Original Research

Return-to-Sport Testing After Medial Patellofemoral Ligament Reconstruction in Adolescent Athletes

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Background: Return to sport (RTS) after patellar stabilization surgery involves the return of strength and dynamic knee stability, which can be assessed using isometric strength and functional performance testing.

Purpose: To investigate the results of isometric strength and functional RTS testing between the surgical and uninvolved limbs in adolescent patients who underwent medial patellofemoral ligament (MPFL) reconstruction for patellar instability.

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

Methods: A retrospective review of adolescent patients who underwent MPFL reconstruction identified 28 patients (20 female, 8 male) who also underwent isometric and functional RTS testing. Data were compared with the uninvolved limb. The recovery of muscle strength was defined by a limb symmetry index (LSI) ≥90%. Differences in peak torque were compared using the Wilcoxon signed-rank test. Correlations were examined between dependent and independent variables using the Spearman correlation.

Results: The mean age of the patients was 14.9 years (range, 12-16 years). Reconstruction was performed with a hamstring autograft in 17 (60.7%) patients. Concomitant tibial tubercle osteotomy was performed in 10 (35.7%) patients. Testing was performed at a mean 7.4 months (range, 5.5-11.9 months) postoperatively. The mean LSIs for quadriceps and hamstring strength were 85.3% and 95.1%, respectively. For knee extension, there was a statistically significant difference between isometric peak torque measured in the surgical and uninvolved limbs ($P = .001$). Only 32.0% of patients passed all 4 hop tests. Also, 63.0% of patients achieved an anterior reach asymmetry of <4 cm on the Lower Quarter Y-Balance Test (YBT-LQ). There were no statistically significant differences in isometric strength testing, hop tests, or the YBT-LQ based on graft type or concomitant procedures. There was no correlation between isometric strength and performance on the YBT-LQ or hop tests.

Conclusion: Adolescent athletes undergoing MPFL reconstruction may need prolonged rehabilitation programs beyond 8 months to allow the adequate recovery of muscle strength for safe RTS. There is a significant deficit in isometric quadriceps strength in the surgical limb after surgery. Further investigation is needed to determine safe RTS criteria after MPFL reconstruction in the pediatric and adolescent population.

Keywords: medial patellofemoral ligament; MPFL; reconstruction; adolescent; rehabilitation

Patellofemoral instability injuries are common in the young athletic patient population, with an overall injury rate of 1.95 per 100,000 athlete-exposures for high school athletes.[13] Reconstruction of the medial patellofemoral ligament (MPFL) is currently the first-choice procedure for patients requiring surgery for recurrent lateral patellar instability.[1] Despite the increased interest in MPFL reconstruction in recent years, there are limited evidence-based data guiding return to sport (RTS) after the procedure, with RTS rates around 60% to 90%.[3,10,14,16] To assist surgeons in their decision making, full RTS clearance is often based on physical therapy recommendations, and successful rehabilitation involves the return of quadriceps strength and endurance and limb symmetry in dynamic functional activity. It has been suggested that muscle strength and functional capacity of the reconstructed leg be "normal" before RTS.[2,3] In a systematic review based on 53 included studies, Zaman et al[27] found that RTS decision making after MPFL surgery was mostly based on time-based criteria and that only a minority (19%) of studies used subjective or objective criteria.

To provide objective data, strength recovery can be assessed using isometric testing, and dynamic knee stability can be assessed using functional performance testing.

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The objective measurements from these tests have been reported in pediatric and adolescent patients after primary anterior cruciate ligament (ACL) reconstruction and have been shown to predict outcomes and assist surgeons in safely returning patients to their full sports activities.[1,5,6,28,29] However, such reports in patients after patellar stabilization surgery are limited.[12] Improving our understanding of these injuries is necessary to help guide targeted evidence-based treatment and rehabilitation approaches needed to provide safe and effective guidelines for RTS after MPFL reconstruction.

The purpose of this study was to investigate the results of isometric strength and functional RTS testing between the surgical and uninvolved limbs in adolescent patients who underwent MPFL reconstruction. We sought to identify any demographic and surgical factors affecting performance on isometric strength or functional testing. Secondarily, we examined correlations between various test results. Previous studies have found that hop test performance and knee extensor strength asymmetries exist in patients 6 to 9 months after ACL reconstruction.[26] Similarly, we hypothesized that deficits in strength and functional performance would be observed in the adolescent population 6 months after MPFL surgery.

METHODS

Patient Selection

Institutional review board approval was obtained before the initiation of this retrospective study. Between May 2014 and August 2017, adolescent patients who underwent MPFL reconstruction at our institution were identified. The search was limited to patients aged 10 to 19 years, consistent with the World Health Organization's definition of adolescence.[25] Patients were included in the study if they (1) underwent primary MPFL reconstruction and (2) had a postoperative RTS assessment consisting of lower extremity isometric strength testing, the Lower Quarter Y-Balance Test (YBT-LQ), and single-legged hop testing. Those with associated abnormalities or chondral injuries were also included, and there were no limits regarding concomitant procedures. Exclusion criteria for this study were (1) a history of patellar stabilization surgery, (2) a history of alignment corrective surgery including femoral/tibial osteotomy and/or guided growth, (3) bilateral patellar instability, and (4) a history of patellar stabilization surgery on the contralateral knee. After applying these criteria, a total of 28 patients (20 female, 8 male) were included in this analysis.

Surgical Techniques

All surgical procedures were performed by one of 2 pediatric fellowship-trained orthopaedic surgeons (M.G.S., G.A.S.). Surgeries were performed with combined general and regional anesthesia. Diagnostic arthroscopic surgery was first performed, and any intra-articular abnormalities were addressed. MPFL reconstruction was performed using the preferred techniques of the treating surgeons; graft choice for the procedure was based on surgeon preference. In all patients, the lateral retinaculum was initially released to best observe patellar tracking. At the time of closure, tissues were reapproximated in a lengthened fashion through the iliotibial band, as described by Saper and Shneider,[19] or with reapproximation of the superficial to deep layers of the lateral retinaculum, as described by Pagenstert et al.[17] The decision to perform a tibial tubercle osteotomy (TTO) was left to the discretion of the surgeon on the basis of skeletal maturity, physical examination findings, diagnostic imaging (eg, increased tibial tubercle–trochlear groove distance), and intraoperative findings (eg, if the patella did not track centrally in the trochlea through passive motion of the knee after lateral release).

Postoperative Rehabilitation

All patients followed a standardized rehabilitation protocol directed by the surgeon and underwent supervised physical therapy until RTS clearance. Before surgery, patients received instruction on postoperative home exercises, gait training, and precautions. Formal physical therapy (phase 1) was initiated within the first week after surgery, emphasizing range of motion (ROM) and exercises to re-establish quadriceps control. Patients were instructed to bear weight as tolerated in a hinged knee brace locked in full extension. If concomitant TTO was performed, patients were restricted to toe-touch weightbearing for the first 2 weeks. During phase 2 (weeks 3-6), the patient worked to gradually improve ROM (ideally 90° by week 4). The brace was discontinued when quadriceps control was regained. Phase 3 (weeks 7-12) goals included working to gradually restore full ROM, muscular strength, neuromuscular control, and full weightbearing ambulation without a brace or assistive devices. Phases 4 (3-6 months) and 5 (7-9 months) focused on strength, power, and endurance as well as the progression of functional activities. Track or treadmill running was not started before 3 months postoperatively. The time of the RTS assessment was determined for each patient on an individual basis when the surgeon and rehabilitation team were considering RTS clearance. The timing and goals of each phase are presented in Table 1.

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Ethical approval for this study was obtained from the Seattle Children's Institutional Review Board (STUDY00000705).

TABLE 1
Rehabilitation Protocol[a]

Phase	Timing	Goals
1	Weeks 1-2	Restore full passive knee extension Re-establish quadriceps control Gradually improve knee flexion Diminish pain and inflammation
2	Weeks 3-6	Maintain symmetrical knee extension Normalize patellar mobility Progress knee ROM Improve muscle control and activation Restore proprioception/neuromuscular control
3	Weeks 7-12	Improve muscular strength, power, and endurance Restore full knee ROM Enhance proprioception, balance, and neuromuscular control
4	Months 3-6	Normalize lower extremity strength Enhance strength and endurance Initiate functional activities
5	Months 7-9	Achieve maximal strength and endurance Progress skill training Progress proprioception/balance skills Progress power Gradually return to sport activities

[a]ROM, range of motion.

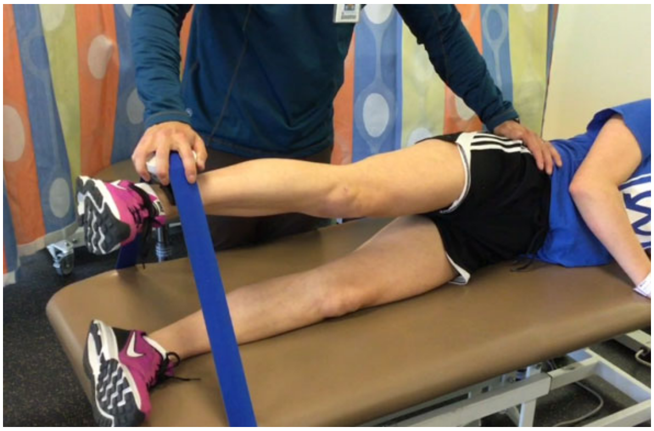

Figure 1. Hip abduction isometric strength testing with a handheld digital dynamometer (right leg).

RTS Testing

All RTS assessments were performed at one of our institution's sports rehabilitation clinics by a licensed physical therapist. Isometric strength was assessed using a handheld digital dynamometer (MicroFET 2; Hoggan Scientific).[8,23] Peak torques for knee extension and flexion were collected with the patient sitting and the knee at 90° of flexion. Peak torque for hip abduction was collected with the patient in the lateral decubitus position and the hip at 10° of abduction (Figure 1). All assessments were performed bilaterally. Two maximum efforts were completed

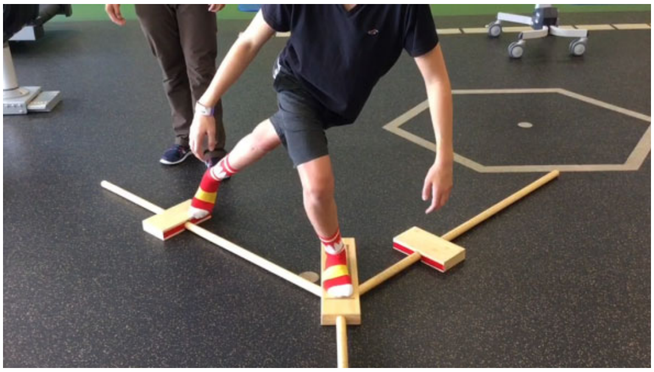

Figure 2. Patient performing a posterolateral reach (left leg) on the Lower Quarter Y-Balance Test.

for each muscle group, and the average torque (in lb) of the 2 attempts was recorded.

Lower extremity strength, neuromuscular control, flexibility, and balance were assessed with the YBT-LQ, which has been shown to have good to excellent intrarater and interrater reliability (Figure 2).[18] Patients performed a single-limb stance while reaching outside their base of support to push a reach indicator box along the measurement pipe of the Y-Balance Test Kit (Perform Better). Patients were allowed 3 practice attempts in each of the 3 directions (anterior, posteromedial, and posterolateral) before recording the best of 3 formal attempts. For each direction, 3 attempts were completed on the uninvolved limb, followed by 3 attempts on the surgical limb, and the maximum reach distance was recorded. A side-to-side difference of <4 cm on the anterior reach and a composite score of ≥90 on each limb were criteria for passing. The composite score was determined using the following equation:

$$\begin{aligned}&\textit{Composite score}\\&\quad = [(\textit{anterior} + \textit{posteromedial} + \textit{posterolateral})\\&\qquad / (3 \times \textit{limb length})] \times 100.\end{aligned}$$

An assessment of function and dynamic strength/stability was performed using 4 different single-legged hop tests: single hop for distance, triple hop for distance, triple crossover hop for distance, and timed hop (Figure 3).[15] One practice attempt was allowed before each of the hop tests. Patients started from a single-limb stance. Each test was repeated 3 times, and the best measurement was recorded. All distance measurements were recorded in feet and inches. The distance for the timed hop test was 18 ft.

Limb symmetry indices (LSIs) were calculated for all tests using the following formula:

$$LSI = (\textit{surgical limb}/\textit{uninvolved limb}) \times 100\%.$$

The recovery of muscle strength was defined by an LSI ≥90%. Passing the dynamic testing component of the RTS assessment was defined as LSIs ≥90% on all 4 hop tests (Table 2). The acceptable threshold of the LSI for hop test performance for safely progressing to more intense sports activity after ACL reconstruction is 90%.[20,26] In the

Figure 3. Single-legged hop testing (right leg).

TABLE 2
Surgical Findings (N = 28 Knees)

Finding	n (%)
Associated lesions	
Chondral injuries (patellofemoral compartment)	10 (35.7)
Grade I	2 (7.1)
Grade II	4 (14.3)
Grade III	3 (10.7)
Grade IV	1 (3.6)
Loose bodies	4 (14.3)
Osteochondral fractures	3 (10.7)
Patella	2 (7.1)
Lateral femoral condyle	1 (3.6)
Concomitant procedures	
Chondroplasty/debridement	4 (14.3)
Distal femoral osteotomy	1 (3.6)
Fixation of osteochondral fracture	1 (3.6)
Lateral lengthening	23 (82.1)
Lateral release/repair	5 (17.9)
Loose body removal	3 (10.7)
Microfracture of patella	1 (3.6)
Proximal tibial hemiepiphysiodesis	1 (3.6)
Tibial tubercle osteotomy	10 (35.7)

literature, the most common recommendation for side-to-side differences is quadriceps strength differences no greater than 10% to 15%. Results indicate that quadriceps deficits of ≥15% negatively affect function and performance. Results also indicate that patients with an LSI ≥90% perform similarly to uninjured persons.[18,20,21]

Data Collection

Medical records were reviewed, and demographic data including patient age at surgery, side, sex, height, weight, and body mass index were collected. Details of the surgical intervention (eg, graft type, block type, concomitant procedures), postoperative follow-up information, and any complications/subsequent operative procedures were recorded. Chondral injuries were graded with the Outerbridge classification. Data from the RTS assessments were tabulated from the physical therapy notes.

Statistical Analysis

All data were entered into Excel (version 2012; Microsoft). For descriptive analysis, continuous variables were expressed as mean ± SD, and categorical variables were expressed as number and percentage. The normality of the distribution of dependent variables was examined using the Shapiro-Wilk test. Results showed a nonnormal distribution; therefore, the Wilcoxon signed-rank test was used to assess differences in peak torque between the surgical and uninvolved limbs. Associations between dependent and independent variables were examined using the Spearman correlation. Data were analyzed using STATA 14.2 (StataCorp), and P values <.05 were considered statistically significant.

RESULTS

The mean age of the patients was 14.9 years (range, 12-16 years). The mean height, weight, and body mass index of the patients were 66.8 ± 19.5 cm, 66.8 ± 19.5 kg, and 24.7 ± 5.2 kg/m^2, respectively. Regional anesthesia included an indwelling adductor canal catheter (32.1%), femoral nerve catheter (64.3%), or single-shot femoral nerve block (FNB) (3.6%). A tourniquet was utilized in 5 (17.9%) patients for a mean duration of 97.4 minutes. Reconstruction was performed on the left knee in 15 (53.6%) patients. A hamstring autograft was utilized in 17 (60.7%) patients. Surgical findings are reported in Table 2. Testing was performed at a mean 7.4 months (range, 5.5-11.9 months) postoperatively. Concomitant TTO was performed in 10 (35.7%) patients. There was no statistically significant difference in the mean time to RTS testing in patients with or without concomitant TTO (7.9 months [range, 5.5-10.5 months] vs 7.2 months [range, 5.5-11.9 months], respectively).

The pass criteria for each test and the percentage of patients who passed are presented in Table 3. The mean LSIs for quadriceps and hamstring strength were 85.3% and 95.1%, respectively (Table 4). For knee extension, there was a statistically significant difference between isometric peak torque measured in the surgical and uninvolved limbs (P = .001). Results of the YBT-LQ and hop tests are presented in Tables 5 and 6, respectively. There were no statistically significant differences in isometric strength testing, the YBT-LQ, or hop tests based on demographics, block type, graft type, or concomitant procedures. There was no correlation between isometric strength and performance on the YBT-LQ or hop tests.

TABLE 3
Return-to-Sport Pass Criteria and Percentage of Patients Who Passed[a]

Pass Criteria	%
LSI ≥90% isometric peak torque at knee extension (n = 27)	44.4
LSI ≥90% isometric peak torque at knee flexion (n = 27)	70.4
LSI ≥90% isometric peak torque at hip abduction (n = 25)	72.0
YBT-LQ anterior reach <4-cm difference between extremities (n = 27)	63.0
YBT-LQ composite score ≥90% of leg length (n = 27)	74.1
LSI ≥90% single hop for distance (n = 25)	64.0
LSI ≥90% triple hop for distance (n = 24)	75.0
LSI ≥90% crossover hop for distance (n = 24)	70.8
LSI ≥90% timed hop (n = 24)	75.0
LSI ≥90% all 4 hop tests (n = 24)	32.0

[a]LSI, limb symmetry index; YBT-LQ, Lower Quarter Y-Balance Test.

TABLE 4
Peak Torque and LSI[a]

	Peak Torque, lb			
Test	Surgical Limb	Uninvolved Limb	LSI, %	*P*
Knee extension	67.9 ± 20.5	79.6 ± 20.1	85.3	**.001**
Knee flexion	42.2 ± 10.1	44.4 ± 10.4	95.1	.064
Hip abduction	30.9 ± 14.2	30.4 ± 15.3	101.6	.527

[a]Data are reported as mean ± SD unless otherwise specified. Bolded *P* value indicates a statistically significant difference between the surgical and uninvolved limbs ($P < .05$). LSI, limb symmetry index.

TABLE 5
Lower Quarter Y-Balance Test

Test	Mean ± SD
Anterior reach difference, cm	3.5 ± 3.5
Composite score of surgical limb, % of leg length	94.9 ± 8.4
Composite score of uninvolved limb, % of leg length	97.2 ± 8.7

TABLE 6
LSI of Surgical Limb on Hop Testing[a]

Test	Mean ± SD, %
Single hop for distance	89.7 ± 16.7
Triple hop for distance	92.3 ± 10.0
Crossover hop for distance	92.5 ± 16.2
Timed hop	95.8 ± 15.0

[a]LSI, limb symmetry index.

DISCUSSION

The principal findings of this study were that adolescent athletes undergoing MPFL reconstruction may not consistently recover adequate muscle strength or dynamic functional stability by 7.4 months postoperatively. There was a significant deficit in isometric strength in the surgical limb after surgery, with deficits more pronounced in the quadriceps. Only 32.0% of patients passed all 4 hop tests. Also, 63.0% of patients achieved an anterior reach asymmetry of <4 cm on the YBT-LQ. Our findings suggest that surgeons should not rely solely on time from surgery to determine when adolescent patients are cleared for RTS but should also utilize the results of strength and functional testing to help determine readiness for RTS.

There is limited published information regarding RTS after patellar stabilization surgery. A recent systematic review identified 53 studies including adults and teenagers that cited rehabilitation guidelines designed to optimize RTS after patellar stabilization including MPFL reconstruction, but only 10 (18.9%) of these studies included objective or subjective criteria for assessing readiness for RTS.[27] Two studies offered subjective criteria only for readiness for RTS; in 1 study,[7] patients progressed to full activities as their comfort and confidence allowed, while in the other,[2] the rate of functional progression was dictated by pain and swelling. Of those citing objective criteria, none explicitly listed a measurement or numeric value for an assessment that would imply readiness for RTS. However, in 1 study,[24] patients were allowed to RTS 5 to 6 months postoperatively once they had passed a functional assessment, although the details of the functional assessment were not described.

Data on the recovery of muscle strength after patellar stabilization surgery in the adolescent population are limited. Krych et al[9] conducted isokinetic strength and functional testing in 39 patients aged 13 to 26 years at 6 months after MPFL reconstruction. These authors demonstrated mean knee flexion (15.8%) and extension (21.4%) strength deficits compared with the contralateral leg that persisted at 6 months after surgery, especially in patients who underwent concomitant TTO. They found that concomitant TTO with MPFL reconstruction significantly slowed rehabilitation and RTS, with the time to RTS averaging 7.0 months for patients having undergone isolated MPFL reconstruction and 9.8 months for those who underwent a combined procedure. In contrast to their findings, our study showed no statistically significant differences in isometric strength between patients with and without concomitant TTO at a mean 7.4 months postoperatively.

Isometric testing of knee extension was the only strength test that resulted in a clinically and statistically significant limb difference. Furthermore, only 44.4% of patients achieved LSIs ≥90% at a mean 7.4 months after surgery. These findings are similar to previous studies showing that patients have significant strength deficits 6 months after surgery.[9,26] The strength impairments noted in our patients after MPFL reconstruction indicate that patients may not be able to generate the forces necessary to maximize functional ability. Schmitt et al[20] studied RTS testing after ACL reconstruction in 90 patients aged between 14 and 25 years and found that quadriceps weakness negatively affected function and performance. In fact, at the time of RTS after surgery, patients with minimal strength deficits (≤10%) demonstrated functional performance similar to uninjured persons. Moreover, there is extensive research showing that quadriceps weakness is related to poor functional outcomes after an ACL injury.[20] These findings support the notion that residual strength deficits are a limiting factor in returning to preinjury levels of function and activity.

The YBT-LQ measures single-limb stance excursion distances while performing lower extremity dynamic balance testing. Poor dynamic balance is considered an intrinsic risk factor for injuries in athletes.[4,21,22] The current literature indicates that an anterior reach asymmetry of >4 cm may be clinically significant with respect to an increased lower extremity injury risk.[4,22] Of note, only 63.0% of patients in our study achieved an anterior reach asymmetry of <4 cm on the YBT-LQ. Although further research needs to be conducted, this finding indicates that a significant proportion of patients may be returning to sport with an elevated risk of lower extremity injuries.

Single-legged hop testing is a common type of functional performance test to simulate sport-specific movements in a controlled manner. While primarily utilized to help determine safe RTS after ACL reconstruction, there is extensive research supporting its reliability.[15] The uninjured limb serves as a control for limb-to-limb comparisons and as a reference against which discharge from physical therapy and RTS may be determined. The acceptable threshold of the LSI for hop test performance for RTS is 90%.[20,26] Of note, only 32.0% of patients in our study passed all 4 hop tests. This finding suggests that the majority of patients were unable to demonstrate satisfactory dynamic strength/stability for return to unrestricted sport activities. Furthermore, our study showed no correlation between quadriceps strength and hop test results. These findings are in contrast to those of Schmitt et al,[20] who found that quadriceps strength deficits could predict hop test functional performance. Results of their study indicated that quadriceps deficits of ≥15% negatively affect function and performance.[20] The reason for the difference in this investigation is unclear, given that there was a statistically significant difference in quadriceps strength between the surgical and uninvolved limbs in our study. However, many factors can contribute to functional performance in addition to quadriceps strength deficits in youth. Other factors could include postural stability, proximal hip strength, and lower extremity biomechanics.[20]

Limitations

The limitations of this study include its retrospective design, small sample size, and lack of both preoperative and postoperative patient-reported outcomes (including RTS questionnaires, eg, Tegner activity scale). While strictly composed of adolescent patients, this was a heterogeneous population including multiple surgeons, techniques, grafts, and concomitant procedures. Moreover, while all patients followed the same rehabilitation protocol, rehabilitation was conducted at different locations. It is unclear how such heterogeneity affected the results, and a larger study in the future should take these variables into account. Also, these results reflect the outcomes of patients at a single children's hospital and, as such, might not be generalizable to the broader orthopaedic community. Furthermore, femoral nerve blocks (single shots and/or indwelling catheters) were given to a large number of patients, and as persistent quadriceps strength deficits have been reported 6 months after a femoral nerve block,[11] it is unclear how/if its use in our patients affected the results. Another limitation is that the contralateral limb was used as the control for comparison with the surgically reconstructed limb, which may not truly reflect preinjury baseline strength and function. A third control group with asymptomatic knees could be considered in the future.

CONCLUSION

Adolescent athletes undergoing MPFL reconstruction may need prolonged rehabilitation programs beyond 8 months to allow the adequate recovery of muscle strength for safe RTS. In the current study, there was a significant deficit in isometric quadriceps strength in the surgical limb after surgery. Further investigation is needed to determine safe RTS criteria after MPFL reconstruction in the pediatric and adolescent population.

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