noted with surface-based (1.3%) and transosseous (3.4%) techniques. For PROs, there were large amounts of heterogeneity among studies, but all reported postoperative improvements, with more positive PROs generally seen in anatomic reconstructions. The RTS rate was 100% for surface-based techniques, 79.4% for distal soft tissue realignments, 79.5% for soft tissue realignment techniques, and 83.2% for transosseous techniques. No negative outcomes as a sequela of growth plate disturbance were reported.

Conclusion: Nonanatomic techniques—such as sling-based and distal soft tissue realignment techniques—have higher rates of redislocation and lower RTS rates in skeletally immature patients undergoing MPFLR. Surface-based and transosseous tunnel-based techniques were shown to have lower redislocation and higher RTS rates.

Clinical Relevance: This review provides insight into the most appropriate surgical management of patellar instability in patients with open growth plates.

Keywords: medial patellofemoral ligament reconstruction; patellar instability; skeletally immature

Patellar dislocations occur at rates of approximately 29 to 43 per 100,000 in children and adolescents, which is 10 times higher when compared with the adult population.[4,8,9,18,32,40,42] The incidence[31] is particularly high in those aged between14 and 18 years at 147.7 per 100,000.

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Several risk factors for patellar dislocations have been described—including patella alta, malalignment, increased tibial tuberosity-trochlear groove (TT-TG) distance, trochlear dysplasia, and soft tissue abnormalities.[7,41]

After a first-time lateral patellar dislocation, there is a 33.6% redislocation rate, ranging from 7.7% to as high as 78.5%, depending on the number of patient risk factors.[11] Primary patellar dislocation may result in poor long-term clinical outcomes—such as recurrent dislocations, chondral lesions, anterior knee pain, and patellofemoral osteoarthrosis—emphasizing the importance of effective treatment.[6]

Medial patellofemoral ligament reconstruction (MPFLR) is generally indicated for recurrent patellar instability as an isolated procedure or in combination with other procedures—such as a tibial tubercle osteotomy.[14,33,40] Recent studies have found this procedure to be a viable option, with redislocation rates of 3.7% to 6.7% at the follow-up, ranging from 3.4 to 5 years, and improved patient-reported outcomes (PROs).[3,27,34,35] Given a predilection of skeletally immature patients to experience patellar instability, several techniques have been developed for MPFLR in adolescents that avoid violating the growth plate and risking growth disturbances.[24,29] The fixation techniques used in MPFLR can be subcategorized as sling-based, surface-based, distal soft tissue realignment, or transosseous techniques.[28] These technique subcategories can be divided into anatomic (surface-based and transosseous techniques) versus nonanatomic (sling-based or distal soft tissue realignment techniques). While some biomechanical studies have shown more favorable graft length changes and adequate tensile properties with anatomic reconstructions, the technique leading to the most beneficial clinical outcomes is still debated.[19,39,44]

In a 2020 systematic review and meta-analysis by Wilkens et al,[43] no significant difference was found in recurrent patella instability rates after MPFLR when compared with other soft tissue realignment techniques. However, this review neither separated their results into the aforementioned subcategories nor evaluated PROs or return-to-sports (RTS) rates. Therefore, this systematic review aimed to examine MPFLR outcomes based on fixation technique in skeletally immature patients. Our goal was to provide insight into the most appropriate surgical management of patellar instability in patients with open growth plates.

METHODS

Article Identification and Selection

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis) guidelines.[26] The PubMed, Scopus, Ovid, Cochrane Library, and CINAHL databases were searched in March 2022 for the literature on the outcomes of MPFLR in the pediatric population with various surgical reconstruction techniques. The generic search terms used were as follows: "medial patellofemoral ligament" OR "medial patellofemoral ligaments" OR mpfl) AND (reconstruct* OR restor* OR transosseous) AND ("growth plate" OR "growth plates" OR "skeletally immature" OR "skeletal immaturity" OR physis OR physes OR epiphys* OR pediatric* OR paediatric.* The following inclusion criteria were utilized: (1) Human clinical studies involving MPFLR; (2) original research reporting clinical outcome data based on PROs, redislocation, and complication; (3) studies assessing outcomes by fixation technique; and (4) patient population composed entirely of skeletally immature patients. The exclusion criteria were as follows: (1) Papers not written in English; (2) any animal study, survey, editorial article, letter to the editor, or expert review; and (3) any non-outcome-based studies. Two investigators (A.A.W. and K.C.) independently screened the articles by titles, abstracts, and full texts when appropriate. The initial title and abstract screening yielded 349 studies, from which 50 full-text studies were assessed for eligibility. Disagreements were discussed by 2 authors (A.A.W. and K.C.) and a consensus was reached. Details of the screening process are illustrated in Figure 1.

Outcome Measures

The primary outcomes evaluated in this systematic review were postoperative redislocation rates, RTS rates, and PROs—including the Tegner, International Knee Documentation Committee (IKDC), Lysholm, Knee injury and Osteoarthritis Outcome Score for Children (KOOS-Child), visual analog scale (VAS), Kujala, and Numerical Rating Scale (NRS) scores—when reported. In addition, data evaluating outcomes involving sequelae of growth plate

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AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.
Ethical approval was not sought for the present study.

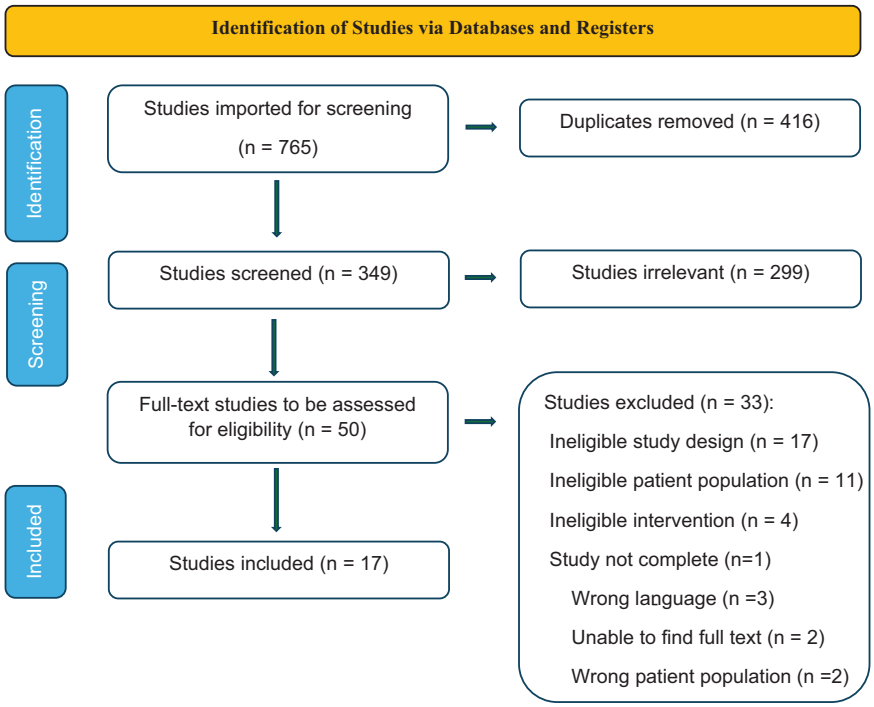

Figure 1. A PRISMA flow diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses.

disturbance—such as leg-length discrepancy or magnetic resonance imaging (MRI)-based evidence of physeal arrest—were also collected. A customized spreadsheet was created to extract all relevant data from the included studies.

Risk of Bias Assessment

Bias analysis was performed by a single author (A.A.W.) utilizing the Methodology Index for Non-Randomized Studies (MINORS) score on the 16 nonrandomized studies that met the inclusion/exclusion criteria.[36] The numerical scale is composed of 12 questions for nonrandomized studies. The ideal score is 16 points for a noncomparative study and 24 points for a comparative study (Appendix Table). The Cochrane risk of bias tool was used for the randomized study conducted by Matuszewski et al[17]. This tool assesses bias in 5 main areas—including the randomization process, missing outcome data, deviations from intended intervention, outcome measurement, and the selection of the reported results.

RESULTS

Study Selection and Characteristics

Data were extracted from 17 full-text studies that met the inclusion criteria. Of these studies, 2 used sling-based techniques, 3 used surface-based techniques, 5 used soft tissue realignments, and 7 used transosseous femoral fixations (Figure 2).

The mean age of patients included in the analysis was 13.7 years (range, 4.5-19 years), with the number of boys and girls varying between each study (Table 1).

Literature Quality Assessment

Bias analysis of the 16 nonrandomized studies was performed using the MINORS bias analysis tool. For noncomparative studies, the mean score was 11.8 (range, 9-14). For 1 comparative study,[15] the total score was 20. These scores demonstrate an overall fair quality of evidence for the noncomparative studies and a high quality of evidence for 1 comparative study. In addition, bias was a concern in 1 randomized study.[17]

Postoperative Dislocations

Of the 54 patients treated with sling-based techniques, the mean redislocation rate reported[2,15] was 14.8%. Alm et al[2] included a cohort of 30 knees with a reported redislocation rate of 13%, with a mean follow-up of 25.6 months (range, 12-43 months). Of the 24 knees evaluated by Lind et al,[15] the redislocation rate was 16.7%, while 20.8% of patients experienced postoperative patellar subluxations within the mean follow-up period of 39 months.

Three papers[1,12,16] evaluated surface-based techniques (72 knees), finding 1 postoperative dislocation for a pooled rate of 1.3%. Machado et al[16] evaluated 35 MPFLRs in

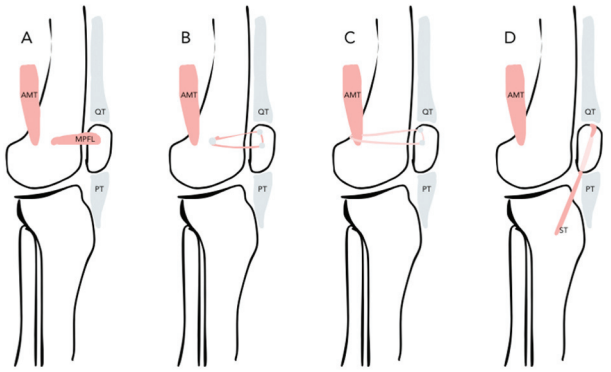

Figure 2. (A) Examples of a native MPFL. (B) Anatomic MPFLR using transosseous femoral tunnels and anchors. (C) Nonanatomic MPFLR using the adductor sling technique. (D) Nonanatomic MPFLR using ST realignment (Galeazzi technique). Additional structures included are the QT, PT, and AMT. AMT, adductor magnus tendon; MPFL, medial patellofemoral ligament; MPFLR, medial patellofemoral ligament reconstruction; PT, patellar tendon; QT, quadriceps tendon; ST, semitendinosus.

TABLE 1
Patient Characteristics[a]

Study (Year)	Age, Years	Boys: Girls
Alm et al[2] (2017)	15.1 (11-17)	11:17
Lind et al[15] (2016)	12.5 (8-16)	9:11
Machado et al[16] (2017)	15.9 (14-17)	11:24
Kodkani[12] (2015)	20.6 (9-19[b])	17:39[c]
Abouelsoud et al[1] (2015)	11.5 (8-15)	5:11
Aulisa et al[5] (2012)	11.6 (9.2-13.7)	7:17
Grannatt et al[10] (2012)	11.1 (4.5-15.8)	9:19
Letts et al[13] (1999)	14.3 (8.9-17.8)	3:19
Musielak et al[20] (2021)	9.1 (7-11)	1:9
Oliva et al[25] (2009)	13.5 ± 3.8	18:7
Matuszewski et al[17] (2018)	14.9 (13-17)	17:27
Nelitz et al[23] (2018)	12.8 (9.5-14.7)	9:16
Nelitz et al[21] (2012)	12.2 (10.3-13.9)	15:6
Pesenti et al[27] (2018)	13.8 ± 2.5	6:19
Rueth et al[30] (2022)	14.8 ± 1.6	51:50
Schlumberger et al[34] (2021)	13.8 ± 1.1	34:11
Uppstrom et al[38] (2019)	13.3 ± 1.6	19:30
Mean	13.7	14:20

[a]Data are presented as mean ± SD or mean (range).
[b]For skeletally immature arms.
[c]All patients.

which the tendon was anchored posteriorly on the soft tissue overlying the medial femoral epicondyle and on the anterior aspect of the medial patellar border. One patient sustained a postoperative dislocation, while 3 patients of the same cohort had patellar apprehension or subluxation. Kodkani[12] performed an anatomic MPFLR with hamstring autografts, localizing their femoral soft tissue fixation using bony landmarks. Abouelsoud et al[1] utilized a technique where a quadriceps tendon was attached based on the location of the Shottle point and secured on the femoral side with a modified Frank Noyes physeal sparing technique. Kodkani[12] and Abouelsoud et al[1] studied 21 and 16 knees, respectively, and reported 0 patellar dislocations (over 26-34 months).

Five studies evaluated a distal soft tissue realignment technique. Three of these studies utilized a semitendinosus tenodesis technique, and 38% (29 out of 76) of patients had postoperative patellar dislocations.[5,10,13,20,25] Of note, 28 patellar dislocations occurred in a single study by Grannatt et al,[10] in which 34 knees in 28 patients underwent a Galeazzi semitendinosus tenodesis. At a 2-year minimum follow-up after surgery, it was reported that 28 of the 34 knees had recurrent instability, which was defined as postoperative subluxation, dislocation, or both. Lett et al[13] used a semitendinosus tenodesis technique and noted 1 lateral patellar dislocation and 1 postoperative medial patellar subluxation. Musielak et al[20] performed a modified Grammont technique, where the medial patellar ligament was transferred, and used a Langenskiöld technique for soft tissue fixation; they found no patellar dislocations at the 24-month follow-up. Oliva et al[25] performed a lateral release, vastus medialis muscle advancement, and transfer of the medial third of the patellar tendon to the medial collateral ligament using suture anchors on 25 total knees; they found 1 postoperative dislocation at a 45.6-month follow-up.

Seven studies utilized a transosseous femoral fixation technique with a pooled 3.4% postoperative dislocation rate.[17,21,22,27,30,34,38] A randomized control trial comparing 22 knees undergoing either a tensor fascia lata allograft with titanium anchor fixation or a gracilis tendon autograft with interference screw fixation demonstrated 1 postoperative dislocation at a 24-month follow-up in the tensor fascia lata group.[17] Two studies published by Nelitz et al[21,23] in 2012 and 2018 reported no postoperative dislocations at a mean of 32 months, with 21 MPFLRs performed with a medial blind tunnel along a guide pin placed distal to the physis and 25 MPFLRs performed with a pedicled superficial quadriceps tendon graft, hardware-free patellar graft, and anatomic femoral fixation distal to the femoral physis. Both studies included 3 patients, each with a TT-TG distance of >20 mm. In the 2012 study,[21] one knee had trochlear dysplasia graded as Dejour A, 10 knees were Dejour B, 4 were Dejour C, and 6 were Dejour D. In the 2018 study,[23] patients with Dejour grades B through D were excluded. Pesenti et al[27] obtained femoral fixation with a medial femoral socket in the distal epiphysis and reported 1 postoperative dislocation out of 27 total knees. Also, 11 knees had trochlear dysplasia—3 with patella alta and 7 with increased TT-TG measurements. Rueth et al[30] analyzed 101 low-risk knees with a mean TT-TG distance of 15.3 mm and minimal trochlear dysplasia that underwent medial femoral fixation with an interference screw placed distal to the physis. They reported 1 postoperative dislocation out of 90 knees, compliant with the final follow-up (1.11%; 32 ± 12 months). Schlumberger et al[34] analyzed 45 knees that underwent MPFLR utilizing

TABLE 2
Pediatric PROs of the MPFL[a]

Study (Year)	Kujala	NRS	Tegner	IKDC	KOOS-Child	VAS	Lysholm	Marx	Modified Cincinnati	Crosby & Insall	Zarins-Rowe
Alm et al[2] (2017)	+		+	+		NS	+				
Lind et al[15] (2016)	+	+									
Machado et al[16] (2017)	+		+								
Kodkani[12] (2015)	+				+						
Abouelsoud et al[1] (2015)	+		+								
Aulisa et al[5] (2012)										+	
Grannatt et al[10] (2012)	NS			NS				NS			
Letts et al[13] (1999)							+				+
Musielak et al[20] (2021)	+				+						
Oliva et al[25] (2009)	+								+		
Matuszewski et al[17] (2018)	+										
Nelitz et al[21] (2012)	+		NS								
Nelitz et al[23] (2018)	+		NS			+					
Pesenti et al[27] (2018)	NS										
Rueth et al[30] (2022)	+										
Schlumberger et al[34] (2021)	+		NS	NS			+				
Uppstrom et al[38] (2019)											

[a]Quality rating refers to excellent, good, neutral, or poor PROs.

Blank cells show data not obtained or analyzed. " + " Indicates statistically significant differences in PROs. "NS" Indicates data analyzed but not statistically significant. IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; MPFL, medial patellofemoral ligament; NRS, numeric rating scale; PRO, patient-reported outcome; VAS, visual analog scale.

femoral sockets and found a dislocation rate of 6.7%. The mean Caton Deschamps Index (CDI) for this cohort was 1.3 + 2, and trochlear dysplasia grades were as follows: A (19), B (19), C (6), D (1). Uppstrom et al[38] observed 54 knees for 26.4 months after transosseous fixation distal to the femoral physis and reported 5 postoperative dislocations, 3 of which required revision surgery.

Postoperative PROs

Of the 17 included studies, 16 reported PROs (Table 2).

Sling. Alm et al[2] found that 4 patients with postoperative redislocation had significantly worse final IKDC ($P < .001$), Kujala ($P = .003$), Lysholm ($P = .002$), and Tegner activity level scores ($P < .001$) compared with the 26 patients without redislocation.

Lind et al[15] reported Kujala score improvements from 61 ± 13 preoperatively to 81 ± 15 at 1 year ($P < .001$) and 71 ± 15 at the final follow-up. In this study, 67% of patients reported >10-point improvements in the Kujala score at 1 year, while 61% reported improvements at the 39-month final follow-up (range, 17-72 months). The NRS pain score with walking decreased from 3 ± 3.1 preoperatively to 1.5 ± 1.3 at 1 year ($P < .001$), but it increased to 3.5 ± 2.6 at the final follow-up.

Surface-Based Technique. Machado et al[16] reported significant improvements in Kujala scores with a preoperative mean of 54 ± 11 compared with 84 ± 9 at a medium-term follow-up (44 months) and 78 ± 3 at a long-term follow-up (9.7 years) ($P < .0001$). Tegner activity levels were 7 ± 2 preoperatively, 6 ± 2 at a medium-term follow-up, and 4 ± 3 at a long-term follow-up ($P < .0001$). Long-term PROs were significantly lower in the presence of trochlear dysplasia type B to D ($P = .0001$), but no significant correlations were found between preoperative patella alta or the presence of intraoperative chondral lesions.

Kodkani[12] found that of the 56 knees that underwent MPFLR (21 of 56 knees belonged to skeletally immature patients), the Kujala score improved from 64.3 to 99.7 after MPFLR. The mean KOOS scoring was near normal (100) in all parameters except for 1 patient who sustained a postoperative patellar fracture. Tegner scores ranged from 1 to 9. Unfortunately, skeletally immature patients and skeletally mature patients were not analyzed independently in this study.

Abouelsoud et al[1] examined 16 skeletally immature patients who underwent a modified Frank Noyes MPFLR technique and found that their mean Kujala scores improved from 56 preoperatively to 94 at the final follow-up ($P < .005$). There was no statistically significant change in Tegner activity score from the preoperative to the final follow-up.

Soft Tissue Realignment. Aulisa et al [5] utilized Crosby and Insall criteria to collect PROs for 14 skeletally immature patients (16 knees), demonstrating 62.5% with excellent results, 37.5% with good results, and no cases showing poor or worse outcomes. They relied on postoperative static and dynamic computed tomography scans to assess the success of MPFLR. Despite no clinical dislocations in their cohort in at least a 4-year follow-up, they demonstrated that the semitendinosus tendon alone could not counteract the force of the quadriceps in patients with significant patella alta.

Grannatt et al[10] utilized a Galeazzi semitendinosus tenodesis for MPFLR and reported higher rates of postoperative failures than others utilizing the same or similar

technique. They compared PROs from patients with recurrent instability (28 knees) with those without (6 knees) and found that patients with recurrent instability had lower mean IKDC (62) and Kujala scores (78) and higher Marx activity scores (9) than stable patients (72, 85, 5.1, respectively) at the final follow-up, although these differences were not statistically significant ($P = .65$, $P = .48$, $P = .10$, respectively).

Letts et al[13] utilized a semitendinosus tenodesis MPFLR and found a mean Lysholm subjective score of 68 (range, 35-95) and a mean Zarins-Rowe score of 33 to 50 (range, 10-48). The Spearmen correlation coefficient between the 2 questionnaires was 0.744, indicating a significant correlation between the results. Based on the results of the questionnaires, the authors stated that 27% of children had an excellent outcome, 55% had a good result, and 18% had a poor result.

Musielak et al[20] utilized a modified Grammont and Langonskiöld technique and reported significant improvements in all 5 KOOS-Child subcategories—Pain, Symptoms, Activities of Daily Living, Sports/Recreation, and Quality of Life ($P < .0001$)—and Kujala scores from baseline (51.1 ± 19.1) to the final follow-up (81.7 ± 21.1; $P < .001$).

Oliva et al[25] analyzed 25 knees that underwent 3-in-1 MPFLR and found that the mean modified Cincinnati scores increased from 51.7 ± 12.6 preoperatively to 94.3 ± 10.8 ($P < .02$) postoperatively, and the mean Kujala scores increased from 52.4 ± 12.7 preoperatively to 93.8 ± 14.2 ($P < .02$) postoperatively.

Transosseous Femoral Fixation. Matuszewski et al[17] conducted a randomized controlled trial comparing fascia lata allograft to gracilis tendon autograft. Within the fascia lata arm, the Kujala score significantly improved from 73.91 ± 7.84 preoperatively to 94.5 ± 3.90 postoperatively ($P < .001$). In the gracilis tendon arm, the Kujala score significantly improved from 70.77 ± 10.30 preoperatively to 94.3 ± 4.5 postoperatively ($P < .001$). No significant differences were observed when comparing PROs across the 2 groups.

Nelitz et al[21] observed a cohort of MPFLR patients receiving gracilis tendon autografts for 2 years and found that the mean Kujala scores improved significantly from 72.9 (37-87) preoperatively to 92.8 postoperatively (74-100; $P < .01$). The mean Tegner activity scores decreased from 6 preoperatively to 5.8 postoperatively ($P = .48$).

Nelitz et al[22] performed another study in 2018 analyzing pediatric MPFLR, but this time utilized a pedicled quadriceps tendon graft instead of a gracilis tendon autograft. The median Kujala score significantly improved from 63 (range, 44-81) to 89 (range, 77-100; $P < .01$), and the median VAS score improved significantly from 4 (range, 1-7) to 1 (range, 0-4; $P < .01$). The Tegner activity scores increased, but not significantly, from 4 (range, 3-8) preoperatively to 5 (range, 3-8) postoperatively.

Pesenti et al[27] analyzed pediatric patients who underwent MPFLR with gracilis of the semitendinosus autograft, looking specifically at whether osseous abnormalities such as trochlear dysplasia, patella alta, or a lateralized tibial tubercle had significant effects on postoperative outcomes compared with patients with no osseous abnormalities. They did not report preoperative Kujala scores; however, they did report a mean postoperative Kujala score of 96.5 for patients without abnormalities versus 93.7 for patients with anatomic abnormalities ($P = .24$).

Rueth et al[30] conducted a retrospective analysis of 101 patients who underwent MPFLR with gracilis tendon autografts and found that Kujala scores improved significantly from 47.1 preoperatively to 85.3 postoperatively ($P < .01$).

Schlumberger et al[34] analyzed 45 knees that underwent MPFLR with gracilis tendon autografts and found that the final mean Tegner, subjective IKDC, Lysholm, and Kujala scores were 6.3 ± 1.6, 93.6 ± 8.8, 95.9 ± 7.4, and 97.9 ± 7.1, respectively. They did not report on preoperative PROs. However, statistical analyses demonstrated that both Lysholm and Kujala scores were significantly lower in patients with retropatellar chondral lesions with ICRS (International Cartilage Regeneration & Joint Preservation Society) grades of ≥III.

Uppstrom et al[38] performed an MRI analysis of 54 knees in skeletally immature patients who underwent MPFLR with the femoral socket placed distal to the physis, looking for evidence of physeal arrest. No patients had evidence of physeal arrest at their last MRI follow-up.

Postoperative RTS

The overall reported RTS rate was 100% in 37 patients for surface-based techniques (two-thirds of the studies). Two studies—Kodkani[12] and Abouelsoud et al[1]—reported that all patients returned to their preinjury level of activities. However, no specification was made regarding whether any patients returned to sports at their preoperative level.

The overall reported RTS rate was 79.4% in 51 patients for distal soft tissue realignments (2 of 5 studies). For soft tissue realignment techniques, Letts et al[13] reported that 74.9% of patients returned to normal activities at a long-term follow-up; however, it was not specified whether there was a change in activity level from a sports perspective. Oliva et al[25] granularly analyzed their patients with respect to RTS. In their study, 9 patients returned to their chosen sport at the same level as before their injury. Two patients dropped from the international level to the county level. Four patients dropped from the national level to the county level. Four patients dropped their sport completely. Two patients progressed from the county level to international competition. For the patients who returned to sports, the mean time from the index operation to return to their sport was 8.2 ± 4.1 months (range, 5-14 months).

The overall reported RTS rate was 83.2% in 263 patients receiving transosseous techniques (6 of 7 studies). Nelitz et al[21] reported that 14 patients returned to sports at their preoperative level, 3 returned to sports at a level higher than preoperatively, and 4 participated at a lower level than preoperatively. In 2018, another study by Nelitz et al[23] demonstrated similar outcomes with respect to RTS, where 14 patients returned to the same level of play, 7 participated at a higher level, and 4 participated at a lower level. The median time for RTS was 5.3 months (range, 4-12 months) in 2012 and 4.8 months (range, 3-11 months) in 2018, respectively. Pesenti et al[27] reported that 80% of patients returned to practicing sports at their preoperative

TABLE 3
Outcomes of MPFLR by Fixation Technique[a]

Technique Category	Study (Year)	Technique Specifics	No. of Knees	Subluxation/ Apprehension Rate, %	Redislocation Rate, %	Reoperation Rate, %	RTS ≥ Prior Level of Play, %	Follow-up, Months
Sling	Alm et al[2] (2017)	Modified adductor sling	30		13			25.6 (12-43)
	Lind et al[15] (2016)	Modified adductor sling	24	20.8	16.7	20.8		39 (17-72)
Surface-based	Machado et al[16] (2017)	Soft tissue femoral fixation based on bony landmarks	35	8.7	2.9			116.4
	Kodkani[12] (2015)	Soft tissue femoral fixation based on bony landmarks	21[b]		0		100[d]	26 (7-48)
	Abouelsoud et al[1] (2015)	Medial one-third of the quad tendon attached to the Schottle point	16		0		100[d]	29 (24-34)
Soft Tissue Realignment	Aulisa et al[5] (2012)	Semitendinosus tenodesis	14					52.8 (49-70)
	Grannatt et al[10] (2012)	Semitendinosus tenodesis	34		82	35		70 (27-217)
	Letts et al[13] (1999)	Semitendinosus tenodesis	26	7.7	3.8	7.7	74.9[d]	38 (24-88)
	Musielak et al[20] (2021)	Modified Grammont & Langenskiöld	15		0			25.8
	Oliva et al[25] (2009)	3 in 1	25		4		84	45.6 (30-72)
Trans Osseous Femoral Fixation	Matuszewski et al[17] (2018)	Fascia lata allograft vs gracilis tendon autograft	44		2.2[c]		100[d]	24 (18-30)
	Nelitz et al[23] (2018)	Pedicled quadriceps tendon allograft	25		0		84	31 (24-40)
	Nelitz et al[21] (2012)	Gracilis tendon autograft	22		0		81.8	33.6 (24-43)
	Pesenti et al[27] (2018)	Gracilis or semitendinosus autograft	27		3.7		80	41 ± 13.5
	Rueth et al[30] (2022)	Gracilis tendon autograft	101		0.9		55.5	32 ± 12
	Schlumberger et al[34] (2021)	Gracilis tendon autograft	45		6.7		100[d]	51.6 ± 20.4
	Uppstrom et al[38] (2019)	Gracilis or semitendinosus autograft	54		9.3	5.6		28.8 (6-96)
Average			33	12	9	17	86	42

[a]MPFL, medial patellofemoral ligament.
[b]Skeletally immature arm.
[c]Redislocation was only observed in the fascia lata allograft arm.
[d]No specification of the level of sport the patient returned to.

level at the final follow-up, while 20% of patients reduced their level of sports—including 2 who never re-engaged in sports. Of the 9 patients participating in professional-level sports, all continued to participate, but 33% dropped to an amateur level. The mean RTS was 7.1 ± 3.5 months. Rueth et al[30] reported that 86.6% of all patients were able to RTS within 2 years after surgery, 55.5% achieved their preinjury level, and 15.5% increased their level by the final follow-up. Schlumberger et al[34] categorized patients based on their sporting activities when collecting RTS data, finding that 37.8% participated in cutting ball games (eg, basketball and soccer), 20% participated in other cutting sports (eg, gymnastics, dancing), and 13.3% participated in low-risk sports (eg, cycling, fitness). Their overall mean return to unrestricted sporting activity was 6.2 ± 3 months (Table 3).

Growth Disturbance

In the studies included, no negative outcomes as a sequela of growth plate disturbance—such as leg-length discrepancy or MRI imaging-based evidence of physeal arrest—were reported.

DISCUSSION

This review aimed to examine outcomes of various anatomic and nonanatomic techniques for MPFLR in skeletally immature patients by evaluating PROs, failure rates, and RTS rates. We looked to expand upon a recently published systemic review that reported no significant difference in recurrent patellar instability when comparing MPFLR with soft tissue realignment techniques.[43] We found higher rates of lateral patellar redislocation, lower PRO scores, and lower RTS rates after sling-based and soft tissue realignment techniques compared with surface-based and transosseous femoral tunnel fixation techniques.

One important finding that should be discussed is the heterogeneity in the reported outcomes of studies that examined soft tissue realignment techniques. Four of the five studies reported redislocation rates of ≤4%, while one published by Grannatt et al[10] reported a postoperative redislocation rate of 82%, with 35% of patients requiring an additional operation. While the exact reason for this increased failure rate is unclear, this study did have the longest follow-up period of the 17 articles reviewed, with a mean follow-up of 70 months (range, 27-217 months). This may demonstrate that patients are more likely to have recurrent instability at long-term follow-ups and studies with short- to medium-term follow-ups do not elucidate this higher failure rate. In addition, there may have been patient-specific risk factors—such as high-grade trochlear dysplasia, significant patella alta, or a TT-TG distance of >20 mm—that were not evaluated in this study and thus not excluded, which could have resulted in poorer

outcomes after semitendinosus tenodesis. Further, Grannatt et al[10] found that the Marx activity scores for patients were higher in the *recurrent instability subset* when compared with the *no recurrent instability group*, demonstrating that patients who returned to higher levels of activity may have had worse failure rates. Last, there was a low response rate (65%) of patients who completed the surveys, which could have led to a response bias, as patients who had recurrent instability may have been more likely to complete surveys compared with patients who were doing well at follow-ups. The exact reason for the increased failure rate found by Grannatt et al, compared with other included studies that evaluated patients undergoing soft tissue realignment, is unknown; nonetheless, it is important to recognize that the data from this study significantly affect our findings. The mean time to repeat surgery in the study by Grannatt et al was 42.2 months (range, 17-144 months), which does overlap with the follow-up ranges of the other examined studies (range, 24-88 months). Two soft tissue realignment studies commented on RTS, with 75% to 84% of patients returning to sports at the same level of play or higher after MPFLR. It is difficult to make conclusions on surface-based techniques given the wide range of outcomes. However, the data show that some patients do well and can perform at preinjury levels and beyond.

One important factor that may guide the treatment of patellar instability is successful RTS, as it is a strong proxy for functional recovery after MPFLR. On average, the RTS at the preinjury level or higher across the 10 studies was 86% (Table 3). It is encouraging to see a high percentage of successful RTS in this population.

Our analysis of the 17 included studies highlights that the decision to choose the best surgical reconstruction technique is not inconsequential and that all patient factors related to patellar instability must be accounted for to ensure the most optimal operation is performed. For instance, when looking at the adductor sling-based techniques included in this review—Alm et al[2] and Lind et al[15]—there was a reported 15% to 16% redislocation rate. The authors of 1 of the 2 studies suggest that increased TT-TG, severe trochlear dysplasia (Déjour type B-D), and valgus malalignment may have predisposed treatment failure in their patients.[2] If surgeons have had success with this technique in their practice and it is the only method they use to address patellar instability in skeletally immature patients, they may be more inclined to use this technique in patients with known anatomic factors that put them at a higher risk for failure of their treatment.

Limitations

There are several limitations to consider in this review. Because of our inclusion/exclusion criteria, only two studies on sling-based techniques made it to the final inclusion, as many sling-based outcomes did not delineate between skeletally mature and skeletally immature patients or employed concomitant procedures such as tibial tubercle osteotomies or trochleoplasties. Many studies excluded or included very few patients with anatomic risk factors for patellar instability—such as high-grade trochlear dysplasia, a TT-TG distance of >20 mm, or significant patella alta—thus, discretion should be used when translating these findings over to patients with significant anatomic abnormalities. The surgical technique varied widely even within assigned subgroups and thus could play a major role in outcome differences seen among studies. Another important limitation pertains to the variations in defining *postoperative failure* among studies. Many of the studies in this review used PROs as their primary endpoint. However, PROs alone may be inferior to objective measures of recurrent patellar dislocation, especially when defining success or failure in patellar instability surgery. For example, subjective measures of a patient's pain may lower PROs after MPFLR surgery despite a successful outcome of a stabilized patella. RTS data give a relatively objective endpoint for a successful procedure and recovery. However, it was not reported in all studies and those that did define it in different ways made it more difficult to draw strong conclusions. In some studies, the authors only comment that *x* percent of patients returned to a sport postoperatively, whereas others granularly reported the level of play both pre- and postoperatively.

CONCLUSION

From our review of 17 studies examining sling-based, surface-based, soft tissue realignment, and transosseous tunnel-based femoral fixation techniques, we have several key results to highlight. In skeletally immature patients with absent or minimal risk factors for patellar instability undergoing MPFLR, nonanatomic techniques—such as sling-based and distal soft tissue realignment—have higher redislocation and lower RTS rates, while surface-based and transosseous tunnel-based techniques have lower redislocation rates and higher RTS rates. The heterogeneity of the data from the available literature makes it difficult to make strong recommendations for the most optimal treatment for patellar instability in skeletally immature patients who are indicated for MPFLR; nonetheless, the evidence does suggest that patients who undergo anatomic reconstructions with transosseous tunnels have improved outcomes.

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