Medial Patellofemoral Ligament Reconstruction Using Allografts in Skeletally Immature Patients

Martin Husen,*† MD, Todd A. Milbrandt,* MD, Veeraj Shah,* Aaron J. Krych,* MD, Michael J. Stuart,* MD, and Daniel B.F. Saris,*‡§ MD, PhD
Investigation performed at the Department of Orthopedic Surgery and Sports Medicine, Mayo Clinic, Rochester, Minnesota, USA

Background: Patellar instability has the highest incidence in adolescents aged between 14 and 18 years. The unique relationship between the medial patellofemoral ligament (MPFL) and the distal femoral physis in skeletally immature patients warrants precisely positioned MPFL graft insertion. A paucity of data are available evaluating the results of MPFL reconstruction using allograft tendon before skeletal maturity.

Purposes: (1) To assess the results of MPFL reconstruction using allograft tendon in skeletally immature patients by analyzing redislocation and reoperation rates, radiological outcomes, and patient-reported outcomes and (2) to determine whether epidemiological, intraoperative, or radiographic factors influence recurrent instability and clinical outcomes.

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

Methods: Prospectively collected data were retrospectively analyzed for 69 skeletally immature patients who experienced a first-time or recurrent lateral patellar dislocation and were treated with anatomic MPFL reconstruction. Inclusion criteria were MPFL reconstruction using allograft and the availability of preoperative magnetic resonance imaging scans in the presence of open or partially open physes. Patients with <2 years of follow-up and patients with previous surgeries on the same knee were excluded from the study. Preoperative radiographic imaging was reviewed and analyzed. Trochlear dysplasia, tibial tubercle–trochlear groove distance, and patellar height were evaluated. Descriptive data, concomitant injuries, surgical procedure details, complications, and postoperative history were assessed via review of medical records and patient charts. Validated patient-reported and surgeon-measured outcomes were collected pre- and postoperatively, including Kujala score, Lysholm score, and Tegner activity score. Return-to-sports rate was assessed. The influence of epidemiological, intraoperative, and radiographic parameters on the redislocation rates and clinical outcomes was assessed using a multiple linear regression model.

Results: A total of 79 physeal-sparing MPFL reconstructions (69 patients) met the inclusion criteria. The mean age of the patient cohort was 14.7 ± 1.8 years (range, 8.5-16.9 years). Within the mean follow-up time of 37.9 ± 12.1 months (range, 24-85 months after surgery, there were 12 patients with clinical failures resulting in reoperation. Eleven patients experienced a redislocation of the patella, and 1 patient sustained a transverse noncontact patellar fracture 6 months after index surgery that required operative fixation. No injuries to the distal femoral physes were clinically observed. At the final follow-up, patients had a mean Lysholm score (1-100) of 96.5 ± 6.7, a mean Kujala score (1-100) of 96.5 ± 7.4, and a mean Tegner Activity Scale score (1-10) of 4.9 ± 1.3. Patellar height and trochlear dysplasia did not influence redislocation or clinical scores. In total, 57 of the 63 patients (90.5%) who were engaged in sports before injury returned to the same or higher level of competition. In a subgroup analysis of patients who underwent isolated MPFL reconstruction (n = 44) without concomitant procedures, 9 patients (20.5%) experienced failure and had a redislocation. A univariate analysis of hazards for failure based on patient-specific variables was carried out. A body mass index ≥30 conveyed a hazard ratio of 2.51 (95% CI, 0.63-10.1; P = .19), and the tibial tubercle-trochlear groove distance by increments of 1 mm was associated with a hazard ratio of 2.02 (95% CI, 0.51-8.11; P = .32).

Conclusion: Physeal-sparing anatomic reconstruction of the MPFL using an allograft tendon in skeletally immature patients was a safe and effective treatment for patellar instability, regardless of patellar height and trochlear dysplasia. Failure rates decreased when the MPFL reconstruction was performed concomitantly with a tibial tubercle osteotomy.

Keywords: MPFL; medial patellofemoral ligament; patellar instability; tibial tuberosity transfer

The American Journal of Sports Medicine
2023;51(6):1513–1524
DOI: 10.1177/03635465231164400

The medial patellofemoral ligament (MPFL) plays a crucial role in maintaining biomechanical stability of the patellofemoral joint and has been reported to account for approximately half of the total restraint to lateral patellar

displacement.[23] Patellar dislocation is the second leading cause of traumatic knee hemarthroses in the general population and is often accompanied by an injury to this thin ligamentous structure that is located within the second layer of the medial knee soft tissue.[23] In children, an acute patellofemoral dislocation is the most common acute knee injury overall, with an injury rate of 1.95 per 100,000 athlete-exposures among high school athletes.[33,55,59] Structural alteration can range from pure elongation of the ligament to complete rupture that usually occurs directly at the femoral insertion.[54] Skeletally immature adolescents have a higher reported rate of patellofemoral instability and patellar dislocation compared with adults.[30] High-level evidence on the appropriate treatment of first-time dislocations is limited, and the final treatment decision in these cases is reached mutually by the surgeon, patient, and parents. However, there remains a need for anatomic reconstruction in the presence of open physes in patients with first-time dislocations and after failed nonsurgical treatment and recurrent dislocations.[15] Although MPFL reconstruction has been proven to restore stability, numerous surgical techniques have been described to address patellar instability.[19,38] Some surgical approaches use soft tissue correction, whereas others aim to achieve stability via bony correction procedures.[62] Although the vast number of surgical procedures aimed at restoring patellar stability makes it difficult to decide the best course of treatment in each case, combinations of bony and soft tissue approaches have been reported to be beneficial in selected patients.[5,15]

Good to excellent results of MPFL reconstruction have been reported in adults, whereas mixed outcomes and comparably higher failure rates have been found in skeletally immature adolescents after stability-restoring operative treatments.[1,2,4,10,31,56,74] Among the reported complications are redislocation of the patella, patellar fractures, patella baja, nerve injuries, tightness, painful limitation of range of motion due to overrestraint, and growth deformity from injury of the physes due to surgical manipulation.[1,2,7,10,31,51,71] Although surgical techniques such as lateral release, the Insall procedure, and the Roux-Goldthwait procedure are established in clinical practice, anatomic MPFL reconstruction using tendon autograft has been advocated as the treatment of choice in skeletally immature patients.[14,17,36,57,58,72] However, allograft tissue has potential advantages of limiting donor-site morbidity, including loss of strength, and decreased surgical time, and it can be used in patients with tissue disorders.[8,32,47] In adults, allograft tissue has shown comparable results in regard to preventing recurrent patellar instability when used for MPFL reconstruction compared with autograft, but little is known about the use of allograft tissue for MPFL reconstruction in children.[29,44,68,69] The proximity of the distal femoral physes to the biomechanically ideal insertion of the MPFL has to be taken into account when reconstructing the ligament. It has been shown that the femoral insertion is located distal to the femoral physes.[48] Considering the significant contribution of the distal femoral growth plate to longitudinal growth, injury of the physes, with the potential implication of growth arrest, has to be avoided to prevent angular or leg-length deformities of the limb.[70] The purpose of the current study was to evaluate the clinical outcome and redislocation rates after MPFL reconstruction with allograft tendon in skeletally immature patients. Furthermore, we aimed to analyze the influence of epidemiological, radiographic, and surgical factors on redislocation rates and clinical outcomes. We hypothesized that a high clinical success rate could be achieved using an allograft tendon for anatomic reconstruction. The reported results of this study may assist surgeons in counseling young patients and their parents regarding the expected outcome of MPFL reconstruction in the setting of lateral patellar dislocation.

METHODS

Study Population and Design

This retrospective review of prospectively collected data was performed at a single institution (Mayo Clinic) between 2015 and 2021 to determine whether patellar instability resulting in lateral patellar luxation could be successfully treated with MPFL reconstruction in a skeletally immature patient population. Institutional review board approval was obtained before the beginning of the study. Participants provided informed consent. A search of the institutional medical database was performed to identify all pediatric patients who underwent surgery for patellar instability with $\geq$1 episode of documented dislocation during that period. Patients were included if they underwent primary MPFL reconstruction and had open or partially open physes at the time of index surgery. Skeletal maturity

§Address correspondence to Daniel B.F. Saris, MD, PhD, Mayo Clinic, 200 First Street SW, Rochester, MN, 55905 USA (email: saris.daniel@mayo.edu).
*Department of Orthopedic Surgery and Sports Medicine, Mayo Clinic, Rochester, Minnesota, USA.
†Department of Orthopedic Surgery, Heidelberg University Hospital, Heidelberg, Germany.
‡Department of Orthopedic Surgery, University Medical Center, Utrecht University, the Netherlands.
This article's contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Institutes of Health.
Submitted October 4, 2022; accepted February 7, 2023.

One or more of the authors has declared the following potential conflict of interest or source of funding: The authors acknowledge support from the Foderaro-Quattrone Musculoskeletal-Orthopaedic Surgery Research Innovation Fund. This study was partially funded by the Deutsche Forschungsgemeinschaft (DFG) (grant No. 466023693) and the National Institute of Arthritis and Musculoskeletal and Skin Diseases for the Musculoskeletal Research Training Program (T32AR56950). T.A.M. has received consulting fees from OrthoPediatrics, Zimmer Biomet, and Medtronic. A.J.K. has received research support from Aesculap/B. Braun, Arthrex, Ceterix, and Histogenics; consulting fees from Arthrex, JRF Ortho, Vericel, and Responsive Arthroscopy; royalties from Arthrex and Responsive Arthroscopy; honoraria from JRF, Vericel, and MTF; and a grant from DJO. M.J.S. has received royalties, consulting fees, and compensation for services other than consulting from Arthrex Inc and research support from Stryker. D.B.F.S. has received consulting fees from Smith & Nephew and research support from JRF. 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.

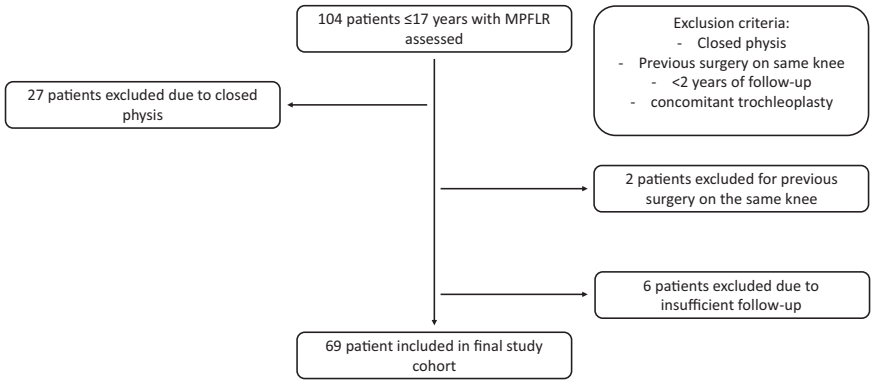

Figure 1. Flowchart of patient exclusion and selection. MPFLR, medial patellofemoral ligament reconstruction.

was assessed using preoperative magnetic resonance imaging (MRI) based on the status of the growth plate closure: open (n = 41 knees), partially open (n = 38 knees), or closed (n = 0 knees). All patients were required to have a minimum of 2 years of follow-up. Exclusion criteria included previous tibial tubercle osteotomy (TTO) and trochleoplasty. Six patients who had <2 years of follow-up and 2 patients who had undergone previous surgery on the same knee were therefore excluded. Patients who underwent concurrent procedures such as hemiepiphysiodesis in the setting of malalignment, anterior cruciate ligament (ACL) reconstruction, or meniscal repair were not excluded from the study. Of note, none of the excluded patients had a redislocation or revision at the time of exclusion. A total of 69 patients (23 male and 46 female) aged 8 to 17 years were included in the study cohort. In total, 79 anatomic MPFL reconstructions were performed. All patients had open or partially open growth plates at the time of index surgery. Bilateral knees were scored separately (Figure 1).

Indication and Surgical Technique for MPFL Reconstruction in Skeletally Immature Patients

Indications for MPFL reconstruction included a recurrent lateral patellar dislocation or a first-time dislocation with either an additional intra-articular injury (chondral or osteochondral fracture or lesion) or the presence of risk factors for recurrent dislocation (eg, history of lateral patellar dislocations in the contralateral knee, trochlear dysplasia). In case of a first-time patellar dislocation without predisposing risk factors, nonsurgical treatment was introduced including physical therapy. If a recurrent patellar dislocation occurred despite nonoperative treatment, patients were converted to MPFL reconstruction.

All MPFL reconstructions were performed by experienced, fellowship-trained orthopaedic surgeons (T.A.M., A.J.K., M.J.S., D.B.F.S.). The knee joint was examined under anesthesia, confirming preoperative findings. Diagnostic arthroscopy was initially performed in all cases to assess for intra-articular lesions and further injuries. Consequently, the superomedial border of the patella was exposed, and then 2 different patellar fixation methods were used. The type of patellar fixation was determined by surgeon preference. In the majority of patients, a shallow trough was created using a bur. Two Arthrex FASTak suture anchors were placed at the superior half of the medial border of the patella (Figure 2). In some patients, a socket was used for patellar graft fixation. In these cases, the osseous medial pole of the patella was exposed. Under image intensifier control, 2 very small K-wires were placed in the medial patellar boarder. A cannulated reamer was then used to create the 3.5 × 15–mm sockets in the patella. A No. 2-0 FiberWire modified Krackow suture (Arthrex) was placed in each end of the allograft over approximately 15 mm. These sutures were passed through a 3.5 × 13.5–mm Swivelock anchor (Arthrex), which was inserted into each socket. A transverse patellar drill hole that crosses the entire patella was strictly avoided. Then, the space between layers 2 and 3 was bluntly developed, beginning at the medial border of the patella and reaching to the origin of the MPFL at the Schöttle point (Figure 3). This landmark is a reproducible anatomic and radiographic point, located 1.3 mm anterior to the posterior cortex extension and 2.5 mm distal to the posterior origin of the medial femoral condyle, just proximal to the level of the posterior point of the Blumensaat line on a lateral view with the posterior condylar margin overlapped determining the mean femoral MPFL center.[64] In skeletally immature patients, this point is approximately 7 mm distal to the medial distal femoral physis.[13] The correct position was confirmed under fluoroscopy. The allograft was doubled over and fixed at its apex to the patella, using the previously placed FASTak anchors. Two limbs of the graft were then guided through the previously developed layer and brought out to the Schöttle point, where they were affixed using a 5.5-mm BioComposite corkscrew anchor (Arthrex) with 2 No. 2-0 FiberWire sutures attached. The femoral socket was positioned distal to the physes, with a distal and slightly ventral angulation (Figure 4). The patellar stability was confirmed by visualizing the patella directly at arthroscopy, as well as using fluoroscopy.

In case of recurrent patellofemoral dislocation after MPFL reconstruction, revision surgery was carried out. If

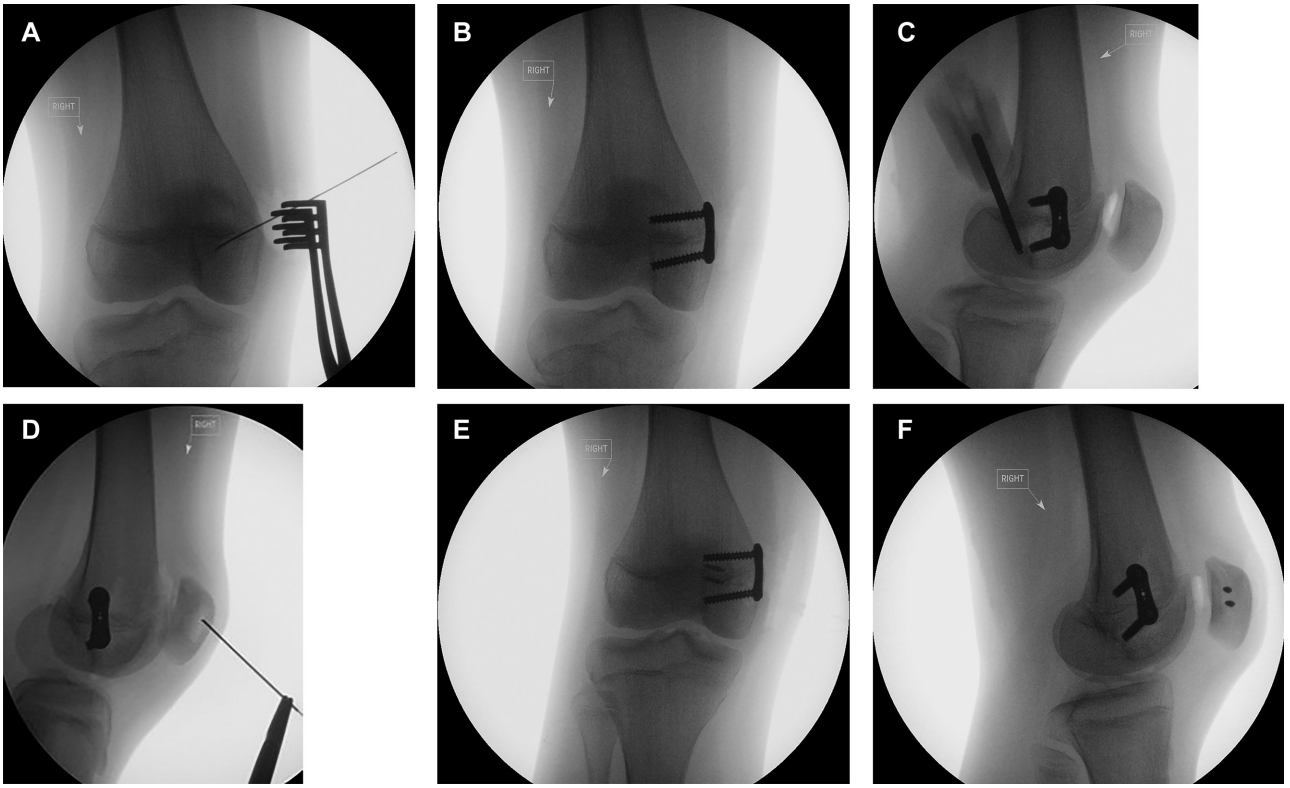

Figure 2. Intraoperative radiographs of distal medial femoral hemiepiphysiodesis and medial patellofemoral ligament (MPFL) reconstruction using gracilis allograft in a 13-year-old patient. (A) Identification of the physis via K-wire. (B) Medial 8-plate in situ. (C) Physis-sparing identification of the femoral MPFL insertion point. (D) Identification of the patellar graft insertion point. (E) Anteroposterior image after MPFL reconstruction and hemiepiphysiodesis. (F) Intraoperative lateral view.

an adequate trauma was reported that led to the recurrent dislocation and a normal tibial tubercle–trochlear groove (TT-TG) distance was present, a MPFL reconstruction was carried out as revision surgery. Inadequate or no trauma as a cause of recurrent dislocation in combination with increased TT-TG distance was addressed with MPFL reconstruction and TTO. In the presence of a dysplastic trochlea, a trochleoplasty was combined with MPFL reconstruction in these revision cases.

Rehabilitation

Patients followed a standardized postoperative rehabilitation protocol with regularly scheduled office visits. In the first 2 weeks after surgery, patients were partially weightbearing and performed range of motion exercises with active flexion and passive extension. Progression to full weightbearing was permitted 6 weeks after surgery. Return to sports training was initiated at 4 months with a goal of unrestricted return to play by 6 months. Ultimate time for sports clearance was based on obtaining symmetric lower extremity strength and having satisfactory performance on functional tests. Patients were seen for regularly scheduled follow-up visits for the first year and then on an annual basis unless complications arose.

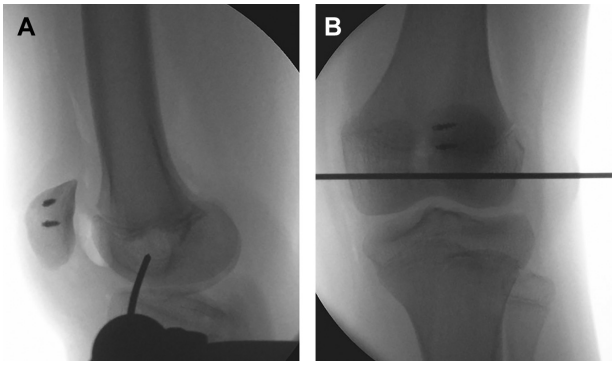

Figure 3. Intraoperative radiographs. (A) Lateral and (B) anteroposterior views of a left knee during femoral socket positioning of medial patellofemoral ligament reconstruction in a skeletally immature patient (12 years of age). (A) Identification and verification of the entry point using a pin on a surface localizing shot. The trajectory of the pin is anterior, strictly extraphyseal. (B) After identification of the entry point, a guide pin is introduced after visualization of the anterior and posterior cruciate ligaments and verification that the structures remain uninjured; a bioabsorbable interference screw is used to secure the graft within the medial condyle distal to the physis. Suture anchors are visible within the patella, facilitating graft fixation.

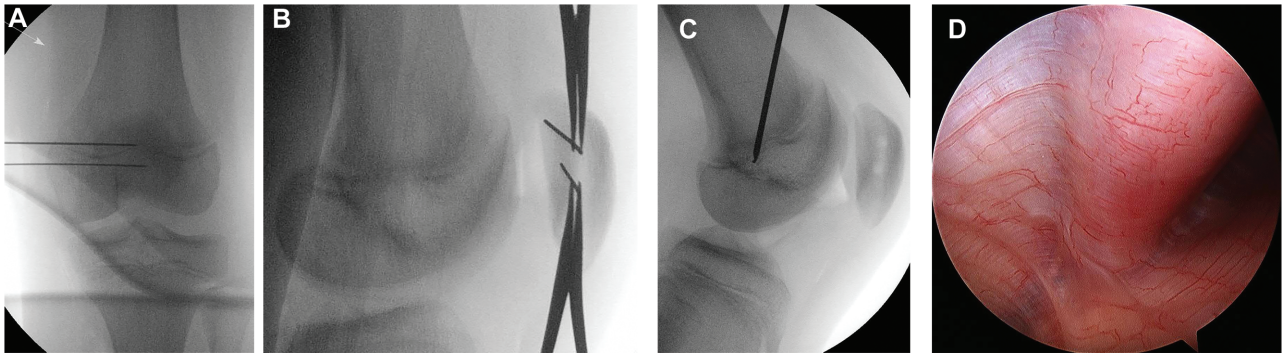

Figure 4. Graft positioning in a skeletally immature patient. (A, B) Intraoperative images of patellar graft fixation. Two small K-wires are positioned within the medial pole of the patella. Care is taken to not cross through the entire length of the patella and thereby weaken it. (C) The correct, physeal-sparing entry point for femoral graft fixation. (D) Medial patellofemoral ligament graft arthroscopically in typical position and depth.

Evaluation Methods

The patients' records were reviewed for preoperative data including age at the time of surgery, body mass index (BMI), dislocation history, previous operations, and Tegner score. Preoperative radiographs of the knee, including anteroposterior (standing, weightbearing) and lateral views, were reviewed for patellar tilt and height as well as sulcus and congruence angles. Patellar height was determined on lateral radiographs using the method described by Insall and Salvati, which has been shown to be the most reliable.[53,73]

In all patients, the presence of trochlear dysplasia was determined based on true lateral radiographs and axial MRI scans. MRI scans of the most proximal craniocaudal transverse plane on which the cartilage along the entire width of the trochlea was visible were performed. The Dejour and Le Coultre classification was used to define no dysplasia, low-grade dysplasia (A), or high-grade dysplasia (B, C, D).[20] In type A dysplasia, a crossing sign is visible on lateral radiographs of the knee, and the trochlear groove is symmetric but shallower than normal, with a sulcus angle $>145°$ on axial images. Type B entails a crossing sign as well as a supratrochlear spur on lateral radiographs, with a flat trochlea on axial images. In type C, a crossing sign and double contour are visible on lateral radiographs, with lateral facet convexity and medial facet hypoplasia on axial images. Type D involves a crossing sign, supratrochlear spur, and double contour on lateral radiographs and a "cliff" on axial images because of asymmetry of the lateral and medial femoral trochlear facets.[21] Given the good interobserver reliability reported for this dichotomous classification, radiographs and axial MRI scans were reviewed by a single fellowship-trained orthopaedic surgeon (M.H.).[41,45] In all patients, the preoperative TT-TG distance was determined from computed tomography scans when available or axial MRI scans, and values $\geq$20 mm were considered abnormal.[22] Measurements were performed by a musculoskeletal radiologist and verified by an orthopaedic surgeon (M.H.). Degenerative changes were not found. Operative chart data included MPFL graft type, presence of concomitant injuries, and concomitant procedures.[52]

The patients were examined and queried regarding redislocation, instability and subluxation events, revision surgery of the same knee, intervention for suspicion of growth disturbance, and surgery on the contralateral knee. Subjective patient outcome and knee function were obtained via Kujala, Lysholm, and Tegner scores that were based on the most recent follow-up for all patients. Patient-reported outcomes were assessed for all patients. We further assessed whether patients had returned to their preoperative preferred sports and, if so, whether they were participating in their sport at the same level, a lower level, or a higher level at the time of final follow-up compared with their preoperative status.

Statistical Analysis

Statistics (mean, standard deviation, median, range, and frequency) were analyzed for patient characteristics (including age, sex, BMI, and activity level), details of the ligamentous injury, imaging findings, operative reports, and postoperative outcome scores. All patient data were inputted and stored in Microsoft Excel (2010). Data analysis was performed using Microsoft Excel and SPSS (Version 28; IBM). The chi-square test and Fisher exact test were used to evaluate nominal data. For statistical evaluation of nonparametric data, the Mann-Whitney *U* test was used. A Student *t* test was used for parametric data. The values of preoperative and postoperative Tegner activity scores were compared using the Wilcoxon signed rank test. Continuous variables were summarized as mean, minimum, and maximum. Frequencies were used to analyze nominal and ordinal variables. Kaplan-Meier survival analyses were undertaken to delineate predicted failure rates over time (Figure 5). All measurements were made with results reported and rounded to the nearest tenth. All calculations carried the same significant digits after the decimal place until the result was reported to the nearest tenth to maintain statistical accuracy. Because

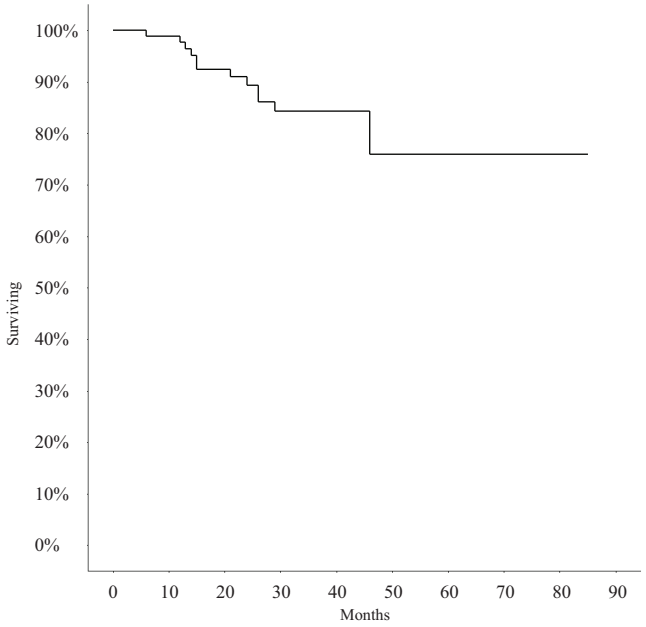

Figure 5. Kaplan-Meier survival curve showing the survival rate after medial patellofemoral ligament reconstruction in the knee.

of the explorative nature of this study, no adjustment for multiple testing was made. All statistical tests were 2-sided, and a P value $<.05$ was considered significant. The results of all statistical tests are interpreted in an exploratory sense. Unless otherwise stated, descriptive data are presented as mean ± SD (range).

RESULTS

The study population consisted of 69 skeletally immature patients (35 with open physes, 34 with partially open physes) who sustained a traumatic patellar dislocation. A total of 79 initial MPFL reconstructions were performed on 79 knees (Table 1). Eight MPFL reconstructions were performed after first-time dislocations in patients who had already experienced failure of nonoperative treatment contralaterally or required surgical intervention for concomitant pathologies such as a meniscal or ACL tear. The remaining 71 procedures were carried out after failed nonoperative treatment and recurrent dislocation. The mean age of the cohort was 14.7 ± 1.8 years (range, 8.5-16.9 years), and 46 patients (66.7%) were female. The mean follow-up after index surgery was 37.9 ± 12.1 months (range, 24-85 months) (Table 1).

Preoperative anteroposterior and lateral radiographs and MRI scans were available for all patients. The mean anatomic tibiofemoral angle as measured on a standing weightbearing image was valgus with an offset of 6° (range, 2°-8° valgus). The mean patellar height calculated using the Insall-Salvati index was 1.3 (range, 0.8-1.8). A total of 46 knees demonstrated patella alta with an Insall-Salvati index ≥1.2. The mean TT-TG distance of all 79 knees was 1.6 cm (range, 0.5-2.7 cm); 17 knees had a TT-TG distance >2 cm. Trochlear dysplasia type A defined according to Dejour was found in 29 knees; type B, in 31 knees; type C, in 9 knees; and type D, in 10 knees (Tables 1 and 2).

Sixteen knees were concomitantly treated with TTO due to an increased TT-TG distance. Four patients required distal medial femoral guided growth procedures using the OrthoPediatrics PediPlates for axis correction (Figure 2). This procedure was carried out for correction of the tibiofemoral axis and not for treatment of patellofemoral instability. In 4 patients and 5 knees, a loose osteochondral fragment was reaffixed using bioabsorbable chondral darts. Two patients were treated concomitantly with matrix-induced autologous chondrocyte implantation because of a chondral lesion of the patellar surface. One patient was treated with osteochondral allograft transplant for an osteochondral lesion of the lateral femoral condyle. One patient sustained an ACL rupture at the time of patellar luxation, which was addressed with an ACL reconstruction, and 1 patient underwent a meniscal suture (Table 1).

In total, 72 MPFL grafts were fixed in the distal medial femoral condyle using an interference screw, 5 grafts were anchored using suture anchors, and 2 grafts were fixed using EndoButtons (Arthrex).

TABLE 1
Patient Data[a]

Patient Characteristics	Parameter Value
Patients, n	69
Knees with MPFLR, n	79
Age, y	14.7 ± 1.8
Sex, n (%)	
Male	23 (33.3)
Female	46 (66.7)
Side, n (%)	
Right	37 (46.8)
Left	42 (53.2)
Body mass index	26.5 ± 6.8
Concomitant procedure, n (%)	
Meniscal suture	1 (1.3)
Tibial tubercle osteotomy	16 (20.3)
Hemiepiphysiodesis	4 (5)
Refixation of osteochondral fragment	5 (6.7)
OCA transplant	1 (1.3)
ACL reconstruction	1 (1.3)
Insall-Salvati index	1.26 ± 0.22
TT-TG distance	1.64 ± 0.48
Trochlear dysplasia, n	
Type A	29
Type B	31
Type C	9
Type D	10

[a]Data are expressed as mean ± SD unless otherwise noted. ACL, anterior cruciate ligament; MPFLR, medial patellofemoral ligament reconstruction; OCA, osteochondral allograft; TT-TG, tibial tuberosity–trochlear grove.

TABLE 2
Radiographic Parameters[a]

	Redislocation (n = 13)	No Redislocation (n = 66)	*P*
Trochlear dysplasia			.62
Type A	4 (30.8)	25 (37.9)	
Type B	6 (46.1)	25 (37.9)	
Type C	2 (15.4)	7 (10.6)	
Type D	1 (7.7)	9 (13.6)	
Trochlear dysplasia			.69
Type B or higher	9 (69.2)	41 (62.1)	
Lower than type B	4 (30.8)	25 (37.9)	
I-S, mean ± SD	1.3 ± 0.2	1.3 ± 0.2	1
Patellar height			.44
I-S <1.2	4 (44.4)	29 (78.4)	
I-S ≥1.2 (patella alta)	9 (56.6)	37 (21.6)	

[a]Data are expressed as n (%) unless otherwise noted. I-S, Insall-Salvati ratio.

Four MPFLs were reconstructed using a hamstring tendon allograft, whereas 75 reconstructions were carried out using a gracilis tendon allograft. No autografts were used in the present study.

Clinical Outcome

At the final follow-up, there were no cases of postoperative stiffness requiring intervention. The clinical assessment did not reveal any findings that suggested a postoperative axis deviation of the leg in any patient. No clinically apparent varus malalignment was encountered that would indicate an injury of the medial part of the distal femoral physes caused by the surgical procedure of MPFL reconstruction. No growth impairment was noted indicating injury of the physes. Eleven patients (15.9%) experienced a total of 13 redislocations after initial MPFL reconstruction, with 2 patients experiencing bilateral redislocation. One patient sustained a nontraumatic transverse patellar fracture 6 months after index surgery (Table 3 and Figure 5). All of these 12 patients underwent revision surgery. Six patients (7 knees) were addressed with a sole MPFL reconstruction. In all 6 patients, a new adequate trauma was the reason for recurrent dislocation, and the surgery was carried out in the same fashion as before using an allograft tendon. Two patients were treated with an MPFL reconstruction in combination with a trochleoplasty, 2 patients received an MPFL reconstruction with TTO, and 1 patient underwent open reduction and internal fixation for a patellar fracture in the setting of an intact and healed MPFL construct (Table 3).

When analyzing risk factors for failure, we noted differences for MPFL reconstruction in conjunction with TTO (n = 16) compared with MPFL reconstruction without TTO (n = 63). Eleven cases of recurrent dislocation were observed in the group that was treated with MPFL reconstruction alone, and no recurrent dislocation was noted in the TTO group ($P = .09$). In 4 patients, an ipsilateral hemiepiphysiodesis was performed concomitantly with MPFL reconstruction because of a preoperatively existing malalignment of the axis. In this group, 2 recurrent dislocations were observed, leading to a higher failure rate compared with the general study population ($P = .15$). One patient experienced failure 6 months after index surgery, and 1 patient experienced failure 25 months after hemiepiphysiodesis. The first patient had a 6° valgus knee at 8-plate implantation and a 3° valgus knee at revision, indicating that complete axis correction was not achieved at recurrent dislocation. In the second patient, neutral leg alignment was present at the time of failure. Patients with a BMI ≥25 had a significantly higher failure rate than patients with a BMI <25 ($P = .04$). We found no statistically significant relationship between failure rate and TT-TG distance, Dejour and Le Coultre dysplasia grade, Insall-Salvati ratio, and sex (Table 4; see also Appendix Figure A1, available in the online version of this article).

The mean Kujala score was 96.5 ± 7.4 (range, 62-100) at the final follow-up. The multiple linear regression model did not reveal a significant relation between Insall-Salvati index and Kujala score ($P = .72$) or preoperative TT-TG distance and Kujala score ($P = .51$) (Table 4).

The mean Lysholm score was 96.5 ± 6.7 (range, 75-100) at the final follow-up. The multiple linear regression model did not reveal a significant relation between Insall-Salvati index and Lysholm score ($P = .51$) or preoperative TT-TG distance and Lysholm score ($P = .24$) (Appendix Figure A2, available online).

TABLE 3
Complications and Reoperations[a]

Patient No.	Complication	Reoperation
1	Recurrent dislocation	Trochleoplasty, MPFL reconstruction
2	Recurrent dislocation	TTO, MPFL reconstruction
3[b]	Recurrent dislocation	MPFL reconstruction
4	Patellar fracture	Open reduction, internal fixation
5	Recurrent dislocation	MPFL reconstruction
6[b]	Recurrent dislocation	MPFL reconstruction
7[c]	Recurrent dislocation	MPFL reconstruction
8[c]	Recurrent dislocation	MPFL reconstruction
9	Recurrent dislocation	MPFL reconstruction
10	Recurrent dislocation	MPFL reconstruction
11	Recurrent dislocation	Trochleoplasty, MPFL reconstruction
12	Recurrent dislocation	TTO, MPFL reconstruction

[a]MPFL, medial patellofemoral ligament; TTO, tibial tubercle osteotomy.
[b]Bilateral recurrent dislocation.
[c]Bilateral recurrent dislocation.

TABLE 4
Multiple Linear Regression Model to Assess the Influence of Patellar Height (Insall-Salvati Index) and TT-TG on the Kujala Score[a]

	Regression Coefficient	*P*	95% CI
TT-TG	–1.26	.51	–4.92 to 2.43
Insall-Salvati	–1.65	.72	–9.80 to 6.53

[a]TT–TG, tibial tuberosity–trochlear groove distance. TT–TG represents the groove distance on the Kujala score. The Insall-Salvati index represents the influence of patellar height on the Kujala score.

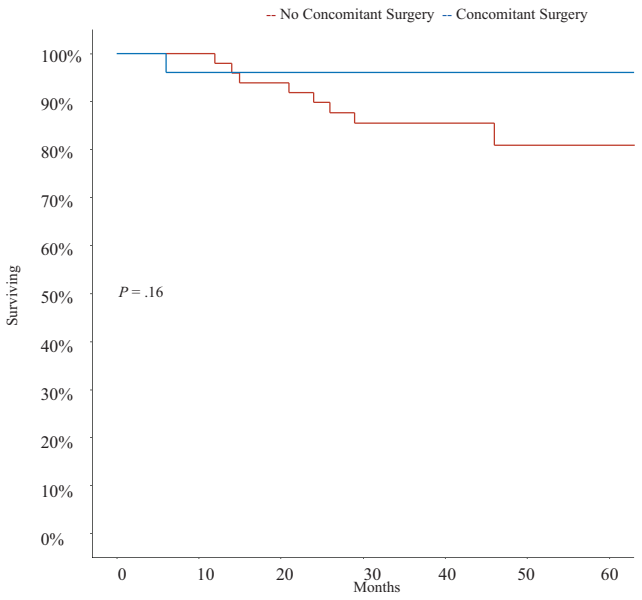

Figure 6. Kaplan-Meier survival curves showing the survival after medial patellofemoral ligament reconstruction in patients with and without concomitant procedures.

The activity levels according to the Tegner activity score were 5.0 ± 1.2 (range, 2-7) preoperatively and 4.9 ± 1.3 postoperatively (range, 2-7). The difference between the variables was not statistically significant ($P = .87$). A total of 49 patients maintained their activity level after surgery, whereas 6 patients reported a lower level of activity than preoperatively. Eight patients reached a higher activity level after MPFL reconstruction than they maintained before the injury (Appendix Figure A2, available online).

In total, 63 patients were engaged in sports preoperatively. Of these, 57 patients returned to sports postoperatively, whereas 6 patients did not reengage in sports at the time of final follow-up. Four patients stated that they quit sports due to graduation from high school and the resulting lack of organized sports events, and 2 patients reported insufficient time for athletic endeavors. No patients cited knee-related causes. The return-to-sports rate was 90.5%. The patients who returned to sports did so at a mean of 6.1 months (range, 5-13 months) after index surgery. Patients returned to a wide range of athletic activities, including recreational, high school, and Division I college level. The sports represented by this cohort included basketball (n = 5; 9%), volleyball (n = 13; 23%), soccer (n = 5; 9%), football (n = 5; 9%), wrestling (n = 3; 5%), baseball (n = 2; 4%), dancing (n = 7; 12%), track and field (n = 6; 11%), gymnastics (n = 3; 5%), and multiple sports (n = 8; 14%).

Subgroup Analysis. A total of 44 patients underwent MPFL reconstruction without concomitant procedures. Of these patients, 7 had bilateral MPFL reconstructions, resulting in a total of 51 surgeries. The mean age of the cohort was 14.3 ± 1.9 years (range, 8.5-16.8 years), and 30 patients (71.4%) were female. The mean follow-up after index surgery was 3.4 ± 1.1 years (range, 2.0-7.1 years). In this cohort, 9 patients (20.5%) experienced failure and had a redislocation. We noted no significant difference between groups with and without concomitant procedures in terms of survival ($P = .16$) (Figure 6).

TABLE 5
Univariate Analysis of the Hazards for Failure Based on Patient-Specific Variables[a]

	MPFLR Without Concomitant Surgery		
Variable	HR	95% CI	*P*
Age at index surgery	0.83	0.62-1.12	.23
Sex, male	0.81	0.16-3.92	.77
BMI	1.11	0.98-1.19	.11
BMI ≥30	2.51	0.63-10.1	.19
Laterality, right	1.65	0.14-6.62	.48
TT-TG distance	2.02	0.51-8.11	.32
TT-TG distance ≥15 mm	1.08	0.26-4.5	.92
TT-TG distance ≥20 mm	1.21	0.24-6.0	.82
I-S ratio	0.42	0.02-9.54	.59
I-S ratio ≥1.2	1.23	0.29-5.14	.78
I-S ratio ≥1.5	0.94	0.11-7.73	.96

[a]BMI, body mass index; HR, hazard ratio; I-S, Insall-Salvati; MPFLR, medial patellofemoral ligament reconstruction; TT-TG, tibial tubercle–trochlear groove.

A univariate analysis of hazards for failure based on patient-specific variables was carried out. A BMI ≥30 conveyed a hazard ratio of 2.51 (95% CI, 0.63-10.1; $P = .19$), and the TT-TG distance by increments of 1 mm was associated with a hazard ratio of 2.02 (95% CI, 0.51-8.11; $P = .32$) (Table 5 and Figure 7).

DISCUSSION

In the present study, we reported the results of anatomic reconstruction of the MPFL using exclusively allograft tendon with mostly femoral interference screw fixation distal to the open femoral physis in skeletally immature patients. This treatment modality was shown to be safe and effective in children and adolescents with open growth plates. Although MPFL reconstruction in skeletally mature patients has been shown to produce reliable and safe results, data on MPFL reconstruction in children are scarce and often limited to small case series in which autografts are used.[14,40,49,57] To the best of our knowledge, this is the largest case series to date to investigate the use of allograft tendon for anatomic MPFL reconstruction in an exclusively skeletally immature patient cohort and report patient-reported outcome scores.

The MPFL was previously found to be responsible for 40% to 80% of the medial stability of the patella, leading to the introduction of MPFL reconstruction for patellar instability 2 decades ago.[14,23,24] Before this shift of paradigm, the tibial tubercle transfer, initially described in the 1970s, was considered the best option for treatment for recurrent patellar dislocations in the presence of an elevated TT-TG distance and/or patella alta.[16] Both treatment options coexist and potentially can be combined for

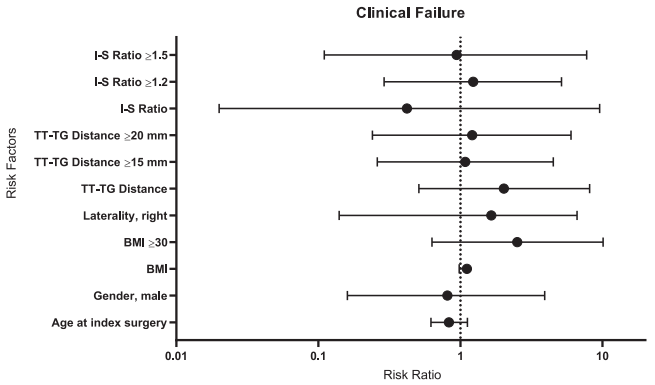

Figure 7. Forest plot displaying the risk ratio for failure by risk factor. BMI, body mass index; I-S, Insall-Salvati; TT-TG, tibial tubercle–trochlear groove.

recurrent patellar dislocation. Berton et al[11] recently demonstrated that combined MPFL reconstruction and TTO avoid focal patellar overload in the setting of elevated TT-TG distances. However, only a few studies have analyzed the results of MPFL reconstruction with and without TTO.[26,46,63] In the present study, we evaluated the subgroup of MPFL reconstruction with concomitant TTO. Secondarily, we evaluated the effect of patellar height and TT-TG on clinical results. Of 16 MPFL reconstructions performed concomitantly with TTO, no clinical failure defined as redislocation or revision was observed. These findings are consistent with previously published studies that reported excellent results of the combination therapy in adults.[26,46] No significant correlation between preoperative patellar height and TT-TG distance with clinical outcome was observed in our cohort. However, preoperative measurements were used to calculate the influence of TT-TG distance on patient-reported outcomes. It is possible that TTO in 16 cases influenced these parameters. The results correspond with the findings of former studies that did not find a causal relationship between the variables.[26,35] These findings imply that primary correction of patellar height is not necessary when performing an MPFL reconstruction.

In patients with open growth plates, the proximity of the ideal anatomic MPFL insertion point and the physes has to be taken into account, which results in a challenging femoral fixation of the MPFL and the proposed use of different fixation techniques. Lind et al[39] addressed this anatomic concern and investigated the use of femoral soft tissue graft fixation in pediatric patients. Those authors reported a revision rate of 21% after a nonbony fixation and concluded that other fixation techniques such as drill hole fixation should be considered. Nelitz et al[49] showed that using drill hole fixation in combination with a biodegradable interference screw placed distal to the physes was a safe procedure with good clinical results. The present study using an anatomic bony femoral fixation of the graft distal to the physes demonstrated excellent clinical results with no observed growth disturbance. The findings correspond to those of Camp et al,[15] who reported that failure to restore anatomic femoral insertion was the main risk factor for failure of MPFL reconstruction. If the femoral insertion point is chosen too proximal and therefore is nonanatomic, then overtightening of the MPFL in knee flexion will occur, which will lead to increased contact stress of the bony partners of the joint.[12,25] Kepler et al[37] determined the distance between the femoral MPFL insertion and the medial distal femoral growth plate on MRI scans. Those investigators showed that the femoral MPFL insertion was located 5 mm distally from the femoral growth plate, which confirms the radiographic landmarks published by Schöttle et al.[64] A large number of publications have reported results of anatomic reconstruction of the MPFL in children and adolescents. However, to the best of our knowledge, the current investigation is the largest study reporting results of anatomic reconstruction of the MPFL considering the relation between the femoral insertion point and distal femoral physis in skeletally immature patients. Femoral graft fixation was in most cases (n = 72) achieved using a biodegradable interference screw. No case of growth disturbance was clinically observed, and no further intervention was undertaken because of impaired growth of the operated extremity. These results are in line with the outcomes of other studies and indicate that bony femoral fixation distal to the femoral growth plate is a safe and reliable technique.[49,50,70] Therefore, femoral soft tissue graft fixation or nonanatomic techniques such as adductor magnus tenodesis or dynamic stabilization are not necessary to avoid injury of the femoral growth plate.[6,9,39,67]

In terms of patellar graft fixation, a variety of drill hole techniques both with and without implanted hardware have been described.[14,39,49] Regardless of tunnel size or tunnel position, high complication rates have been reported due to the smaller size of the pediatric patella compared with the adult patella.[60] An unacceptably high risk of patellar fractures stemming from the use of transverse patellar tunnels has been previously reported, indicating that alternative fixation methods are warranted.[60] In the current study, suture anchors were used in most cases to fix the allograft to the patella, resulting in a low rate of patellar fracture of 1.3% (n = 1).

Redislocation occurred in some patients, and a predictor for worse clinical outcomes was a preoperative BMI of $\geq$25. The overall complication rate of this study of 15.2% (12/79) was comparable with other studies on the subject. Schlumberger et al[61] reported on 49 skeletally immature patients treated with MPFL reconstruction and noted a complication rate of 12.2%. However, patients in that study were treated with isolated MPFL reconstruction irrespective of patellar height and trochlear dysplasia, and no concurrent procedures were performed. Furthermore, those investigators reported on outcomes after reconstruction using gracilis tendon autograft. In our cohort, 44 procedures were performed as isolated MPFL reconstructions using allograft tendon without any concomitant procedures. Patients from this cohort had a mean Lysholm score of 96.5, a Kujala score of 95.9 and a Tegner score of 4.8 at a mean follow-up of 3.4 years. Schlumberger et al reported a Tegner score of 6.3, a Lysholm score of 95.9, and a Kujala score of 97.9 at

a mean follow-up of 4.3 years. Therefore, the patient-reported outcomes of both cohorts show similar results, highlighting the stable results after the use of allograft tendon in our cohort of skeletally immature patients. Allahabadi and Pandya[3] reported a complication rate of 16.7% in a recently published small case series on isolated MPFL reconstruction in skeletally immature patients. Those investigators reported on 9 skeletally immature knees, of which 3 (33.3%) had instability events. This number is much larger than that in our cohort of isolated MPFL reconstructions, in which 20.5% of patients experienced instability events after index surgery. Shah et al[65] conducted a systematic review on MPFL reconstructions mainly in adult patients and reported an overall cumulative complication rate of 26.1%. However, Nelitz et al[49] noted no redislocations after MPFL reconstruction using a similar technique in 21 skeletally immature patients with open growth plates. The group included far fewer cases than the current study, and patients with increased femoral anteversion, genu valgum, and underlying syndromes associated with ligament laxity were excluded. A redislocation rate of 9.3% after a mean follow-up of 2.2 years was reported by Uppstrom et al[70] in their study on 49 skeletally immature patients who underwent MPFL reconstruction. In general, redislocation rates between studies are difficult to compare because of heterogeneous populations with the potential influence of torsional leg deformities and frontal leg axis. These parameters were not systematically assessed in the present study.

In the current cohort, allograft tendons were used exclusively. Gracilis tendon allografts were used in the majority of patients (n = 75), whereas 4 knees were treated with hamstring tendon allograft. In a recent review (7 studies, 132 MPFL reconstructions), Shamrock et al[66] assessed MPFL reconstruction in skeletally immature patients. All grafts included in the systematic review were autografts, and the rate of recurrent instability was 15.2%. Although clinical scores and redislocation rates were comparable with those of the present study, the use of allografts reduces morbidity, operating time, and incision length. Following this line of thought, Hohn and Pandya[34] reported on 23 pediatric and adolescent patients who underwent MPFL reconstruction with gracilis allograft for traumatic patellar instability. Those investigators found that 17% of patients had complications: 2 repeat episodes of patellar instability, 1 patellar fracture, and 1 symptomatic hardware requiring interference screw removal. No patients developed arthrofibrosis or infection. Considering the comparable results of graft types, a conclusion can be drawn that if allografts are available, their use is safe and effective and provides a viable alternative to autograft tendons.

It remains controversial whether MPFL reconstruction should be carried out as a stand-alone procedure in children and adolescents or whether concurrent procedures should be routinely performed to generate better surgical results.[18,42,43] In an effort to gather further evidence, the JUPITER (Justifying Patellar Instability Treatment by Early Results) trial was initiated as the first prospective multicenter trial to compare the safety and efficacy of (1) nonoperative treatment, (2) isolated MPFL reconstruction, and (3) individualized surgical approach to treat patellar instability with a combination of MPFL reconstruction and concomitant procedures.[27,28] The final results of the JUPITER study are currently outstanding. In the present study, we did not see significant differences in terms of failures and survival in the subgroup analysis of our cohorts treated with MPFL reconstruction alone or with MPFL reconstruction in combination with other procedures.

A major strength of this study is the large number of included skeletally immature patients. All patients were assessed using preoperative MRI, and growth plate status was determined via review of tomography sequences. Another factor rendering this study relevant is the availability of preoperative MRI scans and radiographs for all examined patients, allowing for assessment of potentially relevant risk factors for patellofemoral instability. Furthermore, conclusive clinical follow-up with a mean of 37.9 months was provided for all patients. However, several limitations must be acknowledged. The study is limited by its unblinded and retrospective design. Furthermore, only mid-term results were available, so no conclusion can be drawn regarding long-term stability rates. Another limitation of the study design is the lack of a control group. As pointed out above, MPFL reconstruction has been established as the standard procedure for patellofemoral instability. Historically performed procedures, such as patellar reefing and lateral release, have been abandoned as a stand-alone form of therapy. Therefore, no control group was available or created, due to the lack of alternative treatment modalities with promising outcomes.

The current study highlights the excellent clinical results that can be achieved with MPFL reconstruction using a tendon allograft with bony fixation in the femoral socket distal to the physes in skeletally immature patients. However, redislocation and recurrent instability are complications that occur in roughly 15% of patients. These results may provide the surgeon with evidence when counseling patients and parents on treatment decisions and help in reaching a shared decision considering the expected results.

CONCLUSION

Anatomic reconstruction of the MPFL using an allograft tendon is a safe and effective treatment for patellofemoral instability in skeletally immature patients, irrespective of patellar height and trochlear dysplasia. The procedure results in high clinical satisfaction based on Lysholm, Kujala, and Tegner scores and permits patients to return to organized sports regularly within a short amount of time. When MPFL reconstruction is carried out in combination with TTO in the setting of an elevated TT-TG distance, excellent results can be expected. Redislocation still occurs in a certain number of patients, and a higher BMI is a predictor of a worse clinical outcome.

ORCID iDs

Martin Husen https://orcid.org/0000-0002-2852-9542
Aaron J. Krych https://orcid.org/0000-0003-3248-8007

REFERENCES

1. Aarimaa V, Ranne J, Mattila K, et al. Patellar tendon shortening after treatment of patellar instability with a patellar tendon medialization procedure. *Scand J Med Sci Sports*. 2008;18(4):442-446.
2. Abraham E, Washington E, Huang TL. Insall proximal realignment for disorders of the patella. *Clin Orthop Relat Res*. 1989;248:61-65.
3. Allahabadi S, Pandya NK. Allograft medial patellofemoral ligament reconstruction in adolescent patients results in a low recurrence rate of patellar dislocation or subluxation at midterm follow-up. *Arthroscopy*. 2022;38(1):128-138.
4. Allen BJ, Krych AJ, Engasser W, et al. Medial patellofemoral ligament tears in the setting of multiligament knee injuries rarely cause patellar instability. *Am J Sports Med*. 2015;43(6):1386-1390.
5. Allen MM, Krych AJ, Johnson NR, et al. Combined tibial tubercle osteotomy and medial patellofemoral ligament reconstruction for recurrent lateral patellar instability in patients with multiple anatomic risk factors. *Arthroscopy*. 2018;34(8):2420-2426.
6. Alm L, Krause M, Mull C, Frosch KH, Akoto R. Modified adductor sling technique: a surgical therapy for patellar instability in skeletally immature patients. *Knee*. 2017;24(6):1282-1288.
7. Askenberger M, Bengtsson Mostrom E, Ekstrom W, et al. Operative repair of medial patellofemoral ligament injury versus knee brace in children with an acute first-time traumatic patellar dislocation: a randomized controlled trial. *Am J Sports Med*. 2018;46(10):2328-2340.
8. Barrera Oro F, Sikka RS, Wolters B, et al. Autograft versus allograft: an economic cost comparison of anterior cruciate ligament reconstruction. *Arthroscopy*. 2011;27(9):1219-1225.
9. Becher C, Kley K, Lobenhoffer P, et al. Dynamic versus static reconstruction of the medial patellofemoral ligament for recurrent lateral patellar dislocation. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(10):2452-2457.
10. Benoit B, Laflamme GY, Laflamme GH, et al. Long-term outcome of surgically-treated habitual patellar dislocation in children with coexistent patella alta: minimum follow-up of 11 years. *J Bone Joint Surg Br*. 2007;89(9):1172-1177.
11. Berton A, Salvatore G, Nazarian A, et al. Combined MPFL reconstruction and tibial tuberosity transfer avoid focal patella overload in the setting of elevated TT-TG distances. *Knee Surg Sports Traumatol Arthrosc*. Published online July 12, 2022. doi:10.1007/s00167-022-07056-6
12. Bicos J, Fulkerson JP, Amis A. Current concepts review: the medial patellofemoral ligament. *Am J Sports Med*. 2007;35(3):484-492.
13. Bishop ME, Black SR, Nguyen J, Mintz D, Stein BS. A simple method of measuring the distance from the Schöttle point to the medial distal femoral physis with MRI. *Orthop J Sports Med*. 2019;7(4):2325967119840713.
14. Buckens CF, Saris DB. Reconstruction of the medial patellofemoral ligament for treatment of patellofemoral instability: a systematic review. *Am J Sports Med*. 2010;38(1):181-188.
15. Camp CL, Krych AJ, Dahm DL, Levy BA, Stuart MJ. Medial patellofemoral ligament repair for recurrent patellar dislocation. *Am J Sports Med*. 2010;38(11):2248-2254.
16. Caton JH, Dejour D. Tibial tubercle osteotomy in patello-femoral instability and in patellar height abnormality. *Int Orthop*. 2010;34(2):305-309.
17. Chrisman OD, Snook GA, Wilson TC. A long-term prospective study of the Hauser and Roux-Goldthwait procedures for recurrent patellar dislocation. *Clin Orthop Relat Res*. 1979;144:27-30.
18. Dall'Oca C, Elena N, Lunardelli E, Ulgelmo M, Magnan B. MPFL reconstruction: indications and results. *Acta Biomed*. 2020;91(4)(suppl):128-135.
19. Davis DK, Fithian DC. Techniques of medial retinacular repair and reconstruction. *Clin Orthop Relat Res*. 2002;402:38-52.
20. Dejour D, Le Coultre B. Osteotomies in patello-femoral instabilities. *Sports Med Arthrosc Rev*. 2007;15(1):39-46.
21. Dejour H, Walch G, Neyret P, Adeleine P. Dysplasia of the femoral trochlea. Article in French. *Rev Chir Orthop Reparatrice Appar Mot*. 1990;76(1):45-54.
22. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. *Knee Surg Sports Traumatol Arthrosc*. 1994;2(1):19-26.
23. Desio SM, Burks RT, Bachus KN. Soft tissue restraints to lateral patellar translation in the human knee. *Am J Sports Med*. 1998;26(1):59-65.
24. Earhart C, Patel DB, White EA, et al. Transient lateral patellar dislocation: review of imaging findings, patellofemoral anatomy, and treatment options. *Emerg Radiol*. 2013;20(1):11-23.
25. Elias JJ, Cosgarea AJ. Technical errors during medial patellofemoral ligament reconstruction could overload medial patellofemoral cartilage: a computational analysis. *Am J Sports Med*. 2006;34(9):1478-1485.
26. Enderlein D, Nielsen T, Christiansen SE, Fauno P, Lind M. Clinical outcome after reconstruction of the medial patellofemoral ligament in patients with recurrent patella instability. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(10):2458-2464.
27. Fabricant PD, Heath MR, Mintz DN, et al. Many radiographic and magnetic resonance imaging assessments for surgical decision making in pediatric patellofemoral instability patients demonstrate poor interrater reliability. *Arthroscopy*. 2022;38(9):2702-2713.
28. Fabricant PD, Heath MR, Veerkamp M, et al. Reliability of radiologic assessments of clinically relevant growth remaining in knee MRI of children and adolescents with patellofemoral instability: data from the JUPITER cohort. *Orthop J Sports Med*. 2021;9(4):2325967121991110.
29. Flanigan DC, Shemory S, Lundy N, et al. Medial patellofemoral ligament reconstruction with allograft versus autograft tissue results in similar recurrent dislocation risk and patient-reported outcomes. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(7):2099-2104.
30. Gausden EB, Fabricant PD, Taylor SA, et al. Medial patellofemoral reconstruction in children and adolescents. *JBJS Rev*. 2015;3(10):e2.
31. Gerbino PG, Zurakowski D, Soto R, et al. Long-term functional outcome after lateral patellar retinacular release in adolescents: an observational cohort study with minimum 5-year follow-up. *J Pediatr Orthop*. 2008;28(1):118-123.
32. Greis PE, Koch BS, Adams B. Tibialis anterior or posterior allograft anterior cruciate ligament reconstruction versus hamstring autograft reconstruction: an economic analysis in a hospital-based outpatient setting. *Arthroscopy*. 2012;28(11):1695-1701.
33. Hennrikus W, Pylawka T. Patellofemoral instability in skeletally immature athletes. *J Bone Joint Surg Am*. 2013;95(2):176-183.
34. Hohn E, Pandya NK. Does the utilization of allograft tissue in medial patellofemoral ligament reconstruction in pediatric and adolescent patients restore patellar stability? *Clin Orthop Relat Res*. 2017;475(6):1563-1569.
35. Howells NR, Barnett AJ, Ahearn N, Ansari A, Eldridge JD. Medial patellofemoral ligament reconstruction: a prospective outcome assessment of a large single centre series. *J Bone Joint Surg Br*. 2012;94(9):1202-1208.
36. Insall J, Bullough PG, Burstein AH. Proximal ''tube'' realignment of the patella for chondromalacia patellae. *Clin Orthop Relat Res*. 1979;144:63-69.
37. Kepler CK, Bogner EA, Hammoud S, et al. Zone of injury of the medial patellofemoral ligament after acute patellar dislocation in children and adolescents. *Am J Sports Med*. 2011;39(7):1444-1449.
38. Kyung HS, Kim HJ. Medial patellofemoral ligament reconstruction: a comprehensive review. *Knee Surg Relat Res*. 2015;27(3):133-140.
39. Lind M, Enderlein D, Nielsen T, Christiansen SE, Fauno P. Clinical outcome after reconstruction of the medial patellofemoral ligament in paediatric patients with recurrent patella instability. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(3):666-671.

40. Lind M, Jakobsen BW, Lund B, Christiansen SE. Reconstruction of the medial patellofemoral ligament for treatment of patellar instability. *Acta Orthop*. 2008;79(3):354-360.
41. Lippacher S, Dejour D, Elsharkawi M, et al. Observer agreement on the Dejour trochlear dysplasia classification: a comparison of true lateral radiographs and axial magnetic resonance images. *Am J Sports Med*. 2012;40(4):837-843.
42. Liu Z, Yi Q, He L, et al. Comparing nonoperative treatment, MPFL repair, and MPFL reconstruction for patients with patellar dislocation: a systematic review and network meta-analysis. *Orthop J Sports Med*. 2021;9(9):23259671211026624.
43. Martin RK, Leland DP, Krych AJ, Dahm DL. Treatment of first-time patellar dislocations and evaluation of risk factors for recurrent patellar instability. *Sports Med Arthrosc Rev*. 2019;27(4):130-135.
44. Matuszewski L, Trams M, Ciszewski A, et al. Medial patellofemoral ligament reconstruction in children: a comparative randomized short-term study of fascia lata allograft and gracilis tendon autograft reconstruction. *Medicine (Baltimore)*. 2018;97(50):e13605.
45. Mousinho R, Ribeiro JNA, Pedrosa FKS, et al. Evaluation of the reproducibility of the Dejour classification for femoropatellar instability. *Rev Bras Ortop (Sao Paulo)*. 2019;54(2):171-177.
46. Mulliez A, Lambrecht D, Verbruggen D, et al. Clinical outcome in MPFL reconstruction with and without tuberositas transposition. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(9):2708-2714.
47. Nakamura N, Horibe S, Sasaki S, et al. Evaluation of active knee flexion and hamstring strength after anterior cruciate ligament reconstruction using hamstring tendons. *Arthroscopy*. 2002;18(6):598-602.
48. Nelitz M, Dornacher D, Dreyhaupt J, Reichel H, Lippacher S. The relation of the distal femoral physis and the medial patellofemoral ligament. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(12):2067-2071.
49. Nelitz M, Dreyhaupt J, Reichel H, Woelfle J, Lippacher S. Anatomic reconstruction of the medial patellofemoral ligament in children and adolescents with open growth plates: surgical technique and clinical outcome. *Am J Sports Med*. 2013;41(1):58-63.
50. Nelitz M, Dreyhaupt J, Williams SRM. No growth disturbance after trochleoplasty for recurrent patellar dislocation in adolescents with open growth plates. *Am J Sports Med*. 2018;46(13):3209-3216.
51. Nelitz M, Theile M, Dornacher D, et al. Analysis of failed surgery for patellar instability in children with open growth plates. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(5):822-828.
52. Outerbridge RE. The etiology of chondromalacia patellae. *J Bone Joint Surg Br*. 1961;43:752-757.
53. Park MS, Chung CY, Lee KM, Lee SH, Choi IH. Which is the best method to determine the patellar height in children and adolescents? *Clin Orthop Relat Res*. 2010;468(5):1344-1351.
54. Petri M, von Falck C, Broese M, et al. Influence of rupture patterns of the medial patellofemoral ligament (MPFL) on the outcome after operative treatment of traumatic patellar dislocation. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(3):683-689.
55. Popkin CA, Bayomy AF, Trupia EP, Chan CM, Redler LH. Patellar instability in the skeletally immature. *Curr Rev Musculoskelet Med*. 2018;11(2):172-181.
56. Ronga M, Oliva F, Longo UG, et al. Isolated medial patellofemoral ligament reconstruction for recurrent patellar dislocation. *Am J Sports Med*. 2009;37(9):1735-1742.
57. Rueth MJ, Koehl P, Schuh A, Goyal T, Wagner D. Return to sports and short-term follow-up of 101 cases of medial patellofemoral ligament reconstruction using gracilis tendon autograft in children and adolescents. *Arch Orthop Trauma Surg*. 2023;143(1):447-452.
58. Sanders TL, Pareek A, Hewett TE, et al. High rate of recurrent patellar dislocation in skeletally immature patients: a long-term population-based study. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(4):1037-1043.
59. Saper MG, Fantozzi P, Bompadre V, Racicot M, Schmale GA. Return-to-sport testing after medial patellofemoral ligament reconstruction in adolescent athletes. *Orthop J Sports Med*. 2019;7(3):2325967119828953.
60. Schiphouwer L, Rood A, Tigchelaar S, Koeter S. Complications of medial patellofemoral ligament reconstruction using two transverse patellar tunnels. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(1):245-250.
61. Schlumberger M, Schuster P, Hofmann S, et al. Midterm results after isolated medial patellofemoral ligament reconstruction as first-line surgical treatment in skeletally immature patients irrespective of patellar height and trochlear dysplasia: response. *Am J Sports Med*. 2022;50(8):NP34-NP36.
62. Schmiesing A, Engelking M, Agel J, Arendt EA. Distalization of the tibial tubercle for patellar stabilization combined with medial patellofemoral ligament reconstruction: length of distalization or residual patella alta and its affect on outcome. *Am J Sports Med*. 2022;50(6):1627-1634.
63. Schöttle PB, Fucentese SF, Romero J. Clinical and radiological outcome of medial patellofemoral ligament reconstruction with a semitendinosus autograft for patella instability. *Knee Surg Sports Traumatol Arthrosc*. 2005;13(7):516-521.
64. Schöttle PB, Schmeling A, Rosenstiel N, Weiler A. Radiographic landmarks for femoral tunnel placement in medial patellofemoral ligament reconstruction. *Am J Sports Med*. 2007;35(5):801-804.
65. Shah JN, Howard JS, Flanigan DC, et al. A systematic review of complications and failures associated with medial patellofemoral ligament reconstruction for recurrent patellar dislocation. *Am J Sports Med*. 2012;40(8):1916-1923.
66. Shamrock AG, Day MA, Duchman KR, Glass N, Westermann RW. Medial patellofemoral ligament reconstruction in skeletally immature patients: a systematic review and meta-analysis. *Orthop J Sports Med*. 2019;7(7):2325967119855023.
67. Sillanpää PJ, Mäenpää HM, Mattila VM, Visuri T, Pihlajamäki H. A mini-invasive adductor magnus tendon transfer technique for medial patellofemoral ligament reconstruction: a technical note. *Knee Surg Sports Traumatol Arthrosc*. 2009;17(5):508-512.
68. Steensen RN, Dopirak RM, Maurus PB. A simple technique for reconstruction of the medial patellofemoral ligament using a quadriceps tendon graft. *Arthroscopy*. 2005;21(3):365-370.
69. Steiner TM, Torga-Spak R, Teitge RA. Medial patellofemoral ligament reconstruction in patients with lateral patellar instability and trochlear dysplasia. *Am J Sports Med*. 2006;34(8):1254-1261.
70. Uppstrom TJ, Price M, Black S, et al. Medial patellofemoral ligament (MPFL) reconstruction technique using an epiphyseal femoral socket with fluoroscopic guidance helps avoid physeal injury in skeletally immature patients. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(11):3536-3542.
71. Vahasarja V, Kinnunen P, Lanning P, Serlo W. Operative realignment of patellar malalignment in children. *J Pediatr Orthop*. 1995;15(3):281-285.
72. Vavken P, Wimmer MD, Camathias C, et al. Treating patella instability in skeletally immature patients. *Arthroscopy*. 2013;29(8):1410-1422.
73. Verhulst FV, van Sambeeck JDP, Olthuis GS, van der Ree J, Koeter S. Patellar height measurements: Insall-Salvati ratio is most reliable method. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(3):869-875.
74. Zeichen J, Lobenhoffer P, Gerich T, Tscherne H, Bosch U. Medium-term results of the operative treatment of recurrent patellar dislocation by Insall proximal realignment. *Knee Surg Sports Traumatol Arthrosc*. 1999;7(3):173-176.