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Original Research

Medial patellofemoral ligament reconstruction in skeletally immature patients without correction of bony risk factors leads to acceptable outcomes but higher failure rates

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A R T I C L E I N F O

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A B S T R A C T

Objectives: To report outcomes and re-dislocation rates of medial patellar stabilizers reconstruction without bone procedures for correction of anatomical risk factors for patellar instability in skeletally immature patients; to compare isolated medial patellofemoral ligament (MPFL) reconstruction to combined MPFL and medial patellotibial ligament (MPTL) reconstruction in this population.
Methods: Patients with open physis and bone abnormalities including patella alta and/or increased tibial tubercle-trochlear groove (TT-TG) distance and/or trochlear dysplasia underwent MPFL reconstruction, either isolated or associated with MPTL reconstruction. Preoperative, 1-year follow-up and the latest follow-up (5 years minimum) data were collected. Radiological and clinical evaluations were conducted, with special attention to failure rate. Comparison of results from isolated MPFL and combined MPFL/MPTL reconstructions was performed.
Results: Twenty-nine patients were included, 19 in the isolated MPFL group (median 14 years old; follow-up 5.8 ± 1.7 years) and 10 in the combined MPFL/MPTL group (median 13.5 years old; follow-up 5.2 ± 1.4 years). Kujala and Tegner scores increased over time, although without statistically significant differences between the two groups at the latest follow-up ($p = 0.840$ and $p > 0.999$, respectively). During follow-up, 5 of 19 (26.3%) isolated MPFL and 2 of 10 (20%) MPFL/MPTL reconstructions experienced recurrence of patellar dislocation ($p > 0.999$). Trochlear dysplasia type D ($p = 0.028$), knee rotation ($p = 0.009$) and lateral patellar tilt angle ($p = 0.003$) were associated with patellar instability recurrence. The isolated MPFL group showed increased laxity on physical exam at the latest follow-up compared to the 1-year follow-up (patellar glide test ($p = 0.002$), patellar tilt test ($p = 0.042$) and subluxation in extension ($p = 0.019$). This increased laxity was not observed in the MPFL/MPTL group ($p > 0.999$). Comparing both groups, the glide test was significantly better in the combined MPFL/MPTL group in comparison to the isolated MPFL reconstruction group at the latest follow-up ($p = 0.021$).
Conclusion: MPFL reconstruction in isolation or combined with MPTL reconstruction in skeletally immature patients with additional uncorrected anatomical patellofemoral abnormalities leads to acceptable clinical outcomes within a minimum of 5 years follow-up, although has a high failure rate of 24.1%. Addition of a MPTL reconstruction to the MPFL may result in decreased patellar laxity on physical exams, as demonstrated by better patellar glide test, patellar tilt test and subluxation in extension.
Level of evidence: Level III; retrospective cohort study.

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What are the new findings

- Skeletally immature patients with uncorrected anatomic risk factors benefit from medial patellofemoral ligament reconstruction but present a high failure rate (24.1%).
- Isolated reconstruction of the patellofemoral ligament may provide less patellar stability in comparison to a combined medial patellofemoral and patellotibial reconstruction, as observed by the significant decline in the patellar glide test ($p = 0.002$), patellar tilt test ($p = 0.042$) and subluxation in extension ($p = 0.019$) in the isolated medial patellofemoral group between the 1-year follow-up and last follow-up, that was not observed in the combined reconstruction group.
- Trochlear dysplasia ($p = 0.028$), lateral patellar tilt ($p = 0.003$) and knee rotation ($p = 0.009$) were associated with higher risk of recurrence after medial patellofemoral ligament reconstruction.

Introduction

Patellar instability is a common knee condition affecting mostly young and active patients [1–3]. Several anatomical features are related to this disorder, including lower limb malalignment, excessive lateral quadriceps vector, trochlear dysplasia, patella alta and insufficiency of the medial patellar stabilizers (medial patellofemoral ligament [MPFL], the medial patellotibial ligament [MPTL] and the medial patellomeniscal ligament [MPML]) [4–7].

The MPFL plays a critical role in the patellofemoral biomechanics; it is responsible for 50%–60% of the ligamentous restriction to lateral translation during knee flexion between 0 and 30° of flexion [8,9]. Recently, the MPTL and MPML have been shown to also contribute significantly to patellofemoral stability [6,10]. These ligaments help maintain proper patellar tracking, by controlling patellar translation, tilt and rotation. At 90° flexion, the MPTL and the MPML account for 46% of restriction to lateral patellar translation and assist in up to 72% of patellar tilt and 92% of patellar rotation control [8,11].

The cornerstone of surgical stabilization for lateral patellar instability is MPFL reconstruction, associated with other procedures dependent on the anatomical abnormalities present. Although isolated reconstruction of the MPFL reports improvements in clinical examination and functional outcomes in skeletally mature patients [9,12,13], failures occur in 0.7%–21% according to systematic reviews, meta-analyses and registry studies [2,12,14–17]. Reconstruction of the secondary medial patellar restraints (MPTL or MPML) could potentially improve clinical and functional outcomes, as recently demonstrated in a systematic review that showed good to excellent patient-reported outcomes and patellar congruence after MPTL reconstruction [18], by decreasing stress on the MPFL reconstruction, especially when anatomical abnormalities (e.g. borderline patella alta, trochlea dysplasia or increased lateral quadriceps vector) are not surgically corrected [4]. This may be particularly important in skeletally immature patients, in which associated bony procedures are avoided due to the risk of physeal injury. It is already known that unaddressed trochlear dysplasia is associated with an increased risk of failure for MPFL reconstruction [19]. However, there is limited literature on the clinical outcomes of the MPFL reconstruction in isolation or in association with the MPTL reconstruction in skeletally immature patients with other or multiple anatomic risk factors [8,18].

The primary purpose of this study was to present the results of medial patellar stabilizers reconstruction after a minimum of 5 years follow-up in patients with open physes and associated uncorrected anatomical patellofemoral risk factors. The secondary purpose of this study was to compare the clinical and functional outcomes of the combined reconstruction of the MPFL and MPTL to the isolated MPFL reconstruction. Our hypothesis was that medial patellar stabilizers reconstruction in patients with open physes and uncorrected anatomical patellofemoral risk factors results in improved clinical outcomes. In addition, we hypothesized that the combined MPFL/MPTL reconstruction offers more favourable outcomes in the treatment of patellofemoral instability in this specific group when compared to isolated MPFL reconstruction.

Methods

The study was approved by the local institutional review board. This is a retrospective study of prospectively collected data from patients who underwent surgical patellar stabilization between 2011 and 2015 in a Level 1 hospital. The inclusion criteria were: skeletally immature patients (defined as having open tibial and femoral growth plates on MRI), who presented with recurrent lateral patellar dislocation (two or more episodes of patellar dislocation) and at least one of the following major predisposing anatomical risk factor for patellar instability: patella alta (Caton-Deschamps index >1.2), increased tibial tuberosity-trochlear groove (TT-TG) distance (>15 mm) or high-grade trochlear dysplasia (types B,C or D according to Dejour's classification). The exclusion criteria were patients that had previous surgery on the evaluated knee, presented with concomitant knee injuries (e.g. anterior cruciate ligament injury [ACL], collateral ligament injury), and cases of habitual patellar dislocation defined by patellar dislocation during every episode of knee flexion. All procedures were performed by one of the two senior authors. The decision to proceed with isolated MPFL reconstruction or combined MPFL/MPTL reconstruction was to the surgeon's preference. Overall, patients treated before 2014 generally underwent isolated MPFL reconstruction, whereas those treated after 2014 underwent the combined MPFL/MPTL reconstruction, once more studies supporting the MPTL reconstruction for specific cases were published [8,10,11,20–23].

Surgical procedures and rehabilitation

Combined MPFL/MPTL reconstruction

The procedure was performed as described previously [8]. The MPFL was reconstructed with an 8-mm strip dissected from the superficial and medial portion of the quadriceps tendon, maintaining its patellar insertion; the MPTL was reconstructed with a 6-mm strip dissected from the medial patellar tendon, preserving the patellar insertion and releasing its insertion to the tibial tuberosity.

The MPFL graft was passed between the second and the third layers of the medial retinaculum and fixed in the femur with the knee at 30° of flexion with a 3.5 mm metallic anchor at the *Schoettle's* point [24], as identified by fluoroscopy, and just distal to the femoral growth plate. The MPTL graft was fixed to the tibia at 90° of knee flexion with a 3.5 mm anchor, 1.5–2.5 cm below the joint line and 1.5–2.5 cm medially to the patellar tendon, just proximal to the growth plate.

Isolated MPFL reconstruction

Isolated reconstruction of the MPFL was performed with gracilis tendon autograft. *Schoettle's* point [24] was identified for femoral fixation. The patellar fixation point was made in the medial border of the patella between the middle and proximal third. The MPFL graft was passed between the second and third layers of the medial retinaculum and fixed with 3.5 mm metallic anchors in the two fixation points with the knee at 30° of flexion.

In both groups, lateral retinaculum release was performed to correct excessive lateral retinaculum tightness, only when presenting decreased medial patella translation or increased lateral patellar tilt that could not be reduced [25].

Postoperatively, all patients were discharged home with crutches and with a knee brace locked in extension for ambulation for 6 weeks. Physical therapy and home exercises were started on postoperative day 1 with isometric exercises and passive range of motion (ROM) aiming to achieve 90° of flexion in 4 weeks and full range of motion in 6–8 weeks. Weight-bearing was allowed as tolerated, progressing to full weight-bearing as soon as adequate muscular control was achieved. Open kinetic chain exercises were avoided for the first 10 weeks. The return to full activities including sports was allowed 4–6 months post-surgery.

Data collection

Demographic data was obtained. Anatomic risk factors were evaluated on pre-operative imaging exams that included conventional radiographs, and magnetic resonance imaging (MRI). Lateral radiographs were performed with the knee in 20° to 30° of flexion. MRIs were also performed in the supine position with the knee at the maximum extension allowed by the knee coil and the patella facing anteriorly. Two knee surgery fellows trained by the senior authors with experience in image analysis performed all the measurements; the means between the two measures were utilized for statistical analysis. To assess interobserver reproducibility, intraclass correlation coefficients (ICC) were determined for all image parameters. ICC values higher than 0.8 was considered excellent [26]. Regarding the trochlear dysplasia classification, in case of disagreement between the two observers, a senior author decided the classification.

Conventional radiographs were used to assess the Caton-Deschamps index (CDI) and the trochlear dysplasia (based on Dejour's classification) [27]. MRIs were used to measure the TT-TG distance, the lateral trochlear inclination, the boss height, the knee rotation and the patellar tilt angle [27–33]. The abnormality thresholds used for each anatomic risk factor were: patella alta (CDI >1.2) [28], increased TT-TG distance (>15 mm) [34], trochlear dysplasia (based on Dejour classification (types B, C or D) [27], lateral trochlear inclination (<11°) [29], boss height (>8 mm) [35]) and knee rotation (>10°) [33], and patellar tilt (>20°) [36].

Clinical evaluation and patient-reported outcome measures (PROMs) were collected preoperatively, at 1-year follow-up and at the latest follow-up. The latest follow-up was at the time of the recurrence of patellar dislocation or at a minimum of 5 years after the surgical procedure. The clinical evaluation included: knee range of motion (ROM), apprehension test and lateral glide test at 30° of knee flexion (positive when lateral patellar translation was >3 quadrants), tilt test in extension (positive when there was inability to elevate the lateral aspect of the patella beyond the horizontal plane), subluxation in extension (positive when there was lateral and proximal patellar displacement after contracting the quadriceps with the knee extended) [8], patellar compression test (positive when pain after patellar compression against the trochlea was present) and J-sign (positive when there was abnormal lateral deviation of patella close to extension during active knee extension) [8,37]. All tests were dichotomously classified as positive or negative at each time point, as described. Kujala and Tegner activity level were also collected and reported as numerical variables. Preoperative assessments were performed by the senior authors. Further assessments were performed blindly by the same fellows as above. In addition, the recurrence of patellar dislocation (failure) was investigated postoperatively, being considered positive when the patient reported a new episode of dislocation or subluxation.

Statistics

To assess normality of the data, the Shapiro–Wilk test was used. Parametric numerical variables were described using mean and standard deviation (SD), while nonparametric results were presented using median and interquartile range (IQR). Categorical variables were described by frequency and percentages. For numerical variables, differences within the groups were tested with the Wilcoxon signed-rank test. To test differences between groups, the unpaired t-test or Mann–Whitney test was used. The Kujala score and Tegner activity level differences between the three periods of evaluation were also tested in a two-way analysis of variance (ANOVA) with Bonferroni's correction for multiple comparisons. Categorical variables were analysed using Fisher's exact test or Chi-square test, as appropriate. An exploratory post-hoc analysis was performed to evaluate if the anatomical risk factors increased the risk of recurrence of patellar dislocation. For that purpose, the complete cohort was divided into 2 subgroups: "recurrence" and "non-recurrence" subgroups, and the subgroups were compared as described above. An initial sample size estimation was not performed as all patients who met the inclusion criteria were included. SPSS version 28.0 (SPSS Inc, Chicago, IL) was used for analysis. Statistical significance was considered as $p < 0.05$.

Results

A total of 40 patients were initially evaluated. Of these, one had an associated ACL injury, six had habitual patellar dislocation and four were lost at follow-up and were excluded from the study. Therefore, the final cohort consisted of 29 cases. Of these, 10 cases underwent combined MPFL/MPTL reconstruction and 19 isolated MPFL reconstruction [Fig. 1]. Among the combined MPFL/MTPL cases, three required concomitant lateral retinaculum release, whereas among the isolated MPFL reconstruction cases, four underwent concomitant lateral retinaculum release and four underwent vastus medialis advancement. The median age of surgery was 13.5 years old (range 10–17) for the combined group, while the isolated MPFL group had a median age of 14 (range 11–17) years old. The combined group had a follow-up of 5.2 ± 1.4 years, and the isolated group had a follow-up of 5.8 ± 1.7 years. Caton-Deschamps index (1.39 ± 0.21 in the combined reconstruction group versus 1.30 ± 0.17 in the isolated group; p = 0.221), TT-TG distance (16.2 ± 3.6 in the combined group versus 17.0 ± 4.9 in the isolated group; p = 0.662) and the presence and degree of trochlear dysplasia (p = 0.422) were not statistically significantly different between the groups [Table 1]. Overall, 93.1% of patients presented at least two major anatomic risk factors. There was no significant difference among all the evaluated parameters between the two groups [Table 1]. Interobserver reliability showed excellent agreement for all imaging parameters (ICC 0.86 for CDI, 0.85 for TT-TG distance, 0.81 for lateral trochlear inclination, 0.85 for boss height, 0.86 for knee rotation, and 0.85 for patellar tilt).

Clinical evaluation

All patients regained full ROM after the first year of follow-up. Overall, physical exam tests improved at 1-year follow-up, except for the J-sign evaluation, which remained unchanged in all cases until the latest follow-up [Table 2]. In the combined MPFL/MPTL group, improvements were maintained between 1-year follow-up and the latest follow-up in regard to the apprehension test, patellar glide test, patellar tilt test and subluxation in extension; however, there was a decline in the patellar compression test (with no statistically significant difference) [Table 2]. In the isolated MPFL reconstruction group, there was a statistically significant decline in the patellar laxity physical exam between the 1-year follow-up and last follow-up (patellar glide test (p = 0.002), patellar tilt test (p = 0.042) and subluxation in extension (p = 0.019)), as well as increased instability symptoms during the apprehension test (0.062). The patellar compression test showed no difference between 1-year follow-up and the latest follow-up (p = 0.495) [Table 2]. Furthermore, the glide test was significantly better in the combined MPFL/MPTL reconstruction group in comparison to the isolated MPFL reconstruction group at the latest follow-up (p = 0.021) [Table 2].

Functional evaluation

The Kujala score showed a statistically significant increase at 1 year and at the latest follow-up for both groups, although no differences were found between the two groups [Table 3].

The two groups presented a statistically significant increase in the Tegner score from the pre-operative to the latest follow-up. Additionally, there was no statistically significant difference between the preinjury

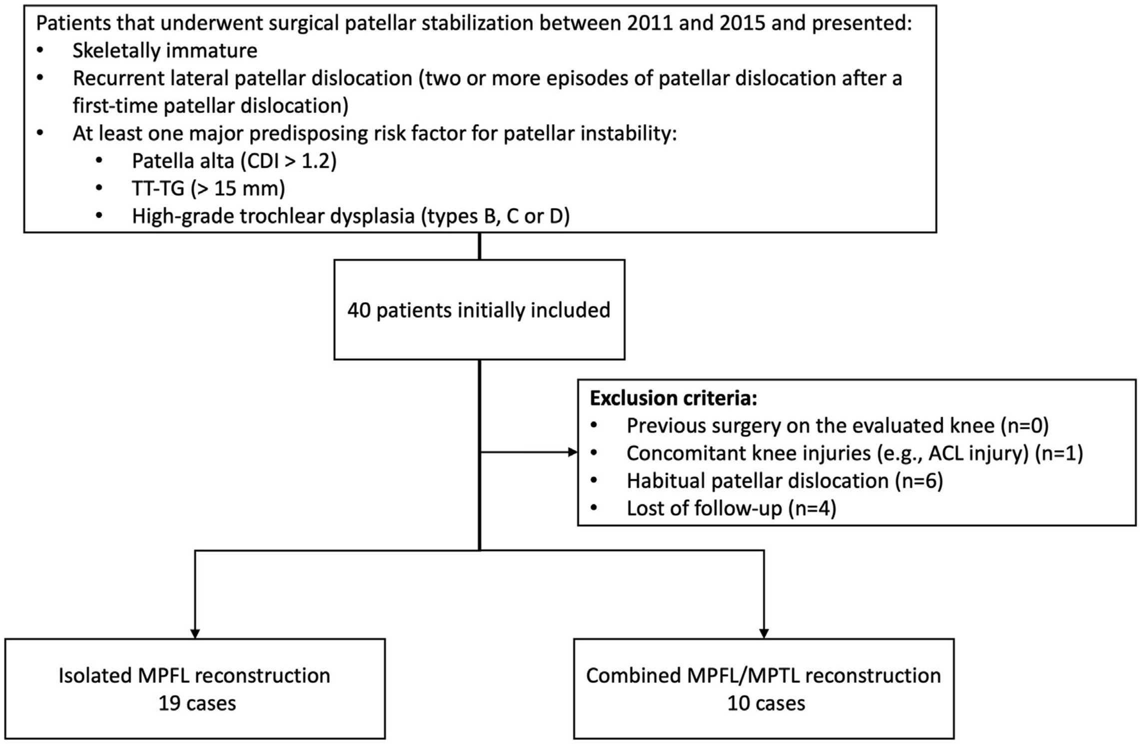

Fig. 1. Flowchart of the included patients. CDI: Caton-Deschamps index; TT-TG: tibial tuberosity to trochlear groove distance; ACL: anterior cruciate ligament; MPFL: medial patellofemoral ligament; MPTL: medial patellotibial ligament.

(pre-instability) and the latest follow-up Tegner score for both groups [Table 3].

No statistically significant differences were observed between the isolated MPFL and combined MPFL/MPTL groups for the Kujala score and Tegner activity level at 1 year and at the latest follow-up [Table 3].

Recurrence of patellar dislocation

Seven cases (24.1%) reported recurrence of patellar dislocation after surgery (recurrence subgroup), five (26.3%) in the isolated MPFL reconstruction group (time to failure after surgery for each patient: 20, 42, 50, 60 and 66 months; mean 47.6 $\pm$ 18.0 months) and two (20%) in the combined reconstruction group (time to failure after surgery for each patient: 15 and 60 months, mean 37.5 $\pm$ 31.8 months). The mean follow-up was 3.7 $\pm$ 1.7 years for the recurrence subgroup and 6.2 $\pm$ 1.1 years for the non-recurrence subgroup [Table 4].

In the recurrence group, type D trochlear dysplasia was statistically more prevalent, and patellar tilt angle and knee rotation were significantly higher. The Kujala score was not statistically and significantly different between the recurrence and non-recurrence at 1 year and latest follow-up. Still, in the recurrence group, an improvement of the Kujala score was observed after 1-year follow-up and maintained until the latest evaluation, although this improvement was not statistically significant ($p = 0.05$). No differences were found in the Tegner activity level between the two groups. For the recurrence group, the Tegner score was statistically higher at 1-year follow-up in comparison to preoperative levels and was maintained over time [Table 4].

Discussion

The most relevant findings of this study are that skeletally immature patients with uncorrected anatomic risk factors who underwent surgical patellar stabilization through reconstruction of the medial patellar stabilizer(s) showed statistically significant improvements in clinical and functional outcomes after a minimum of 5 years follow-up. Improvements were seen in the Kujala score and Tegner activity level at the latest follow-up for both the combined MPFL/MPTL reconstruction and the isolated MPFL reconstruction groups, without statistically significant differences between them. Additionally, no statistically significant difference between these two groups was found regarding the recurrence of patellar instability. Conversely, clinical examinations demonstrated that the patellar apprehension test, glide test, tilt test and subluxation in extension presented better results in the combined MPFL/MPTL reconstruction group at the latest evaluation. These findings suggest that, even though the recurrence rate is high for this challenging and complex cases, both procedures were able to restore patellar stability and knee function, and the addition of an MPTL reconstruction to the MPFL resulted in less laxity on the physical exam at 5-year results.

Isolated reconstruction of the MPFL has been widely studied due to its importance as the major medial patellar stabilizer [1]. However, there is a lack of knowledge on the outcomes of isolated MPFL reconstruction in patients with uncorrected anatomic risk factors. In the majority of the studies, a homogenous population was selected as part of the authors' surgical indications for isolated MPFL reconstruction. That is, exclusion criteria omit patients with excessive anatomic factors based on physical examination and/or imaging criteria [14]. In this setting, failure rates of isolated MPFL reconstruction, with recurrence of objective or subjective patellar instability that may require further revision stabilization surgery, are reported to be between 0.7% and 21% (most <10%) by systematic reviews, meta-analyses and registry studies [2,12,14–17,38–40], although values greater than 30% have been described [41]. In skeletally immature patients, a systematic review found a failure rate of 15.2% (3.8% dislocations and 11.4% subluxations) [42].

In the current study, a 24.1% recurrence rate was observed, which is, overall, higher than reported in the literature [2,12,14–17,38–40]. That can be explained by the population of the current study, which consisted solely of patients with anatomic risk factors, with 93.1% of patients presenting at least two major anatomic risk factors. Indeed, the notable rate of failure must draw the attention of surgeons who treat these patients. High-grade trochlear dysplasia, increased tibial-tuberosity to

Table 1
Demographics and radiological characteristics of the included patients.

	Complete cohort	Combined MPFL/MPTL Reconstruction	Isolated MPFL reconstruction	p
Number of cases	29	10	19	
Age at surgery in years, median (IQR)	14 (2.5)	13.5 (3.5)	14 (2)	0.105[b]
Range	(10–17)	(10–17)	(11–17)	
Follow-up length in years, mean ± SD	5.6 (±1.6)	5.2 (±1.4)	5.8 (±1.7)	0.333[a]
Caton-Deschamps Index, mean ± SD	1.33 (±0.19)	1.39 (±0.21)	1.30 (±0.17)	0.221[a]
CDI> 1.2 - n (%)	24 (82.8)	9 (90%)	15 (78.9)	
TT-TG – mm, mean ± SD	16.7 (±4.4)	16.2 (±3.6)	17.0 (±4.9)	0.662[a]
> 15 mm - n (%)	21 (72.4)	7 (70%)	14 (73.7)	
Trochlear dysplasia (Dejour classification) - n (%)				0.422[c]
Normal/A	6 (20.7)	3 (30)	3 (15.8)	
B	3 (10.3)	2 (20)	1 (5.3)	
C	4 (13.8)	1 (10)	3 (15.8)	
D	16 (55.2)	4 (40)	12 (63.2)	
Lateral trochlear inclination - degrees (±SD)	11.1 (±6.2)	11.3 (±6.2)	11.0 (±6.3)	0.906[a]
< 11° - n (%)	14 (48.3)	5 (50)	9 (47.4)	
Boss height - mm (±SD)	5.3 (±2.5)	5.8 (±1.4)	5.1 (±2.9)	0.468[a]
> 8 mm - n (%)	3 (13.9)	0 (0)	3 (15.8)	
Knee rotation - degrees (±SD)	7.2 (±3.5)	5.8 (±3.0)	8.0 (±3.6)	0.102[a]
> 10° - n (%)	9 (31.0)	2 (20)	7 (36.8)	
Patellar tilt angle - degrees (±SD)	24.0 (±10.2)	25.4 (±10.1)	23.3 (±10.4)	0.606[a]
> 20° - n (%)	20 (69)	7 (70)	13 (68.4)	
Prevalence the anatomic risk factors studied - n (%)				
Patients with one factor	1 (3.4)	0	1 (5.3)	
Patients with two factors	4 (13.8)	1 (10)	3 (15.8)	
Patients with three factors	2 (6.9)	1 (10)	1 (5.3)	
Patients with four or more factors	22 (75.9)	8 (80)	14 (73.7)	

Anatomic risk factors represent the prevalence of patella alta (>1.2), increased TT-TG (>15 mm), trochlear dysplasia (type B, C or D based on Dejour classification, or lateral trochlear inclination <11° or the boss height >8 mm) and knee rotation (>10°). Values are shown as %.
TT-TG: Tibial tuberosity-trochlear groove.
[b] Fisher's exact test.
[a] Unpaired t-test.
[b] Mann–Whitney test.
[c] Chi-square test.

Table 2
Clinical evaluation. Complete cohort is composed by 29 patients, 10 in the combined MPFL/MPTL reconstruction group and 19 in the isolated MPFL reconstruction group. Only the number of patients with positive tests are shown in the table. Values shown in n (%).

	Preoperative	1-year Follow-up	Latest Follow-up	p_1	p_2
Positive apprehension Test					
Complete cohort	23 (79.3)	2 (6.9)	9 (31.0)	**<0.001**	**0.041**
MPFL + MPTL	8 (10)	0	1 (10)	**<0.001**	>0.999
MPFL	15 (78.9)	2 (10.5)	8 (42.1)	**<0.001**	0.062
p between groups	>0.999	0.532	0.107		
Positive patellar glide test					
Complete cohort	27 (93.1)	4 (13.8)	15 (51.7)	**<0.001**	**0.005**
MPFL + MPTL	8 (80)	1 (10)	2 (20)	**0.006**	>0.999
MPFL	19 (100)	3 (15.8)	13 (68.4)	**<0.001**	**0.002**
p between groups	0.111	>0.999	**0.021**		
Positive patellar tilt test					
Complete cohort	18 (62.1)	1 (3.4)	8 (27.6)	**<0.001**	**0.025**
MPFL + MPTL	6 (60)	0	1 (10)	**0.010**	>0.999
MPFL	12 (63.2)	1 (5.3)	7 (36.8)	**<0.001**	**0.042**
p between groups	>0.999	>0.999	0.201		
Positive subluxation in extension					
Complete cohort	26 (89.7)	2 (6.9)	9 (31.0)	**<0.001**	**0.041**
MPFL + MPTL	10 (100)	1 (10)	1 (10)	**<0.001**	>0.999
MPFL	16 (84.2)	1 (5.3)	8 (42.1)	**<0.001**	**0.019**
p between groups	0.532	>0.999	0.107		
Positive patellar compression test					
Complete cohort	22 (75.9)	7 (24.1)	12 (41.4)	**<0.001**	0.263
MPFL + MPTL	7 (70)	2 (20)	4 (40)	0.070	0.629
MPFL	15 (78.9)	5 (26.3)	8 (42.1)	**0.003**	0.495
p between groups	0.464	>0.999	>0.999		
Positive J sign					
Complete cohort	16 (55.2)	16 (55.2)	16 (55.2)	>0.999	>0.999
MPFL + MPTL	5 (50)	5 (50)	5 (50)	>0.999	>0.999
MPFL	11 (57.9)	11 (57.9)	11 (57.9)	>0.999	>0.999
p between groups	0.714	0.714	>0.999		

p_1 = Preoperative (post-instability) vs 1-year follow-up.
p_2 = 1-year follow-up vs latest follow-up.
p between groups refers to the analysis between the two groups (Combined MPFL/MPTL reconstruction and isolated MPFL reconstruction) in the respective follow-up.
Fisher's exact test.

Table 3
Functional assessment. Complete cohort is composed by 29 patients, 10 in the combined MPFL/MPTL reconstruction group and 19 in the isolated MPFL reconstruction group. Values shown in mean (±*SD)* or median (*IQR*).

	Pre-instability	Preoperative (Post-instability)	1-year Follow-up	Latest Follow-up	P p_1	p_2	p_3	p_4
Kujala Score								
Complete cohort	–	55.8 (±15.9)	75.8 (±10.6)	82.3 (±15.0)	**<0.01**	**<0.01**	0.08	
MPFL + MPTL	–	62.7 (±12.0)	77.4 (±12.0)	86.2 (±8.7)	**<0.030**	**<0.001**	0.183	
MPFL	–	52.1 (±16.8)	74.9 (±9.9)	80.3 (±17.3)	**<0.001**	**<0.001**	0.579	
p between groups		0.161	>0.99	0.840				
Tegner activity level								
Complete cohort	5 (2.5)	2 (1.5)	3 (0)	3 (1)	**<0.01**	**<0.01**	0.320	0.14
MPFL + MPTL	5 (2.25)	3 (2)	3 (3)	4 (1)	0.221	**0.005**	0.177	0.559
MPFL	4 (2)	2 (1)	3 (0)	3 (1)	**0.002**	**<0.001**	0.497	0.130
p between groups	>0.999	>0.999	>0.999	>0.999				

p_1 = Preoperative (post-instability) vs 1-year follow-up.
p_2 = Preoperative (post-instability) vs latest follow-up.
p_3 = 1-year follow-up vs latest follow-up.
p_4 = pre-instability vs latest follow-up.
Two-way ANOVA with Bonferroni's correction for multiple comparisons.

posterior cruciate ligament (TT-PCL) distance, patella alta and the presence of J-sign have been shown to increase failure rates after isolated MPFL reconstruction [9,13,19,43–45]. Therefore, cases that presented recurrence of patellar instability were analysed to identify the risk factors for failures in our cohort. Our results confirmed the association between severe trochlear dysplasia and recurrence of patellar instability, and, in addition, demonstrated that knee rotation was also associated with recurrence. Increased knee rotation is associated with increased lateral quadriceps vector (e.g. TT-TG), and likely associated with femoral and tibial torsion [33,46,47]. The increased tilt found in the recurrence group is likely a consequence of the severe trochlear dysplasia and increased knee rotation present in this group and is seen as a “marker” of the severity of those factors. Our study suggests that the combination of those factors can be particularly unfavourable.

Table 4
Comparison between recurrence and non-recurrence groups. Values are expressed as number (%) and mean (±*SD*) or median (*IQR*).

	Recurrence	Non-recurrence	*p* between groups
Number of cases (%)	7 (24.1)	22 (75.9)	
Age	13.9 (±1.8)	14.5 (±1.9)	0.472[a]
CDI	1.3 (±0.2)	1.4 (±0.2)	0.339[a]
> 1.2 - n (%)	5 (71.4)	19 (84.6)	
TT-TG	17.1 (±4.1)	16.5 (±4.6)	0.753[a]
> 15 mm - n (%)	6 (85.7)	15 (68.2)	
High-grade trochlear dysplasia (Dejour types B/D)	D (100%)	B (13.6%) D (40.9%)	**<0.028**[b]
Lateral trochlear inclination	8.7 (±5.2)	11.9 (±6.4)	0.245[a]
< 11°- n (%)	5 (71.4)	9 (40.9)	
The boss height (mm)	6.4 (±3.0)	5.0 (±2.3)	0.206[a]
> 8 mm - n (%)	1 (14.3)	2 (9.1)	
Knee rotation	10.5 (±2.9)	6.5 (±3.9)	**0.009**[a]
> 10 - n (%)	6 (85.7)	4 (18.2)	
Patellar tilt angle	33.4 (±9.1)	21.0 (±8.7)	0.003[a]
> 20° - n (%)	7 (100)	13 (59.1)	
Kujala score			
Preoperative	50.0 (±15.4)	57.6 (±16.0)	0.635
1-year Follow-up	69.0 (±8.8)	77.9 (±10.3)	0.131
Latest Follow-up	71.7 (±17.3)	85.7 (±12.9)	0.227
p_1	0.057	**<0.001**	
p_2	0.132	**<0.001**	
p_3	>0.999	**0.030**	
Tegner activity level			
Pre-instability	3 (3)	5 (3)	0.34
Preoperative (post-instability)	2 (1)	3 (1)	0.18
1-year Follow-up	3 (1)	3 (1)	0.13
Latest Follow-up	3 (2)	3.5 (1)	0.29
p_1	**0.006**	**0.009**	
p_2	0.070	**<0.001**	
p_3	>0.999	**0.026**	
p_4	>0.999	**0.001**	

p_1 = Preoperative (post-instability) vs 1-year follow-up.
p_2 = Preoperative (post-instability) vs latest follow-up.
p_3 = 1-year follow-up vs latest follow-up.
p_4 = pre-instability vs latest follow-up.
2way ANOVA with Bonferroni's correction for multiple comparisons.
CDI - Caton-Deschamps index.
TT-TG - tibial tuberosity-trochlear groove.
[a] Unpaired t-test.
[b] Fisher's exact test.

This study presents evidence that the reconstruction of the medial patellar stabilizers without bony procedures improves the clinical outcomes by improving the clinical examination tests. Moreover, although both techniques described here provided acceptable outcomes, our results suggest that the combined MPFL/MPTL reconstruction offers longer-lasting results. In fact, within 1-year follow-up, there was no difference between the groups regarding any patellofemoral physical examination. However, in the latest follow-up, patients that underwent combined MPFL/MPTL reconstruction presented with decreased laxity, as measured by the glide, tilt tests and subluxation in extension as well as decreased apprehension with lateral patellar displacement. The differences could be attributed to the addition of the MPTL to the MPFL reconstruction or to MPFL technique (quadriceps vs semitendinosus reconstruction). Both semitendinosus and quadriceps tendon techniques utilized single-bundle autografts, and the literature shows improved PROMS and low rates of failure for both [48,49]. Furthermore, results of MPFL reconstruction have been shown to be similar among different techniques and graft choices [42,50,51], although some studies favour the semitendinosus over the gracilis tendon graft [48] and the double-bundle over the single-bundle reconstruction; these differences, however, seem to be small [52,53].

In addition, the inconsistencies in reporting risk factors for failure after MPFL reconstruction might compromise the comparison among different techniques [54]. In this current study, different risk factors were considered and were similar between the isolated MPFL and the combined MPFL/MPTL reconstruction patients. Therefore, we believe that the improvement in the physical exam found in the current study between semitendinosus graft for isolated MPFL reconstruction and patellar grafts for combined MPFL/MPTL reconstruction is mainly due to the addition of the MPTL reconstruction and not due to graft option [4]. This hypothesis is supported by a biomechanical study from Grantham et al. [55] that showed that both isolated MPFL and combined reconstruction provided improved stability, however full range of motion native patella tracking was best recreated with combined MPFL/MPTL reconstruction [55]. Other biomechanical studies also support those findings [11,20]. On the other hand, a major concern of the addition of the MPTL reconstruction is that it can potentially increase patellofemoral pressure and pain, similar to what can occur with the MPFL reconstructions [56]. However, a biomechanical study demonstrated that when the MPFL is fixed at 90° there is no increase in the patellofemoral pressure [57]. Our study did not find increased knee pain on the physical exam in the combined MPFL/MPTL group compared to the isolated MPFL group. Similar findings were reported in the literature in a systematic review of MPTL reconstructions [18]. It is the authors' opinion that, to preserve the ligamentous reconstruction function of both MPFL and MPTL without overloading the patellofemoral joint, it is important to fix them independently in different degrees of flexion (MPFL in 30° to 45° of flexion and the MPTL at 90° of flexion [58,59]).

In regard to the functional evaluation, the literature reports a mean postoperative Kujala score of 85.8 (95% CI, 81.6–90%) [2] with an improvement of 23.11–38.8 points [16]. Here, similar results were achieved, with a mean of 82.3 (±15.0) and improvement of approximately 27 points. Likewise, the Tegner activity level improved postoperatively, resulting in a median of 3 points during the latest evaluation. There were no statistically significant differences between the isolated MPFL and combined MPFL/MPTL groups. Both the median preoperative and post-operative Tegner scores in our cohort are lower than the values reported in previous studies [2,21]. These are likely a consequence of the variability in patient demographics as ours is composed of younger patients with more severe instability and less engaged in organized sports due to the presence of multiple patellofemoral anatomic risk factors. Importantly, conflicting results are shown in the literature regarding the reestablishment of preinjury Tegner score after MPFL and MPTL reconstructions [21,60,61]. In our study, while there was no statistically significant difference between the preinjury and the latest follow-up for the combined MPFL/MPTL group, isolated MPFL group reconstruction was not able to re-establish preinjury scores. Furthermore, comparing the failure cases to those who did not fail, lower functional scores were observed in the former group, as expected. Interestingly, even in the patients who had recurrence, the Kujala score showed a trend toward statistical significance at 1 year ($p = 0.057$). Unfortunately, due to lack of follow-up between 1 year and the recurrence we cannot access when the decline of function actually occurred, however, we believe that most of the decline occurred acutely at the time of the re-dislocation instead of gradually. Therefore, the reconstruction of the medial stabilizers in patients with anatomic risk factors provide temporary positive effects, of at least a year, even when failures occur.

Our study has several limitations. First, it is a non-randomized study, and allocation was made by convenience and surgeon preference. Future controlled and randomized studies between combined MPFL/MPTL reconstruction versus other reconstruction methods could emphasize the real benefit of the procedure and should be encouraged. Second, before 2014 the included patients underwent isolated MPFL reconstruction, while after that period a combined MPFL/MPTL reconstruction was performed. Improvements in the surgical technique over time could also be responsible for some of the gains observed in the combined reconstruction patients. Third, the study may be underpowered for clinical findings and failure rate, and compromises conclusions regarding the associations for failures. Indeed, because of the small number of cases, a multivariable analysis was not conducted. Studies with a larger number of cases may be better powered for definitive conclusions. Nevertheless, our work is one of the few comparing those two treatment modalities with a minimum of 5 years follow-up, considering that there are no controlled trials comparing those techniques, and the small number of studies evaluating the combined MPFL/MPTL reconstructions have shorter follow-up time. Therefore, our data may offer a novel insight into the treatment of young patients with risk factors that have contraindications to bony procedures.

Conclusion

MPFL reconstruction in isolation or combined with MPTL reconstruction leads to clinically acceptable outcomes within a minimum of 5 years follow-up in skeletally immature patients with additional uncorrected anatomical patellofemoral abnormalities, though a high failure rate is reported compared to a mature population. The addition of a MPTL reconstruction to the MPFL may result in decreased patellar laxity on physical exams, as demonstrated by better patellar glide test, patellar tilt test and subluxation in extension.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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