Anatomic Reconstruction of the Medial Patellofemoral Ligament in Children and Adolescents With Open Growth Plates

Surgical Technique and Clinical Outcome

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Background: Recurrent lateral patellar dislocation is a common knee injury in the skeletally immature adolescent. Because of the open physis, operative therapy in children is challenging. This study presents the outcomes of a minimally invasive technique for anatomic reconstruction of the medial patellofemoral ligament (MPFL) in children that respects the distal femoral physis.

Hypothesis: Anatomic reconstruction of the MPFL in children that maintains the distal femoral physis will prevent redislocation, preserve the distal femoral physis, and improve knee function.

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

Methods: Twenty-one consecutive patients with patellofemoral instability and open growth plates underwent anatomic reconstruction of the MPFL that maintained the distal femoral growth plate. Preoperative radiographic examination included AP and lateral views to assess patella alta and limb alignment. Magnetic resonance imaging was performed to evaluate trochlear dysplasia and tibial tubercle–trochlear groove (TT-TG) distance. Evaluation included preoperative and postoperative physical examination, Kujala score, and Tegner activity score.

Results: The average age at the time of operation was 12.2 years (range, 10.3-13.9). The average follow-up after operation was 2.8 years after surgery (range, 2.0-3.6). No recurrent dislocation occurred, but 2 patients with high-grade trochlear dysplasia still had a positive apprehension sign. The Kujala score significantly improved from 72.9 (range, 37-87) preoperatively to 92.8 (range, 74-100) postoperatively ($P < .01$). The Tegner activity score decreased, but not significantly, from 6.0 (range, 3-9) preoperatively to 5.8 (range, 3-9) postoperatively ($P = .48$).

Conclusion: Anatomic reconstruction of the MPFL that respects the distal femoral physis in skeletally immature patients is a safe and effective technique for the treatment of patellofemoral instability and allows patients to return to sports without redislocation of the patella.

Keywords: medial patellofemoral ligament; open growth plate; patellofemoral instability; children and adolescents

Recurrent lateral patellar dislocation is a common knee injury in the skeletally immature adolescent. Cash and Hughston[11] found a recurrence rate of 60% in patients younger than 14 years, which underlines the high risk in young active individuals. The dislocation causes a traumatic disruption of the previously uninjured medial patellofemoral ligament (MPFL), a part of the medial parapatellar structures.[28] The stabilizing role of the MPFL as the main restraining force to lateral displacement of the patella has been emphasized by many authors.[4,28] In adults, reconstruction of the patellofemoral ligament has shown good results.[3,7,9,31] Different authors have emphasized the need for an anatomic reconstruction with tightening of the MPFL in knee flexion when the femoral origin is placed too proximally.[7,16,38] In children, good results have been reported from operative procedures such as the technique described by Insall et al,[19] the lateral release, and the Roux-Goldthwait procedure.[2,12,21,24] However, other authors have reported a high rate of complications such as redislocation of the patella, patella infera, or

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nerve injury.[1,2,6,17,27,40] Because reconstruction of the MPFL is a more anatomic procedure, it has been advocated as the treatment of choice in skeletally immature patients.[8,14,37] Because of the adjacent physis of the femoral insertion of the MPFL, different nonanatomic techniques have been described.[8,14,37] It has been shown that the femoral insertion of the MPFL is distal to the femoral physis.[22,25] As several authors have noted the importance of an anatomic repair that respects the femoral and patellar insertion of the ligament, this prospective study evaluated the results of anatomic, physeal-sparing reconstruction of the MPFL in children and adolescents with open growth plates after a minimum follow-up of 2 years.

MATERIALS AND METHODS

Patients

This study was approved by the ethics committee of the institution. Twenty-two children were treated with anatomic reconstruction of the MPFL between 2008 and 2009 because of recurrent patellar dislocation. Inclusion criteria were skeletally immature children with open growth plates who had experienced at least 2 recurrent dislocations of the patella despite a nonoperative treatment program. Patients with a structural anatomic predisposition to patellar instability were excluded from the study because increased femoral anteversion or genu valgum was present. Femoral anteversion was measured clinically according to the technique described by Ruwe et al[32]; patients were in the prone position with their knees flexed to 90°. An anteversion greater than 40° was an exclusion criterion. Patients with increased genu valgum greater than 9° as measured on an AP weightbearing radiograph were excluded from the study as well. We further excluded patients with underlying syndromes with ligamentous laxity such as Down syndrome. Four patients had undergone previous surgery before MPFL reconstruction. In 2 patients a medial reefing and in another 2 patients lateral release and medial reefing had been performed.

Only patients with a minimum follow-up of 2 years were included in this study. One patient was lost to follow-up, resulting in a cohort of 21 patients (15 men and 6 women) with 21 MPFL reconstructions.

Surgical Technique

Before surgery, every patient's knee was examined clinically under anesthesia, and a diagnostic arthroscopy was performed to rule out intra-articular lesions.

After the diagnostic arthroscopy, an oblique incision was made along the pes anserinus. After the fascia was exposed, the gracilis tendon was harvested proximally with a tendon stripper. Distally the tendon was sharply detached from the tibia. The tendon was prepared with a Vicryl suture (Ethicon Products, Norderstedt, Germany) on both ends.

A longitudinal incision was made over the medial proximal two-thirds of the patella. The medial border of the patella was exposed subperiosteally; injury of the joint capsule was avoided. Two converging V-shaped tunnels were drilled to the depth of about 1.5 cm at the superomedial half of the patella with sufficient distance between tunnels to avoid fracturing. The graft was then inserted into the tunnel, forming a loop through the patella.[26]

By blunt dissection, the interval between the capsule and the vastus medialis obliquus was developed to the femoral insertion of the MPFL. With the indirect radiographic method described by Schöttle et al,[35] the anatomic femoral insertion of the MPFL was identified under fluoroscopic control. A guide pin was placed at the femoral insertion. Fluoroscopy was used to confirm that placement of the guide pin maintained the distal femoral physis. Because of the concave curvature of the distal femoral physis, the lateral radiograph alone can be misleading to determine the relation between the distal femoral physis and the medial patellofemoral ligament.[13,25] The cross-reference onto an AP view shows that the same point that is projected on or proximal to the physis on the lateral view is located distally to the physis on the AP view (Figure 1). After verification of the entry point, the guide pin was drilled to the lateral condyle distal to the physis. A medial blind tunnel was drilled along the guide pin to accommodate a double thickness of graft to an adequate depth to allow optimal graft tensioning. The graft was then pulled between the second and third layer to the femoral insertion point.

A locking suture was passed through the transepicondylar axis to pull the graft into the medial tunnel. The knee was cycled several times from full flexion to full extension with the graft under tension. A bioresorbable interference screw was then used to secure the graft within the medial condyle tunnel with the knee flexed to 30° (Figure 2). Finally, the aponeurosis of the vastus medialis obliquus was sutured back to the patella, with further closure of subcutaneous tissues and skin. Routine dressings and bandages were applied.

Rehabilitation

Postoperatively, partial weightbearing using crutches was allowed. Daily physical therapy with active and passive flexion and extension exercises of the knee, strengthening of the vastus medialis muscle, and straight leg–raising exercises were recommended for 15 minutes 4 times a day. Full weightbearing was allowed at 2 weeks and return to sport at the third postoperative month.

Evaluation Methods

Preoperative radiographic examination of the knee included AP (standing, weightbearing) and lateral views to assess patella alta and signs of malalignment and to exclude further skeletal abnormalities. Patellar height was measured on lateral radiographs with the method described by Insall and Salvati,[20] because it has shown to be the most reliable.[30]

In all patients, trochlear dysplasia and the distance between the tibial tuberosity and the trochlear groove and (TT-TG) were evaluated by magnetic resonance imaging (MRI). To assess trochlear dysplasia, axial MRI scans (fat-saturated, proton-density weighted, fast spin-echo

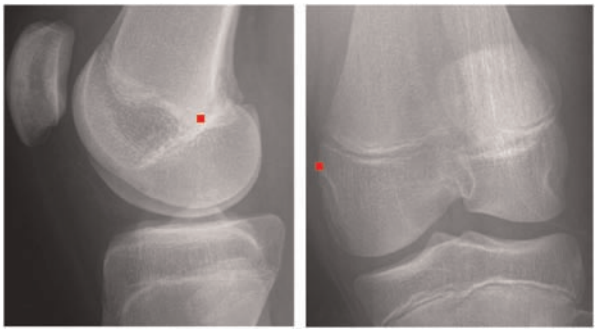

Figure 1. Cross-reference of the physis on the lateral view onto an AP view shows that the same point (dot) that is projected on or proximal to the physis on the lateral view is distal to the physis on the AP view.

imaging sequence, Siemens 1.5-T VA17A–Symphony, A Tim System; Munich, Germany) of the most proximal craniocaudal transverse magnetic resonance image on which the cartilage along the entire width of the trochlea was visible were performed. Trochlear dysplasia was classified according to Dejour and Le Coultre.[15] The TT-TG measurement was performed on superimposed axial slices.

Preoperative and postoperative knee assessment included clinical examination and assessment of symptoms, range of motion, and patellar apprehension. The clinical assessment of the leg axis at follow-up was carried out in a standardized fashion. Patients stood barefoot with knees fully extended, patellae facing forward, and feet in a neutral position at hip width apart. Knee function was assessed with the Kujala score[23] and Tegner activity score.[39] Although the Tegner activity score is not validated for children, it is a helpful tool to compare sporting activity preoperatively and postoperatively. Patient satisfaction with the procedure was recorded. Additionally, we 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 follow-up compared with preoperatively. The final clinical outcome was rated as very satisfied (knee function much exceeded their preoperative status), satisfied (knee function improved with no subluxation), partially satisfied (knee function improved but still apprehensive), or not satisfied (knee function same as preoperative status with 1 or more episodes of patellar subluxation).

Statistical Analysis

Continuous variables were summarized as mean, minimum, and maximum. Frequencies were used to analyze nominal and ordinal variables. The values of preoperative and postoperative Tegner activity score and the Kujala score were compared using the Wilcoxon signed rank test. The influence of patellar height and TT-TG on Kujala score was investigated with a multiple linear regression model. Statistical analyses were carried out using SAS 9.2 (SAS Institute, Cary, North Carolina). Because of the explorative nature of this study, no adjustment for multiple testing was made. A P value less than .05 was considered significant. The results of all statistical tests are interpreted in an exploratory sense.

Figure 2. After identification of the entry point, a bioresorbable interference screw is used to secure the graft within the medial condyle distal to the physis.

RESULTS

The mean age at the time of operation was 12.2 years (range, 10.3-13.9). The average follow-up after operation was 2.8 years after surgery (range, 2.0-3.6).

Preoperative AP and lateral radiographs and MRI were available for all patients. The mean anatomic tibiofemoral angle as measured on a standing weightbearing film was 6° (range, 3°-9°). The mean patellar height by the Insall-Salvati index was 1.2 (range, 1.0-1.3). Two children demonstrated patella alta with an Insall-Salvati index of greater than 1.2. The mean TT-TG of all 21 patients was 1.6 cm (range, 1.1-2.2); 3 patients had a TT-TG greater than 2 cm. Trochlear dysplasia type A defined according to Dejour was found in 1 patient, type B in 10 patients, type C in 4 patients, and type D in 6 patients (Table 1).

Preoperative physical examination showed a positive apprehension sign in all patients. The J-sign was positive in 16 of 21 patients. At arthroscopy, superficial chondral lesions of the lateral femoral condyle were observed in 8 patients. Two patients required microfracturing because of full-thickness chondral lesions.

Clinical Outcome

Fourteen patients indicated that they were very satisfied with the surgical procedure, 4 patients were satisfied,

TABLE 1
Patient Characteristics

Age, mean (range), y	15.0 (14.4-16.4)
Age at time of primary surgery, mean (range), y	12.2 (10.3-13.9)
No. of girls	6
No. of boys	15
No. of previous operations	4
Mechanical axis, mean (range), deg	6 (3-9)
Insall-Salvati index, mean (range)	1.2 (1.0-1.3)
TT-TG distance, mean (range), cm	1.6 (1.1-2.2)
Trochlear dysplasia, No.	
Type A	1
Type B	10
Type C	4
Type D	6

and 3 were partially satisfied. Two of these latter 3 patients had high-grade trochlear dysplasia (type D). They additionally exhibited a positive J-sign and a positive apprehension sign. No patient was dissatisfied with the procedure, and no redislocation of the patella occurred. Four patients complained of pain during vigorous activities, but none used any pain medication. At follow-up, all knees had regained full extension and flexion. Clinical assessment did not reveal an axis deviation of the leg in any patient. No varus malalignment was encountered that would indicate an injury of the medial part of the distal femoral physis.

The average Kujala score improved significantly from 72.9 (range, 37-87) preoperatively to 92.8 (range, 74-100) at follow-up ($P < .01$) (Table 2). The multiple linear regression model did not reveal a significant relation between TT-TG versus difference in Kujala score and patellar height versus difference in Kujala score. The P values were .37 and .43, respectively (Table 3).

The activity levels according to the Tegner activity score decreased from 6.0 (range, 3-9) preoperatively to 5.8 postoperatively (range, 3-9), which was not statistically significant ($P = .48$) (Table 2). In 14 of 21 patients, no change in the Tegner activity score from preoperative to postoperative time points was visible. In 4 patients the Tegner activity score decreased, and in 3 patients the Tegner activity score improved from preoperative to postoperative time points.

Three patients returned to sports at a higher level than preoperatively. Fourteen patients returned to sport at their preoperative level, and only 4 participated in sports on a lower level than preoperatively. In 2 patients the reason given for participation at a lower level than preoperatively was fear of reinjury, whereas in the other 2 patients the reason was lack of time or interest.

For those who returned to organized sports, the mean time from the operation to return to sport was 5.3 months (range, 4-12).

Complications

One patient required a prolonged rehabilitation with reduced flexion 6 weeks after surgery. Full range of motion was achieved after an intensified physical therapy program.

TABLE 2
Comparison of Tegner Activity Score and Kujala Knee Function Score Before and After Medial Patellofemoral Ligament Reconstruction[a]

	Preoperative	Postoperative	P Value[b]
Tegner score	6.0 (3-9)	5.8 (3-9)	.48
Kujala score	72.9 (37-87)	92.8 (74-100)	<.01

[a]Values are expressed as average (range).
[b]P significant at <.05 (Wilcoxon signed rank test).

TABLE 3
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 Value	95% CI
TT-TG	1.17	.37	−1.51 to 3.86
Insall-Salvati	4.97	.43	−7.89 to 17.83

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

DISCUSSION

In the present prospective study, anatomic reconstruction of the medial patellofemoral ligament was shown to be a safe and effective procedure for the treatment of recurrent patellar dislocation in children and adolescents with open growth plates. As Palmu et al[29] reported, redislocations typically occur within 2 years after surgery; hence, a minimum follow-up of 2 years was considered to be essential.

The need for an anatomic reconstruction is now widely accepted. If the femoral origin is too proximal, tightening of the MPFL in knee flexion with concomitant increased contact stress will occur.[7,16,38] Camp et al[10] found the failure to restore the anatomic femoral insertion to be a main risk factor for the failure of MPFL reconstruction.

Because of the adjacent physis, anatomic reconstruction of the MPFL is challenging in the skeletally immature adolescent. On MRI scan, Kepler et al[22] measured the distance between the MPFL insertion onto the distal femur and the medial distal femoral growth plate or physeal scar. The femoral MPFL insertion averaged 5 mm distal to the femoral growth plate. A radiographic study that used the radiographic landmarks described by Schöttle et al[35] confirmed the results of Kepler et al.[22] The authors have shown that the origin of the MPFL as seen on the AP view was on average 6.4 mm (range, 2.9-8.5) distal to the femoral physis.[25] For patients with open physis, this means that an insertion proximal to the physis has to be strictly avoided because it can create increased medial patellofemoral pressure.[16,38] Shea et al[36] found the MPFL origin to be just proximal to the femoral physis in children who approached skeletal maturity. Because the authors did not consider the concave curvature of the physis, their conclusion was incorrect.

Although numerous publications have reported results after anatomic reconstruction of the MPFL in adults, to our knowledge this is the first prospective study reporting the results of anatomic reconstruction of the MPFL considering the relation of its femoral insertion to the distal femoral physis.

Deie et al[14] described good results after nonanatomic MPFL reconstruction in children between 6 and 10 years of age. Those investigators chose the posterior one-third of the proximal attachment of the MCL as the site for pulley. Brown and Ahmad[8] described a technique for skeletally immature patients involving combined medial patellofemoral ligament and medial patellotibial ligament reconstruction that left the insertion of the semitendinosus tendon intact. They sutured the free limb to the MCL as proximally as possible. Both of these techniques can produce an inadvertent distalization of the patella, even if it is not needed. Sillanpää et al[37] described a technique for children using a free graft wrapped around the adductor magnus tendon.

None of the described techniques is strictly anatomic, as they use the femoral insertion of the MCL or of the adductor magnus tendon as a reference for the femoral insertion of the MPFL. In a detailed anatomic study, Baldwin[5] showed that the adductor tubercle provides exclusive attachment for the adductor magnus tendon and that the medial epicondyle provides specific attachment for the MCL, whereas the insertion of the MPFL is found in a groove between these 2 landmarks. With these nonanatomic techniques, it is difficult to maintain accurate tension of the graft during fixation.

The technique described in this study has 2 major advantages. First, it reconstructs the anatomy of the MPFL and at the same time does not affect the distal femoral physis. To avoid injury of the physis, the clinician must check the femoral insertion as well as the direction of the blind hole radiographically on lateral and AP view. Because the femoral insertion of the MPFL is distal to the physis, the bone tunnel has to be strictly in the epiphysis. Standardized clinical assessment at follow-up did not reveal an axis deviation of the leg in any patient: Because different studies[18,33] have shown that frontal plane alignment measurement with the described method is a valid surrogate for the radiographic gold standard, we did not perform radiographs at follow-up. Second, the technique described in the present study technique uses a sling through the proximal half of the patella, which recreates the double-bundle structure of the MPFL and decreases patellar rotation compared to single-point fixation.[34]

Preoperatively, increased patella alta or increased TT-TG was not associated with unfavorable results; all patients with patella alta or increased TT-TG were satisfied or very satisfied with the procedure. Those who had undergone previous surgical procedures before index surgery did not have inferior results. Although no redislocation was found in our study group, 2 patients with high-grade trochlear dysplasia had a positive apprehension sign and a positive J-sign at follow-up and were only partially satisfied with the operation. However, when patellar stability is achieved in childhood, remodeling of the shallow trochlea may occur and it is hoped that trochleoplasty in adulthood will be avoided.[6] Nevertheless, high-grade trochlear dysplasia was related to inferior results in 2 patients in our study group. Although no further surgical stabilization in these 2 patients has been necessary to date, trochleoplasty may be necessary in the future if knee function further deteriorates.

All patients were able to perform sports postoperatively, but only 3 patients returned to sports on a higher level than preoperatively. Fear of reinjury and lack of time or interest were the reasons given by the 4 patients who did not return to sports at their preoperative levels. Although physical activity as measured with the Tegner activity score decreased from 6.0 preoperatively to 5.8 postoperatively, this was not statistically significant ($P = .48$). These results indicate that patients did not increase their activity postoperatively, although no redislocation occurred and 86% of the patients were satisfied or very satisfied with their knee function. Some patients were concerned about the risk of redislocation during vigorous sports and therefore chose to limit their activities.

A major strength of this study is the fact that all operations were performed by a single surgeon and that preoperative MRI and radiographs were available for all examined patients to assess the risk factors for patellofemoral instability. That the evaluation at follow-up was not blinded is a limitation of this study. Another limitation is the lack of a control group. Because MPFL reconstruction has become the standard procedure in our institution and the historically performed procedures medial reefing and lateral release have been abandoned, a control group is not available at our center, and we could not ethically create one.

CONCLUSION

Anatomic reconstruction of the MPFL in skeletally immature patients that respects the distal femoral physis is a safe and effective treatment for patellofemoral instability in children. The procedure permits patients to return to organized sports without redislocation of the patella. High-grade trochlear dysplasia might be considered as a risk factor for inferior results of MPFL reconstruction in skeletally immature children and adolescents.

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