Original Article

Medial Patellofemoral Ligament Reconstruction in the Pediatric Population: Skeletal Immaturity Does Not Affect Functional Outcomes but Demonstrates Increased Rate of Subsequent Knee Injury

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Purpose: To evaluate short- to mid-term-outcomes, including instability rates, following medial patellofemoral ligament (MPFL) reconstruction in skeletally immature versus mature pediatric patients. **Methods:** Patients younger than age 18 with recurrent patellar instability who underwent primary allograft MPFL reconstruction by a single surgeon from 2013 to 2019 were identified. Skeletally immature patients underwent all-epiphyseal drilling and mature patients underwent metaphyseal drilling at the Schöttle's point. Patients 1 year from surgery were contacted to complete questionnaires, which included the International Knee Documentation Committee score. Further data included chart and imaging review. Significance was determined by $P < .05$. **Results:** Of 118 eligible patients, 88 completed questionnaires. There were 67 skeletally mature and 21 skeletally immature patients. The mature group was older (15 vs 13 years, $P < .001$), predominantly female (67 vs 43%, $P = .046$), and heavier (24.7 vs 18.9, $P < .001$). Trochlear dysplasia ($P = .594$), concomitant procedures ($P = .336$), graft choice ($P = .274$), and follow-up length ($P = .107$) did not differ, although mature patients more often underwent suture tape augmentation (68 vs 13%, $P < .001$). Immature patients had greater rates of ipsilateral injury (35 vs 16%, $P = .043$); redislocation rate did not differ (9 vs 3%, $P = .225$). Mature patients were more likely to respond "definitely yes or probably yes" when asked if they would undergo the same care if needed (96 vs 76%, $P = .007$). At minimum 2-year follow-up, subsequent ipsilateral injury rates did not differ, although willingness to undergo the same care remained significant (95 vs 69%, $P = .010$). In a multivariable elimination logistic regression model, skeletal maturity was the only variable associated with subsequent ipsilateral injury ($P = .049$). **Conclusions:** Pediatric patients undergoing MPFL reconstruction have good and comparable outcomes regardless of skeletal maturity. However, younger age and lack of tape augmentation in skeletally immature patients may predispose them to subsequent injury. **Level of Evidence:** III, case-control study.

Lateral patellar instability is one of the more common pediatric knee ailments and may progress to recurrent instability, particularly in young patients. Thoughtful evaluation by providers is crucial, as a number of factors may contribute to instability, including trochlear dysplasia, rotational profile, coronal malalignment, patella alta, or generalized laxity.[1] While both bony and soft-tissue restraints contribute to

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patellar stability, the medial patellofemoral ligament (MPFL) is widely recognized as the primary soft-tissue restraint to lateral translation.[2] As such, MPFL reconstruction has become a mainstay of treatment for patellar instability. This is particularly true in pediatric patients as their osseous structures continue to develop.[3]

However, MPFL reconstruction poses a technical challenge in skeletally immature patients due to the close proximity of the ideal graft fixation point to the physis of the distal femur. The target isometric fixation point for an MPFL graft (Schöttle's point) is just anterior to the posterior cortex of the femur and just proximal to the Blumensaat line.[4] A systematic review by Sochacki et al.[5] reported that the MPFL typically originates distal to the femoral physis but ranged from 3.7 mm proximal to 10 mm distal, indicating some controversy in the literature regarding whether the anatomic origin is proximal or distal to the physis. Regardless, there is concern that placing the graft near this location may lead to disruption of the physis and result in premature growth disturbance or arrest. It is also unclear whether continued growth alters mechanics of the graft or leads to greater rates of residual instability. Although not commonly reported in the literature, Seitlinger et al.[6] did publish a case report of partial posterior physeal growth arrest leading to flexion deformity and recurrent instability following MPFL reconstruction in a skeletally immature patient.

As a result of these concerns, various techniques for MPFL reconstruction in skeletally immature patients have been described in an effort to minimize damage to the physis.[7-9] Different reconstruction options include a variety of grafts and graft routes to replicate the function of the MPFL. Additionally, a few fixation options exist including suture or interference screws.[10-16] A recent systematic review and meta-analysis on autograft MPFL reconstructions in skeletally immature patients reported that neither fixation technique nor graft choice was associated with residual instability, with an overall redislocation rate of 3.8% and subluxation rate of 11.4%.[3] There were no cases of physeal arrest; however, modification of tunnel placement may result in graft malposition, which has been implicated as a major cause of poor outcomes and graft failure.[4,17] A cadaveric study by Black et al.[18] confirmed that three described skeletally immature MPFL techniques (distal epiphyseal socket, adductor sling, and adductor transfer) all lead to abnormal graft mechanics compared to Schöttle's point reconstruction.

Current studies lack comparative analyses between skeletally mature and immature patients, specifically in a pediatric population; however, the skeletally immature population seems to have a slightly greater rate of persistent instability following MPFL reconstructions compared to what is reported in the adult population.[13] The purpose of this study was to evaluate short- to mid-term-outcomes, including instability rates, following MPFL reconstruction in skeletally immature versus mature pediatric patients. We hypothesized that skeletally mature patients would have superior outcomes and fewer subsequent instability events compared with skeletally immature patients.

Methods

Cohort Selection

This study was performed under the University of Utah Institutional Review Board—approved protocol IRB#: 74041 All patients who underwent MPFL reconstruction by the senior author (S.K.A.) from January 2013 through April 2019 were identified by Current Procedural Terminology codes. Exclusion criteria were older than 18 years of age at the time of surgery, less than 1-year follow-up at time of chart review, concurrent ligamentous reconstruction, concurrent alignment correction, previous patellar instability surgery, and bilateral surgery using different techniques on each limb. During the time of this study, the senior author primarily treated patellar instability with isolated MPFL reconstruction without alignment procedures. On clinical examination, 6 had femoral anteversion and 10 demonstrated tibial torsion. Long-standing radiographs were obtained if there was clinical concern for alignment with 4 patients demonstrating genu valgum. These patient characteristics did not alter management.

Surgical Technique and Postoperative Protocol

All patients underwent an allograft MPFL reconstruction for recurrent patellar dislocations. Allograft was chosen due to surgeon preference to avoid donor-site morbidity and to preserve anatomy in this young athletic population, who may sustain future injury, and given graft incorporation at an extra-articular location. Skeletal maturity was based on preoperative radiographic appearance of the distal femoral physis at the discretion of the senior author as either open (skeletally immature) or closed (skeletally mature). A diagnostic knee arthroscopy was first performed to evaluate the chondral surfaces of the patellofemoral joint, remove loose bodies, and inspect the remainder of the knee for concomitant pathology. Attention was then directed to the MPFL reconstruction. Incisions were made over the medial patella and medial epicondyle, and dissection was tunneled down to the layer above the capsule. Following exposure of the medial patellar surface, a guide pin was placed under fluoroscopy at the junction between the superior third and inferior two-thirds of the patella. A 5-mm reamer was used to drill the patellar tunnel. The graft was trimmed to fit 5-mm tunnels and fixed into the tunnel using a 4.75-mm

PEEK (polyether ether ketone) tenodesis interference screw (Arthrex, Naples, FL). In patients who underwent tape augmentation, MERSILENE tape was whip stitched to the allograft. Tape augmentation was based on surgeon discretion. It is the senior author's practice to augment with tape in skeletally mature patients and select individuals who are skeletally immature but close to physeal closure for added stability. Augmentation was not performed in those further from skeletal maturity due to concern for overconstraint and altered growth with continued development.

Attention was then directed to the femur and a perfect lateral radiograph of the knee was obtained. Using fluoroscopy, a guide pin was placed corresponding to Schöttle's point slightly proximal and posterior to the medial epicondyle.[19] In skeletally immature patients, the position of the guide pin was then confirmed on the anteroposterior fluoroscopy view to assure that the guide pin was distal to the physis and the angle of drilling was aimed away from the physis and within the epiphysis (Fig 1). Isometry was confirmed using the sutures attached to the patellar side. The femoral tunnel was drilled using a 5-mm reamer and the graft was placed into the femoral tunnel. The knee was then taken through flexion and extension repeatedly to allow the graft to settle. Dynamic examination and findings during isometry testing were used to guide adjustments of the flexion angle during fixation. The position where the graft was the longest was chosen for fixation to avoid overtensioning. Patients were placed in a knee immobilizer locked in full extension and permitted toe-touch weight-bearing using crutches. Range of motion was permitted from 0 to 90° while seated. After the first week, patients gradually progressed to weight-bearing as tolerated with crutches. Immobilizer brace remained locked in extension while ambulating. At 6 weeks, patients weaned off of crutches and out of the brace. Low-impact exercises, such as stationary bike, were initiated. At 3 months, gradual increase in cutting/twisting/pivoting activities was permitted with a goal of return to sport between 4 and 6 months.

Survey Methodology

Patient contact information including mailing address, phone number, and e-mail were obtained through chart review. Patients were first contacted by mail regarding the study. Patients willing to participate were asked to complete a questionnaire using the Research Electronic Data Capture (REDCap, Vanderbilt University, Nashville, TN) online service. Questionnaires were completed over the phone with the researcher inputting responses directly, or patients were sent an e-mail link to the REDCap survey for completion. If patients did not reply to the initial mail, they were then contacted via telephone or email. Patients were attempted to be contacted at least 5 times between March 11, 2020, and September 30, 2020, to maximize response rate.

The REDCap questionnaire included the International Knee Documentation Committee (IKDC) form, the Marx Activity Scale, and questions pertaining to knee pain and function, satisfaction with surgery, and additional injury or surgery on either knee (Appendix Table 1, available at www.arthroscopyjournal.org). In patients who had bilateral procedures, they were directed to respond to the survey using their worse knee as a reference point.

Chart Review

Chart review was performed to collect demographic, surgical, and postoperative data. Preoperative IKDC scores were collected when available. Additional chart review was performed to confirm patient-reported

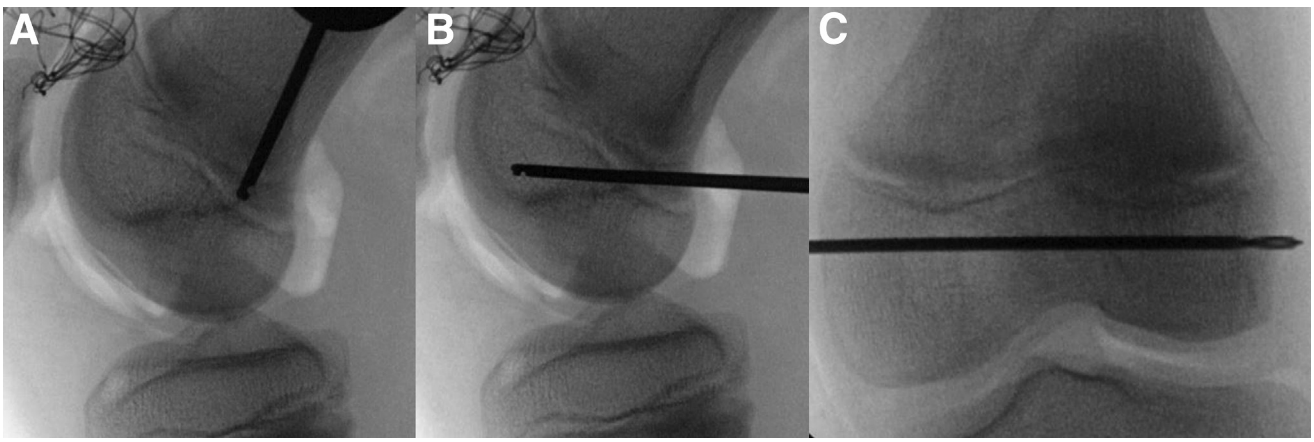

Fig 1. Intraoperative fluoroscopy of a right knee. In all skeletally immature patients, the drill was started at Schöttle's point as visualized on lateral radiograph (A). The drill was aimed distally into the epiphysis to avoid crossing the physis. Trajectory for femoral tunnel placement is demonstrated on lateral (B) and anteroposterior (C) radiographs.

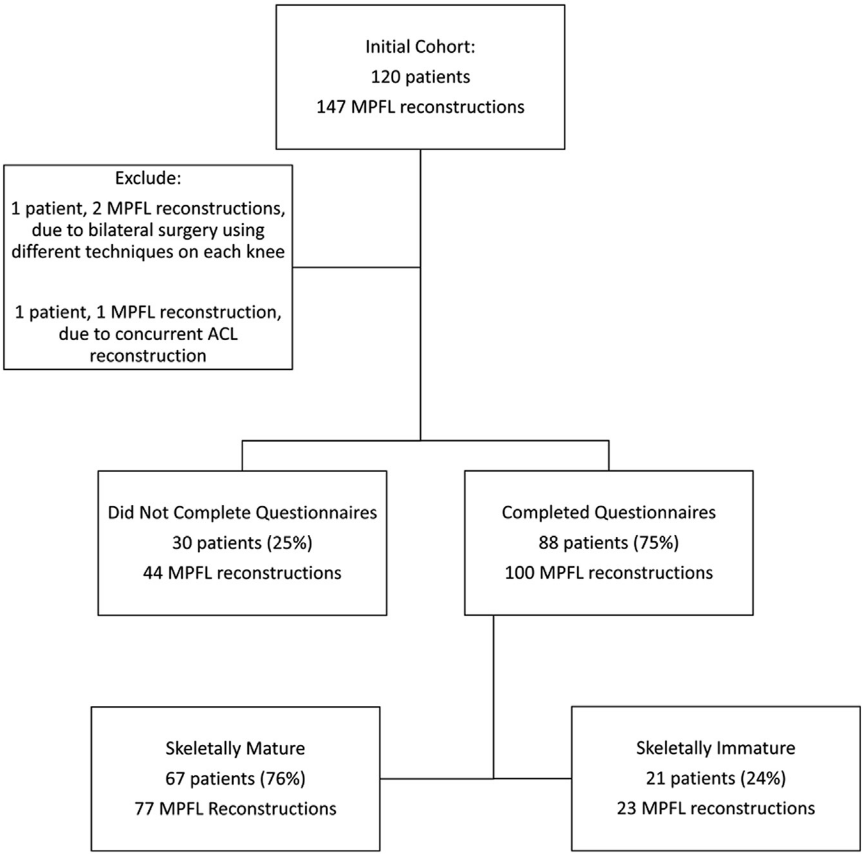

Fig 2. Flowchart detailing study cohort and group breakdown. (ACL, anterior cruciate ligament; MPFL, medial patellofemoral ligament.)

subsequent injury or surgery to either knee. When available, radiographs were reviewed by 2 fourth-year orthopaedic surgery residents (N.J.Q., T.E.H.) for trochlear dysplasia, Dejour classification, Insall—Salvati ratio, and Caton-Deschamps index. Trochlear dysplasia was defined as positive with the presence of the crossing sign on lateral radiographs. Sunrise radiographs were used for Dejour classification of trochlear dysplasia.

Statistical Analyses

REDCap data were exported to Microsoft Excel (Microsoft Corp., Redmond, WA) and SPSS, version 26 (IBM Corp., Armonk, NY) for analysis. The study cohort was analyzed twice: first all patients with minimum 1-year follow-up and then patients with minimum 2-year follow-up. Demographic, radiographic, and surgical data were analyzed on a per knee basis, as some patients underwent bilateral procedures at separate times. Outcome measures were analyzed per patient. All variables were assessed for normality using the Shapiro—Wilk test. Unpaired *t*-tests were used for normally distributed data and Mann—Whitney *U* tests were used for non-normally distributed data. For categorical variables, Pearson χ^2 and Fisher exact tests were used. Significance was set at a *P* value less than .05. Elimination multivariable logistic regression was used for all significant patient-reported outcomes variables on bivariate analysis, with nonsignificant variables eliminated in a stepwise fashion until a final model was established. Skeletal maturity status, age at surgery, sex, body mass index (BMI), and tape augmentation were included as independent variables. Inclusion at each step was set at an alpha value of 0.10. Post hoc power analysis was performed to determine power for detecting a difference in terms of recurrent dislocation with the chi square test using a medium effect size of 0.3, alpha of 0.05, 1 degree of freedom, and our final cohort size of 100 knees. The computed achieved power was 0.85 indicating the study was appropriately powered.

Results

The initial cohort included 120 patients who underwent 147 MPFL reconstructions. One patient was excluded for bilateral surgery using different techniques on each knee, and 1 patient was excluded for undergoing concurrent ACL reconstruction. Of 118 patients (144 MPFL reconstructions) who met study criteria, 88 patients (100 MPFL reconstructions) completed follow-up questionnaires. There were 67 patients (77 MPFL reconstructions) in the skeletally mature group, and

Table 1. Demographics, Minimum 1-Year Follow-Up Cohort

	Skeletally Mature (67 Patients, 77 Knees)	Skeletally Immature (21 Patients, 23 Knees)	*P* Value
Age at time of surgery, y, mean (SD)	15.4 (1.5)	13.1 (1.5)	<.001*
Range	11.9, 17.8	8.0, 15.3	
Sex, n (%)			.046*
Male	22 (33%)	12 (57%)	
Female	45 (67%)	9 (43%)	
Operative knee, n (%)			.812
Right	38 (49%)	12 (52%)	
Left	39 (51%)	11 (48%)	
BMI, mean (SD)	24.7 (5.2)	18.9 (2.4)	<.001*
Range	16.1, 41.0	15.1, 24.2	
Preoperative IKDC,† mean (SD)	40.8 (17.4)	37.9 (16.9)	.673
Prior knee surgery, n (%)	7 (9%)	0 (0%)	.347
Trochlear dysplasia,‡ n (%)			.594
No	22 (29%)	5 (22%)	
Yes	48 (62%)	16 (70%)	
Unknown	7 (9%)	2 (8%)	
Trochlea Dejour classification, n, (%)			.605
A	34 (78%)	9 (64%)	
B	8 (18%)	4 (29%)	
C	1 (2%)	0 (0%)	
D	1 (2%)	1 (7%)	
Insall—Salvati,‡ mean (SD)	1.33 (0.24)	1.34 (0.39)	.876
Caton—Deschamps‡, mean (SD)	1.29 (0.24)	1.26 (0.25)	.676

BMI, body mass index; IKDC, International Knee Documentation Committee; SD, standard deviation.

*Significance at the .05 level.

†Preoperative IKDC was available in 35 skeletally mature patients (52%) and 8 skeletally immature patients (38%).

‡Lateral radiographs were available in 70 mature knees (91%) and 21 immature knees (91%). Sunrise radiographs were available in 60 mature knees (78%) and 15 immature knees (65%). Trochlear dysplasia was classified using the Dejour classification if both lateral and sunrise radiographs were available.

21 patients (23 MPFL reconstructions) in the skeletally immature group (Fig 2). The skeletally mature cohort was older (15.4 ± 1.5 vs 13.1 ± 1.5, $P < .001$), had a greater proportion of female patients (67 vs 43%, $P = .046$), and had a greater BMI (24.7 ± 5.2 vs 18.9 ± 2.4, $P < .001$). There was no significant difference in preoperative IKDC scores (40.8 vs 37.9, $P = .673$). Radiographically, there was no difference in trochlear dysplasia when defined simply as presence of crossover sign (62% mature vs 70% immature, $P = .594$). In those who had dysplasia, the Dejour classification did not differ as 78% of mature knees compared with 64% of immature dysplastic knees were Type A ($P = .605$; Table 1).

Although the majority of patients underwent primary MPFL reconstruction, additional procedures at time of reconstruction were noted with the most common being loose body removal. There was no difference in these procedures between the skeletally mature and immature group ($P = .336$). All patients underwent MPFL reconstruction using allograft, which was predominantly semitendinosus or gracilis. Graft choice differed among patients due to graft availability at the institution. Fifty-three mature knees had tape augmentation compared with 3 immature knees (68 vs 13%, $P < .001$; Table 2).

Average follow-up in the skeletally mature group occurred at 4.2 years compared with 3.5 years in the immature group ($P = .107$). There were no differences in IKDC scores, Marx Activity Scale score, knee rating as a percentage of normal, or overall satisfaction with the results of the surgery. However, when asked if they would undergo the same care if needed, a significantly greater distribution in the skeletally mature group reported “definitely yes or probably yes” (96 vs 76%, $P = .007$). Additionally, there were no differences between the groups in current sport participation, sport avoidance, stiffness, subjective

Table 2. Surgical Data, Minimum 1-Year Follow-up Cohort

	Skeletally Mature (77 Knees)	Skeletally Immature (23 Knees)	*P* Value
Procedure performed, n (%)			.336
Isolated MPFL reconstruction	47 (61%)	16 (70%)	
Loose body removal	25 (32%)	5 (22%)	
Chondral debridement	4 (5%)	1 (4%)	
OCD drilling, partial excision	1 (1%)	0 (0%)	
Partial lateral meniscectomy	0 (0%)	1 (4%)	
Graft, n (%)			.274
Semitendinosus allograft	34 (44%)	14 (61%)	
Gracilis allograft	27 (35%)	3 (13%)	
Peroneus longus allograft	1 (1%)	1 (4%)	
Tibialis anterior allograft	1 (1%)	0 (0%)	
Unspecified allograft	14 (19%)	5 (22%)	
Tape augmentation, n (%)	53 (68%)	3 (13%)	<.001*

MPFL, medial patellofemoral ligament; OCD, osteochondrosis dissecans; SD, standard deviation.

*Significant at the .05 level.

Table 3. Patient-Reported Outcomes, Minimum 1-Year Follow-up Cohort

	Skeletally Mature (67 Patients, 77 Knees)	Skeletally Immature (21 Patients, 23 Knees)	*P* Value
Follow-up length, y, mean (SD)	4.2 (1.7)	3.5 (1.8)	.107
Range	1.0, 7.4	1.6, 6.5	
IKDC score, mean (SD)	77.6 (19.2)	82.9 (15.3)	.258
Range	20.7, 100	47.1, 100	
Marx Activity Scale score, mean (SD)	9.7 (5.0)	9.4 (4.6)	.804
Range	0, 16	0, 16	
Knee rated as a percentage of normal, mean (SD)	83.4 (19.4)	88.3 (11.6)	.164
Range	10, 100	65, 100	
Pain on a visual analog scale <3, n (%)			
At rest	62 (93%)	19 (91%)	.761
With activities of daily living	56 (84%)	18 (86%)	.923
With sport	43 (64%)	12 (57%)	.561
Satisfaction with surgery, n (%)			.586
Very satisfied	41 (61%)	10 (71%)	
Satisfied	17 (25%)	6 (29%)	
Neutral	6 (9%)	2 (10%)	
Unsatisfied	2 (3%)	2 (10%)	
Very unsatisfied	1 (1%)	0 (0%)	
Satisfaction dichotomized, n (%)			.257
Very satisfied/Satisfied	58 (87%)	16 (76%)	
Neutral/Unsatisfied/Very unsatisfied	9 (13%)	5 (24%)	
Undergo same care if needed, n (%)			.034*
Definitely yes	56 (84%)	14 (67%)	
Probably yes	8 (12%)	2 (10%)	
Neutral	1 (1%)	4 (19%)	
Probably no	1 (1%)	1 (5%)	
Definitely no	1 (1%)	0 (0%)	
Undergo same care dichotomized, n (%)			.007*
Definitely yes/yes	64 (96%)	16 (76%)	
Neutral/probably no/definitely no	3 (4%)	5 (24%)	
Play sports, n (%)	22 (32%)	9 (43%)	.402
Avoid sports, n (%)	25 (37%)	10 (48%)	.400
Due to knee	18 (27%)	5 (24%)	.781
Stiffness	29 (43%)	8 (38%)	.802
Limit activity	14 (48%)	5 (63%)	.693
Instability frequency, n (%)			.771
Weekly or more	16 (24%)	4 (19%)	
Monthly or less	51 (76%)	17 (81%)	
Subsequent ipsilateral injury,[†] n (%)	12 (16%)	8 (35%)	.043*
Subsequent patellar dislocation,[†] n (%)	2 (3%)	2 (9%)	.225
Subsequent ipsilateral surgery,[†] n (%)	9 (12%)	4 (17%)	.489
Subsequent ipsilateral surgery for patellar instability,[†] n (%)	8 (10%)	3 (13%)	.522
Subsequent contralateral injury,[†] n (%)	10 (18%)	6 (32%)	.194
Subsequent contralateral surgery,[†] n (%)	3 (5%)	2 (11%)	.594

*Significant to the .05 level.
[†]Confirmed via chart review.

instability, ipsilateral surgery, contralateral injury, or contralateral surgery. However, in the skeletally immature group there was a significantly greater rate of subsequent injury (35 vs 16%, $P = .043$; Table 3). In the immature group, these injuries included nondislocation instability events (3, 13%), patella dislocation (2, 9%), and nonspecific knee injury (3, 13%). In the mature group, these injuries included nondislocation instability events (8, 10%), patella dislocation (2, 3%), anterior cruciate ligament rupture (1, 1%), medial collateral ligament tear (1, 1%), and nonspecific knee injury (1, 1%). Of note, the repeat dislocation rate was not statistically significant between the immature group (9%) and mature group (3%) at 1-year follow-up ($P = .225$).

Regarding subsequent ipsilateral surgery, 9 patients (12%) in the mature group underwent additional surgery compared with 4 patients (17%) in the immature group ($P = .489$). In the mature group, there were 7 revision MPFL reconstructions (9%), 3 with tibial tubercle transfer (4%), 1 with lateral femoral condyle microfracture (1%), 1 with tibial osteotomy (1%), and 1 with lateral distal femoral osteotomy that later required a second revision MPFL reconstruction (1%). One patient underwent anterior cruciate ligament reconstruction with lateral femoral chondroplasty and microfracture (1%), and another patient underwent isolated tibial tubercle transfer (1%). In the immature group, there were 2 revision MPFL reconstructions (9%), 1 with concurrent distal realignment (5%), 1 tibial tubercle transfer with lateral retinacular release and patellofemoral chondroplasty (5%), and 1 lateral retinacular release (5%). Follow-up surgeries were not all performed by the senior author. No cases of growth disturbance were observed based on the senior author's clinical evaluation of limb alignment. Additionally, 6-month postoperative knee radiographs are routinely obtained with no evidence of premature physeal arrest.

Minimum Two-Year Follow-Up Analysis

When restricting analysis to patients with minimum 2 years follow-up, there were 58 skeletally mature patients (67 MPFL reconstructions) and 16 skeletally immature patients (17 MPFL reconstructions). Skeletally mature patients were significantly older (15.4 vs 13.5 years, $P < .001$) and had a greater BMI at time of surgery (24.8 vs 18.9, $P < .001$). There were no differences in sex, laterality, or preoperative IKDC scores. Radiographically, there were no differences regarding trochlear dysplasia, Dejour classification, or Caton—Deschamps Index. The skeletally mature group had a greater mean Insall—Salvati ratio (1.35 vs 1.18, $P = .018$; Table 4).

Similar to the analysis of the entire cohort, isolated allograft MPFL reconstructions were performed in a majority of cases as the index surgery. There were no differences in additional procedures or graft choice. Tape augmentation was more common in the skeletally mature compared to immature group (64 vs 18%, $P < .001$; Table 5).

Average follow up was 4.6 and 4.1 years in the mature and immature groups, respectively ($P = .295$). There were no differences in IKDC score, Marx Activity score, and knee rating as a percentage of normal, pain, or overall satisfaction with the results of the surgery. The difference observed in willingness to undergo the same care if needed persisted, with 95% of skeletally mature patients responding "definitely yes or probably yes" compared with 69% of skeletally immature patients ($P = .010$). There were no differences in current sport participation, sport avoidance, stiffness, subjective instability, subsequent ipsilateral injury, ipsilateral surgery, contralateral injury, or contralateral surgery (Table 6).

Multivariable Analysis

Elimination multivariable logistic regression was performed with subsequent injury as the dependent variable given its significance in bivariate analysis (Table 7). In the final model, skeletal maturity status was the only significant variable with skeletally immature associated with subsequent injury ($\beta = 1.061$, odds ratio [95% confidence interval] = 2.889 [1.005-8.307], $R^2 = 0.058$, $P = .049$).

Discussion

The findings of this study suggest that both skeletally mature and immature patients undergoing MFPL reconstruction have similarly excellent functional outcomes. However, at minimum 1-year follow-up, the skeletally immature group had a greater rate of subsequent ipsilateral knee injuries and were less likely to report they would undergo the same procedure if needed. There was no significant difference in subsequent dislocation rate between skeletally mature and immature patients (3 vs 9%, respectively). At 2 years follow-up, the only significant difference was that skeletally immature patients remained less likely to report they would undergo the same procedure if needed.

Parikh et al.[20] reported on a series of 179 MPFL reconstructions in patients younger than the age of 21 years. They reported on overall complication rate of 16%, of which they attributed 47% of these complications to technical error. Recurrent lateral patellar instability occurred in 4%. There were 28 reconstructions in patients younger than the age of 12 years, but none experienced growth disturbance.[20] Several studies specific to MPFL reconstruction in skeletally immature patients have been published that report results using a number of grafts and techniques to avoid physeal injury. Outcomes are quite good in these cohorts, with low rates of recurrent dislocation, although with some patients exhibiting apprehension on examination and experience instability.[10-16] A systematic review and meta-analysis by Shamrock et al.[3] evaluating these studies totaled 132 autograft MPFL reconstructions in skeletally immature patients with an overall re-dislocation rate of 3.8% and subsequent subluxation rate of 11.4%. Neither femoral fixation technique nor autograft choice was associated with persistent instability. There were no instances of premature physeal arrest, and all reported high Kujala scores.

In contrast, there is far more literature regarding MPFL reconstruction in skeletally mature patients. In addition, while techniques vary in terms of graft choice and fixation strategy, location of graft placement in the patella and femur for isometric fixation are well

Table 4. Demographics, Minimum 2 Years Follow-up Cohort

	Skeletally Mature (58 Patients, 67 Knees)	Skeletally Immature (16 Patients, 17 Knees)	*P* Value
Age at time of surgery, y, mean (SD)	15.4 (1.6)	13.5 (1.0)	<.001*
Range	11.9, 17.8	10.8, 15.3	
Sex, n (%)			.086
Male	19 (33%)	9 (56%)	
Female	39 (67%)	7 (43%)	
Operative knee, n (%)			.959
Right	35 (52%)	9 (53%)	
Left	32 (48%)	8 (47%)	
BMI, mean (SD)	24.8 (5.4)	18.9 (2.7)	<.001*
Range	16.1, 41.0	15.1, 24.2	
Preoperative IKDC, mean (SD)	39.2 (18.2)	38.6 (18.1)	.882
Previous knee surgery, n (%)	7 (10%)	0 (0%)	.335
Trochlear dysplasia, n (%)			.787
No	29 (43%)	7 (41%)	
Yes	32 (48%)	9 (53%)	
Unknown	6 (9%)	1 (6%)	
Trochlea Dejour classification,† n (%)			.488
A	23 (92%)	5 (83%)	
B	1 (4%)	1 (17%)	
C	1 (4%)	0 (0%)	
D	0 (0%)	0 (0%)	
Insall—Salvati, mean (SD)	1.34 (0.25)	1.18 (0.18)	.018*
Caton—Deschamps, mean (SD)	1.3 (0.24)	1.22 (0.25)	.236

NOTE. Sunrise radiographs were available in 51 mature knees (76%) and 11 immature knees (65%). Trochlear dysplasia was classified using the Dejour classification if both lateral and sunrise radiographs were available.

Preoperative IKDC was available in 31 skeletally mature patients and 8 skeletally immature patients.

BMI, body mass index; IKDC, International Knee Documentation Committee; SD, standard deviation.

*Significance at the .05 level.

†Lateral radiographs were available in 62 mature knees (93%) and 16 immature knees (94%).

established, unlike what has been described for the skeletally immature patient. This procedure generally achieves good to excellent results with a redislocation rate consistently less than 10%.[21] Schneider et al.[22] performed a meta-analysis and systematic review on isolated MPFL reconstructions in patients with an average age of 24 years, which is more consistent with our skeletally mature group. This cohort also demonstrated high postoperative Kujala scores (average 85.8) with 84% returning to sport, and a recurrent instability rate of 1.2%. Although our findings did not reach statistical significance, they would support that although both skeletally mature and immature patients do well, skeletally immature patients had a greater rate of residual instability. Interestingly, when asked if they would undergo the same care again

Table 5. Surgical Data, Minimum 2 Years Follow-up Cohort

	Skeletally Mature (58 Patients, 67 Knees)	Skeletally Immature (16 Patients, 17 Knees)	*P* Value
Procedure performed, n (%)			.260
Isolated MPFL reconstruction	41 (61%)	12 (71%)	
Loose body removal	21 (31%)	3 (17%)	
Chondral debridement	4 (6%)	1 (6%)	
OCD drilling, partial excision	1 (2%)	0 (0%)	
Partial lateral meniscectomy	0 (0%)	1 (6%)	
Graft, n (%)			.461
Semitendinosus allograft	35 (52%)	11 (65%)	
Gracilis allograft	25 (37%)	3 (18%)	
Peroneus longus allograft	1 (2%)	1 (6%)	
Tibialis anterior allograft	1 (2%)	0 (0%)	
Unspecified allograft	5 (7%)	2 (11%)	
Tape augmentation, n (%)	43 (64%)	3 (18%)	<.001*

MPFL, medial patellofemoral ligament; OCD, osteochondrosis dissecans.

*Significant at the .05 level.

Table 6. Patient-Reported Outcomes, Minimum 2 Years Follow-up Cohort

	Skeletally Mature (58 Patients, 67 Knees)	Skeletally Immature (16 Patients, 17 Knees)	*P* Value
Follow-up length, y, mean, (SD)	4.6 (1.4)	4.1 (1.6)	.295
Range	2.0, 7.2	2.3, 7.4	
IKDC score, mean (SD)	77.8 (18.0)	77.3 (22.5)	.921
Range	20.7, 100	20.7, 100	
Marx Activity Scale score, mean (SD)	9.0 (4.8)	10.0 (5.3)	.487
Range	0, 16	0, 16	
Knee rated as a percentage of normal, mean (SD)	84.1 (16.3)	83.9 (23.4)	.967
Range	17, 100	10, 100	
Pain on a visual analog scale <3, n (%)			
At rest	53 (91%)	14 (89%)	.639
With activities of daily living	47 (83%)	13 (81%)	.911
With sport	36 (62%)	10 (63%)	.975
Satisfaction with surgery, n (%)			.267
Very satisfied	35 (60%)	7 (43%)	
Satisfied	15 (26%)	4 (25%)	
Neutral	6 (10%)	2 (13%)	
Unsatisfied	1 (2%)	2 (13%)	
Very unsatisfied	1 (2%)	1 (6%)	
Satisfaction dichotomized, n (%)			.104
Very satisfied/Satisfied	50 (86%)	11 (69%)	
Neutral/unsatisfied/very unsatisfied	8 (14%)	5 (31%)	
Undergo same care if needed, n (%)			.012*
Definitely yes	50 (86%)	9 (56%)	
Probably yes	5 (9%)	2 (13%)	
Neutral	1 (2%)	4 (25%)	
Probably no	1 (2%)	1 (6%)	
Definitely no	1 (2%)	0 (0%)	
Undergo same care dichotomized, n (%)			.010*
Definitely yes/probably yes	55 (95%)	11 (69%)	
Neutral/probably no/definitely no	3 (5%)	5 (31%)	
Play sports, n (%)	18 (31%)	6 (38%)	.625
Avoid sports, n (%)	22 (38%)	9 (56%)	.189
Due to knee	16 (28%)	4 (25%)	.837
Stiffness	26 (45%)	8 (50%)	.713
Limit activity	14 (24%)	5 (31%)	1.000
Instability frequency, n (%)			.943
Weekly or more	14 (24%)	4 (25%)	
Monthly or less	44 (76%)	12 (75%)	
Subsequent ipsilateral injury,† n (%)	11 (16%)	6 (35%)	.084
Subsequent patellar dislocation,† n (%)	2 (3%)	2 (12%)	.181
Subsequent ipsilateral surgery,† n (%)	8 (12%)	4 (24%)	.251
Subsequent ipsilateral surgery for patellar instability,† n (%)	7 (10%)	3 (18%)	.415
Subsequent contralateral injury,† n (%)	9 (18%)	5 (33%)	.220
Subsequent contralateral injury,† n (%)	3 (6%)	2 (13%)	.363

IKDC, International Knee Documentation Committee; SD, standard deviation.
*Significant to the .05 level.
†Confirmed via chart review.

if needed, the skeletally immature group was far less likely to respond "yes," which may be a reflection of residual stability issues. While we did not see a significant difference in rate of dislocation following reconstruction between the groups, there was a greater rate of subsequent ipsilateral knee injury in the skeletally immature group with minimum 1-year follow-up. This finding was no longer significant at 2 years and may indicate that injuries over time equalize between skeletally mature and immature patients, or a larger cohort is needed at this time point to identify a significant difference.

There are a few key differences between the cohorts. First, as expected, the skeletally immature group was younger, which may predispose them to subsequent instability compared to an older cohort. Second, there was a lower rate of tape augmentation in the skeletally immature group, which may also partially explain the

Table 7. One-Year Cohort Elimination Multivariable Logistic Regression With Subsequent Injury (Yes = 1) as the Dependent Variable

Variable*	β†	OR (95% CI)	$R^{2‡}$	*P* Value
Step 1				
Skeletal maturity	0.864	2.372 (0.453-12.420)	0.098	.307
Age at surgery	0.172	1.187 (0.810-1.741)		.379
Sex	−0.229	0.795 (0.259-2.441)		.689
BMI	−0.071	0.931 (0.816-1.063)		.291
Tape usage	−0.333	0.717 (0.217-2.366)		.585
Step 2				
Skeletal maturity	0.978	2.658 (0.562-12.574)	0.096	.218
Age at surgery	0.190	1.209 (0.835-1.750)		.316
BMI	−0.067	0.936 (0.821-1.066)		.317
Tape usage	−0.356	0.700 (0.213-2.304)		.558
Step 3				
Skeletal maturity	1.150	3.159 (0.740-13.494)	0.091	.120
Age at surgery	0.195	1.215 (0.839-1.761)		.302
BMI	−0.074	0.929 (0.816-1.057)		.265
Step 4				
Skeletal maturity	0.7745	2.107 (0.631-7.031)	0.074	.226
BMI	−0.065	0.937 (0.822-1.067)		.326
Step 5				
Skeletal maturity	1.061	2.889 (1.005-8.307)	0.058	.049

BMI, body mass index; CI, confidence interval; OR, odds ratio.

*Variable definitions: skeletal maturity (mature = 0, immature = 1); age at surgery reported in years; sex = (male = 0, female = 1); BMI reported as points; tape usage (no = 0, yes = 1).

†β = beta coefficient.

‡R^2 = Nagelkerke R squared.

greater rate of subsequent injury. Tape augmentation was avoided in skeletally immature patients due to the theoretical inability of a nonbiologic material to stretch with continued growth. Theoretically, use of tape augmentation may alter growth, lead to altered graft mechanics, and over constrain the patella. In the senior authors practice, it is standard to use suture tape augmentation in the skeletally mature patient. Finally, the skeletally immature group had a lower BMI and smaller proportion of females compared with the skeletally mature group. The impact of this on our findings may be the focus of further studies; however, on multivariable analysis, skeletal immaturity was the only factor associated with subsequent injury.

Limitations

There are several limitations in this study. First, the response rate was 75%. This loss to follow-up leads to attrition bias, which may affect the validity of the conclusions. A larger sample size may have demonstrated more significant differences among the 2 groups. Second, the study population consisted of patients operated on at a single center by a single surgeon, which may limit generalizability of our findings. Third, preoperative sunrise radiographs were unavailable for classification of trochlear dysplasia in 15% of knees, whereas lateral radiographs from outside institutions were unavailable in 8% of knees for calculation of presence of trochlear dysplasia (crossing sign), the Insall−Salvati ratio and Caton-Deschamps index. Fourth, preoperative IKDC scores and functional information were not consistently available as part of clinical practice. However, we are uncertain if this information would be helpful as patients often presented following an injury with altered knee function. Fifth, these mid-term outcomes were evaluated using chart review and questionnaires and as such are limited by information available in the chart, as well as patient responses. Sixth, the IKDC score is a validated patient-reported outcome measure; however, the remaining questions in our survey addressing function, satisfaction, and pain have not been validated. Finally, this study is inherently limited through its design as a retrospective study.

Conclusions

Pediatric patients undergoing MPFL reconstruction have good and comparable outcomes regardless of skeletal maturity. However, younger age and lack of tape augmentation in skeletally immature patients may predispose them to subsequent injury.

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