

Descriptive Epidemiology of a Surgical Patellofemoral Instability Population of 492 Patients

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Background: Patellofemoral instability (PFI) occurs most commonly in pediatric and adolescent patients, with evolving indications for surgery and changes in surgical techniques over the past decade.

Purpose: To characterize the demographic, clinical, and radiologic characteristics of a large cohort of patients undergoing PFI surgery and investigate longitudinal trends in techniques utilized over a 10-year period at a tertiary-care academic center.

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

Methods: Electronic medical records of patients younger than 25 years of age who underwent primary surgery for lateral PFI from 2008 to 2017 at a single center by 1 of 5 different sports medicine surgeons were retrospectively reviewed. Demographic, clinical, and radiographic parameters of instability were analyzed. Routine surgical techniques included medial retinacular plication/reefing/repair (MRP), medial patellofemoral ligament reconstruction (MPFLR), tibial tubercle osteotomy (TTO), or a combination thereof, with or without lateral retinacular release (LR) or lateral retinacular lengthening (LRL). Exclusion criteria, selected for potentially altering routine surgical indications or techniques, included fixed/syndromic PFI, a formally diagnosed collagen disorder, cases in which a chondral/osteochondral shear fragment underwent fixation or was >1 cm in diameter, and body mass index >30 kg/m².

Results: Of the 492 study patients (556 knees; 71% female; median age, 15.2 years; 38% open physes), 88% were athletes, with the most common sports participated in being soccer, basketball, dance, football, gymnastics, and baseball/softball. While 91% of the cohort had recurrent dislocations, the 9% with primary dislocations were more likely to have small osteochondral fractures/loose bodies ($P < .001$). Female patients were younger ($P = .002$), with greater patellar tilt ($P = .005$) than male patients. Utilization of MPFLR and TTO increased significantly over the study period, while use of MRP+LR decreased.

Conclusion: Most patients younger than 25 years of age who underwent PFI surgery were skeletally immature, female, and athletes and had recurrent dislocations. The <10% who had primary dislocations and underwent surgery were likely to have osteochondral fractures. Surgical techniques have changed significantly over time, with increasing use of TTO and MPFLR, while the use of MRP+LR/LRL has significantly decreased.

Keywords: patellar instability; patellofemoral instability; young athletes; medial patellofemoral ligament reconstruction; tibial tubercle osteotomy

Patellofemoral instability (PFI) is a common pathology of the knee, with lateral patellar dislocations accounting for 2% to 3% of all knee injuries.⁸ Affected patients may sustain patellar subluxations, dislocations, subjective feelings of patellar instability, or some combination thereof. The population by far most affected is young athletes, with the vast majority of PFI events occurring during the second decade of life.^{12,14,35} Nevertheless, existing research concerning

these injuries has largely arisen from adult populations and institutions. As early sports specialization and the potential for overuse injuries increase,^{4,20} improved study of this most vulnerable population of young athletes is even more critical.

Patellar subluxations and dislocations are associated with numerous adverse sequelae, including recurrent PFI episodes, persistent pain and disability, chondral and osteochondral shear injuries, and long-term degenerative joint disease. Recurrent dislocations after a first-time patellar dislocation are the most commonly recognized complication, with several studies clearly documenting rates over

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50%.^{14,19,22,23,30} Disability because of pain or persistent subjective instability has also been reported in up to 50% of patients, even many months after injury.^{2,17,29} Long-term degenerative joint disease may persist, with more than 1 in 5 patients developing osteoarthritis of the knee in less than 20 years.²⁴

Treatment of first-time PFI events without substantial cartilaginous injury has traditionally consisted of nonoperative measures, such as bracing and physical therapy.^{7,10,30} However, given the subsequent risk of recurrent PFI and other consequences, some authors have advocated for more aggressive management of initial instability episodes, even in skeletally immature patients. Just as the indications for surgical treatment remain controversial, understanding of the epidemiologic features of the predominantly young, athletic patient population remains incomplete, particularly among those receiving operative care. The purpose of the present study is therefore to characterize the demographic, clinical, and radiologic characteristics of this population and investigate surgical treatment trends over a 10-year period in patients who underwent surgery for patellar instability by a number of different surgeons at a single institution.

METHODS

After receiving institutional review board approval, we reviewed the electronic medical records at a large, metropolitan, tertiary-care pediatric center to identify patients aged <25 years with a diagnosis of PFI from 2008 to 2017. This end date was chosen to allow for sufficient patient follow-up and identification of medium-term postoperative complications.

Patients were included if they had undergone surgical treatment using 1 of 3 major forms of patellar realignment or stabilization surgery (medial patellofemoral ligament (MPFL) reconstruction [MPFLR], medial retinacular plication/reefing/repair [MRP], or tibial tubercle osteotomy [TTO]) or a combination of those procedures. Recording of additional procedures commonly performed in conjunction with such techniques (eg, lateral retinacular release [LR] or lateral retinacular lengthening [LRL], or the arthroscopic removal of loose bodies) was also performed.

We excluded patients who underwent surgical techniques that are less well-established or techniques for which the indications are controversial or demonstrate significant variation in utilization (eg, Galeazzi semitendinosus tenodesis or Roux-Goldthwaite reconstruction). No cases of trochleoplasty have been performed at the study institution. Patients were also excluded if they had a syndromic diagnosis (eg, Down, William, Noonan, or chronic regional pain syndrome); a known diagnosis of a severe collagen disorder or syndrome (eg, Ehlers Danlos [29 knees] or Marfan); body mass index (BMI) >30 kg/m² (79 knees); prior surgery of the ipsilateral knee; concomitant cruciate ligament tear; coronal plane realignment techniques such as high tibial osteotomy, distal femoral osteotomy, or guided growth procedures; a large osteochondral fracture with fragments >1 cm in any dimension (46 knees); or fixation of an osteochondral fracture of any size. While these excluded patients represent important and well-established subpopulations in the overall PFI population, inherent presenting clinical or postoperative factors in each subpopulation are likely to alter routine surgical indications, technical approaches, or the typical postoperative course or outcomes. For example, patients with large osteochondral fragments generally undergo implant-based fixation and/or cartilage resurfacing techniques that increase the rates of secondary surgery for implant removal or arthrofibrosis, implant-related complications, or more rapid progression to degenerative joint disease. Each of these excluded subpopulations is the subject of either prior or ongoing investigations at the study institution designed to elucidate the unique features and course of such populations.

Surgery was performed by 1 of 5 sports medicine fellowship-trained orthopaedic surgeons (M.S.K., Y.M.Y., D.E.K., L.J.M., B.E.H.). Choice of operative procedure was individualized for each patient and determined independently by the patient's surgeon, with limited documentation in the medical record regarding the specific selection of technique or combination of techniques.

Surgical Techniques

Medial Retinacular Plication/Reefing/Repair. MRP was performed in different patients by each of the 5 different surgeons, with some inherent variation in technique.

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Ethical approval for this study was obtained from Boston Children's Hospital (protocol No. IRB-P00023829).

Terms utilized variably and interchangeably to describe this technique included medial retinacular or MPFL “plication,” “imbrication,” “repair,” “shortening,” and “tightening.” Common to all was reconfiguration of native medial retinacular or MPFL tissue for an effective shortening of the length of the MPFL and the absence of any graft material. Common steps included a 2- to 3-cm skin incision and dissection through the subcutaneous layer and through layer 1 to expose the retinacular/MPFL layer (layer 2). In most instances, plication of retinacular tissue was performed with figure-of-8 high-strength braided sutures placed over a segment of tissue spanning 1.5 to 3 cm in width (from the medial border of the patella, lateral to the mid-MPFL region) and 1.5 to 3 cm in length (from the level of the superior pole of the patella to the inferior quartile of the patella). In some instances, a similar elliptical-shaped segment of retinacular tissue was excised, allowing for side-to-side closure of this layer, and in other instances, 2 double-loaded suture anchors were placed into the patella along the medial border (at approximately three-fourths height and half height), and simple or horizontal mattress sutures were placed into the medial retinaculum 1.5 to 3 cm from the medial border. In all variations of the above techniques, the knee range of motion and dynamic patellar stability were checked after the plication, with subsequent modifications made, as needed, to the tension of the repair.

Lateral Retinacular Release or Lengthening. LR, which was performed as a concomitant procedure in the vast majority of MRP cases, was performed arthroscopically with arthroscopic electrocautery or scissors dividing the lateral synovial, retinacular, and fascial layers of the knee from within the joint. The LR was typically placed 8 to 12 mm lateral to the lateral border of the patella and longitudinally from the level of the superior extent of the patella to the inferolateral portal. Care was taken to utilize the arthroscopic electrocautery or a radiofrequency ablation device to achieve hemostasis at the level of the superior lateral geniculate artery on both sides of the LR.

LRL was performed through an open lateral incision, usually the same utilized for the lateral approach to the TTO. The fascial layer was divided longitudinally approximately 5 mm lateral to the lateral border of the patella, along the full superior-to-inferior extent of the patella. The dissection between the fascial layer and retinacular layer was developed laterally to 20 mm lateral to the patella, where the retinacular layer was divided along the same longitudinal extent. An absorbable running suture was then used to approximate the medial cuff of retinacular tissue with the lateral cuff of fascial tissue, thereby reestablishing a lengthened retinaculum/lateral soft tissue patellar restraint. For the purposes of technique grouping and tables in the study, cases of LRL were included in a combined LR/LRL category.

MPFL Reconstruction. MPFLR was performed in patients by 4 of the 5 different surgeons, with some inherent variations in technique. Either gracilis or semitendinosus allograft was used in the majority of cases, although semitendinosus autograft was utilized in a small subset of patients, with standard harvesting technique. Graft fixation on the patellar side most commonly involved 2 suture anchors placed into the patella along the medial border (at

approximately three-fourths height and half height), with the high-strength braided anchor sutures wrapped around the diameter of graft with multiple simple sutures, although in some instances a docking technique was utilized, and in others, a medial quadriceps tendon femoral ligament (MQTFL) reconstruction (MQTFLR) was also performed with one of the strands from the folded tendon being affixed with sutures to the quadriceps. For the purposes of technique grouping and tables in the study, cases of MQTFLR were included in the MPFLR category. Femoral fixation most commonly involved a single suture anchor or tenodesis screw placed at the Schöttle point using fluoroscopic guidance, with minor adjustments made, as needed, to place implants distal to the physis or optimize graft isometry.

Tibial Tubercle Osteotomy. TTO was performed on different patients by all 5 surgeons, with some inherent variation in technique, and varying indications, with 2 surgeons (L.J.M., B.E.H.) performing primary patellar stabilization technique regardless of tibial tubercle–trochlear groove (TT-TG) distance, and 2 using 20 mm as a threshold for TTO. Most commonly, a primary tubercle medialization, or Elmslie-Trillat procedure, was performed, although a variation of the Trillat procedure to include a component of anteromedialization was performed by 1 surgeon (B.E.H.), and a more formal Fulkerson osteotomy was performed by another (D.E.K.). In all instances, medialization of the tubercle measured between 8 mm and 15 mm, with bony screw fixation consisting of 3, or occasionally 3, 4.5-mm fully threaded bicortical countersunk screws or a single cannulated 6.5-mm partially threaded screw and washer. The goal of the above procedures was to decrease elevated TT-TG distance to a normal value (<15 mm).

Data Collection

Collected data included demographic information such as age, sex, BMI, mechanism of injury, and sports participation. Available preoperative radiographs and magnetic resonance imaging (MRI) obtained within 1 year of surgery were reviewed. Patellar morphology was classified according to the Wiberg classification¹⁵ on axial slices, and trochlear morphology was classified according to the Dejour classification on axial MRI.^{15,21} Additional measures were also performed based on previously described methods.^{1,9} Trochlear depth was measured by the cartilaginous sulcus angle on the most cranial axial MRI slice showing cartilage covering the whole trochlea. Patellar tilt was measured via the patellar inclination angle on the axial slice through the central portion of the patella. The TT-TG distance was measured from the deepest point of the cartilaginous trochlea to the central portion of the patellar tendon insertion on the tibial tubercle in a line drawn parallel to the posterior femoral condyles on MRI. Patellar height was measured via the Caton-Deschamps Index on the sagittal MRI slice with the greatest length of the patella.³³ Physeal status was classified as open (no evidence of bony bridging between the metaphysis and epiphysis on either the distal femur or the proximal tibia), closing (any evidence of incomplete bony bridging), or closed (complete bridging of the epiphysis and metaphysis on the distal femur and proximal tibia) on preoperative MRI when

TABLE 1

Patient Characteristics (N = 492 patients, 556 knees)^a

Characteristic	Value
Sex, female	392 (70.5) ^b
BMI, kg/m ²	22.7 [20.2-26.3]
Laterality, left	301 (54.1)
Age at presentation, y	14.6 [13.1-16.3]
MOI, noncontact (n = 383)	307 (80.2)
Athlete, yes (n = 549)	483 (88.0) ^b
Most common primary sport (among 'athletes')	
Soccer	81 (16.8)
Basketball	66 (13.7)
Dance	47 (9.7)
Football	35 (7.2)
Gymnastics	30 (6.2)
Baseball/softball	29 (6.0)

^aData are presented as n (%) or median [interquartile range].^bPercentage based on knees not patients. BMI, body mass index; MOI, mechanism of injury.TABLE 2
Radiologic Features^a

Characteristic	Value
Patients with MRI available	463 (83.3)
Dejour classification	
A	191 (41.3)
B	128 (27.6)
C	73 (15.8)
D	30 (6.5)
No dysplasia	41 (8.9)
Wiberg classification	
A	48 (10.4)
B	334 (72.1)
C	81 (17.5)
TT-TG, mm	16.8 [13.8-19.7]
Sulcus angle, deg	161.0 [154.0-167.7]
Patellar tilt, deg	24.0 [17.2-30.1]
Caton-Deschamps Index	1.24 [1.11-1.37]
Physeal status	
Open	199 (38.3)
Closing	157 (30.3)
Closed	163 (31.4)

^aData are presented as n (%) or median [interquartile range].

MRI, magnetic resonance imaging; TT-TG, tibial tubercle–trochlear groove.

available. If no MRI scans were available for review, physeal status was assessed on preoperative radiographs.

Statistical Analysis

Measures of clinical, radiologic, and surgical characteristics were summarized using descriptive statistics. Comparison of epidemiologic factors, including sex, skeletal maturity, and number of instability events, was conducted using the Fisher exact test for categorical variables and the independent-samples *t* test or the Wilcoxon rank-sum

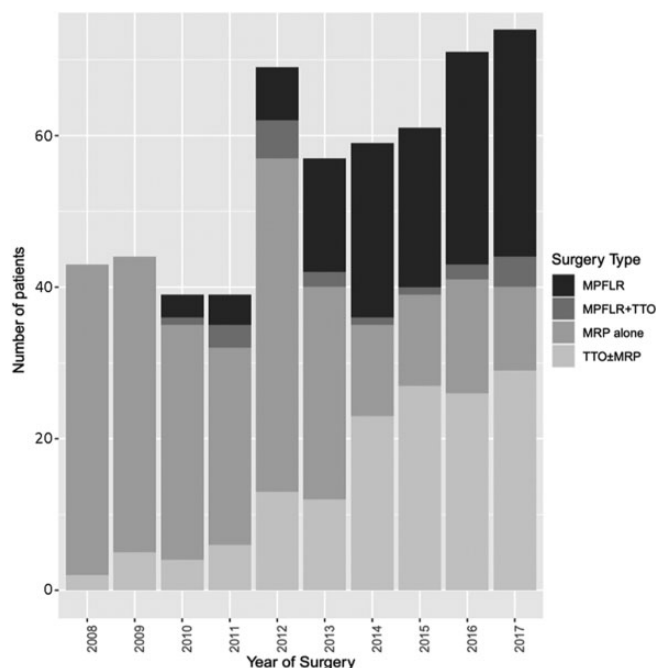


Figure 1. Surgical treatment for patellar instability over a 10-year period. MPFLR, medial patellofemoral ligament reconstruction; MRP medial retinacular plication/reefing/repair; TTO, tibial tubercle osteotomy.

test for continuous variables. All tests were 2-sided, and $P < .05$ was considered statistically significant.

RESULTS

Detailed patient information is presented in Table 1. We identified 492 patients (556 knees) who underwent surgical treatment for PFI using the described surgical techniques. In all the operative knees, 70.5% were in female patients. The median age at presentation was 14.6 years (interquartile range [IQR], 13.1-16.3 years) and the median BMI was 22.7 kg/m² (IQR, 20.2-26.3 kg/m²). In total, 88% of the cases occurred in patients who were self-reported athletes, with the most common primary sports being soccer, basketball, dance, football, gymnastics, and baseball/softball. Preoperative MRI scans within 1 year of surgery were available for review in 463 (83.3%) knees. Detailed radiologic measures are reported in Table 2.

The median patient age at the time of surgery was 15.2 years (IQR, 13.8-17.1 years). Of the total knees, 507 (91.2%) knees received surgery after multiple instability events, while 49 (8.8%) knees underwent surgery after the initial instability event. An MRP alone was performed in 259 (46.6%) knees, while 131 (23.6%) knees received MPFLR, and 147 (26.4%) knees underwent TTO with or without concomitant MRP. Nineteen (3.4%) knees underwent combined MPFLR+TTO at the index operation. Procedure volume and physician choice of procedure over the study period are shown in Figure 1.

TABLE 3
Clinical and Radiologic Parameters by Sex^a

Characteristic ^b	Male (n = 164 knees)	Female (n = 392 knees)	P
BMI, kg/m ²	23.0 [20.6-27.7]	22.6 [20.1-25.8]	.095
Age at presentation, y	14.9 [13.5-16.7]	14.3 [12.9-15.9]	.002
MOI, noncontact	79 (66.9)	228 (86.0)	<.001
Athlete	148 (91.9)	335 (86.3)	.083
Dejour classification			.015
A	71 (51.8)	120 (36.8)	
B	37 (27.0)	91 (27.9)	
C	16 (11.7)	57 (17.5)	
D	7 (5.1)	23 (7.1)	
No dysplasia	6 (4.4)	35 (10.7)	
Wiberg classification			.006
A	14 (10.2)	34 (10.4)	
B	87 (63.5)	247 (75.8)	
C	36 (26.3)	45 (13.8)	
TT-TG, mm	16.9 [14.0-20.7]	16.8 [13.5-19.2]	.137
Sulcus angle, deg	161.0 [155.0-167.0]	161.0 [153.0-167.9]	.677
Patellar tilt, deg	22.0 [15.0-29.0]	25.0 [18.0-31.8]	.005
Caton-Deschamps Index	1.23 [1.11-1.38]	1.24 [1.11-1.36]	.786
Physeal status			<.001
Open	80 (51.0)	119 (32.9)	
Closing	39 (24.8)	118 (32.6)	
Closed	38 (24.2)	125 (34.5)	
Age at surgery, y	15.9 [14.1-17.3]	15.0 [13.7-16.8]	.004
Surgery type			.557
MPFLR	44 (26.8)	87 (22.2)	
MRP	77 (47.0)	182 (46.4)	
TTO	38 (23.2)	109 (27.8)	
MPFLR+TTO	5 (3.0)	14 (3.6)	

^aData are presented as n (%) or median [interquartile range]. ^bPercentages for each characteristic are based on the number of knees over the denominator of male or female knees in which a given characteristic was reported in the electronic medical record. Due to inconsistency in reporting of each variable, denominators vary by characteristic. Boldface *P* values indicate a statistically significant difference between groups ($P < .05$). BMI, body mass index; MOI, mechanism of injury; MPFLR, medial patellofemoral ligament reconstruction; MRP, medial retinacular plication/reefing/repair; TT-TG, tibial tubercle–trochlear groove; TTO, tibial tubercle osteotomy.

Patients were compared by sex, with complete comparisons presented in Table 3. Female patients were younger than male patients at the time of surgery (15.0 vs 15.9 years; $P = .004$), although they were more likely to be skeletally mature. There was no significant difference in BMI between sexes. A higher percentage of female patients were injured by noncontact mechanisms compared with male patients (86.0% vs 66.9%; $P < .001$). Radiologically, female patients had a higher degree of patellar tilt than male patients (25.0° vs 22.0°; $P = .005$). There were no significant sex-based differences in the distribution of type of surgical procedure performed.

Patients were also compared by skeletal maturity. Skeletally immature patients were defined as those with open growth plates on radiologic assessment, and skeletally mature patients were those with closing or closed growth plates, as defined in the methods. Complete results are presented in Table 4. Skeletally immature patients were found to have a significantly lower BMI ($P < .001$) and a significantly higher Caton-Deschamps Index ($P = .019$) than skeletally mature patients. Expectedly, the distribution of surgical choices differed by skeletal maturity ($P < .001$), as skeletally mature patients were more likely to receive a TTO.

While a number of skeletally immature patients underwent TTO surgery, all were within 1 year of skeletal maturity.

Finally, patients who had surgery after multiple instability events were compared with those who underwent surgery after their first event. There was no significant difference in sex distribution or in the proportion of patients who had contact versus noncontact injuries. Patellar tilt, as measured on MRI, was significantly higher in patients who had multiple instability events (24.0°) as compared with those who had surgery after 1 event (20.0°) ($P = .020$). The distribution of surgical types performed was also significantly different between groups ($P < .001$), with most primary instability patients undergoing MRP, compared with significantly higher rates of MPFLR and TTO in those who had recurrent dislocations. Small osteochondral or chondral fractures were also significantly more common in those with first-time dislocations receiving surgery ($P < .001$) (Table 5).

DISCUSSION

The current investigation provides a comprehensive assessment of the major demographic, clinical, and radiologic

TABLE 4
Clinical and Radiologic Parameters by Skeletal Maturity^a

Characteristic ^b	Immature (n = 199 knees)	Mature (n = 320 knees)	P
Sex, female	119 (59.8)	243 (75.9)	<.001
BMI, kg/m ²	21.1 [18.8-24.4]	23.3 [21.0-27.8]	<.001
MOI, noncontact	110 (81.5)	179 (79.2)	.683
Athlete, yes	179 (91.3)	272 (85.3)	.054
Dejour classification			.432
A	67 (37.4)	124 (43.7)	
B	58 (32.4)	70 (24.6)	
C	29 (16.2)	44 (15.5)	
D	11 (6.1)	19 (6.7)	
No dysplasia	14 (7.8)	27 (9.5)	
Wiberg classification			.988
A	18 (10.1)	30 (10.6)	
B	130 (72.6)	204 (71.8)	
C	31 (17.3)	50 (17.6)	
TT-TG, mm	16.6 [14.0-20.1]	16.9 [13.2-19.5]	.776
Sulcus angle, deg	162.0 [154.0-168.5]	161.0 [154.0-167.0]	.281
Patellar tilt, deg	23.0 [18.0-33.0]	24.0 [17.0-30.0]	.568
Caton-Deschamps Index	1.26 [1.15-1.38]	1.22 [1.10-1.36]	.019
Surgery type			<0.001
MPFLR	71 (35.7)	60 (18.8)	
MRP	99 (49.7)	127 (39.7)	
TTO	26 (13.1)	117 (36.6)	
MPFLR+TTO	3 (1.5)	16 (5.0)	

^aData are presented as n (%) or median [interquartile range]. ^bPercentages for each characteristic are based on the number of knees over the denominator of male or female knees in which a given characteristic was reported in the electronic medical record. Due to inconsistency in reporting of each variable, denominators vary by characteristic. Boldface *P* values indicate a statistically significant difference between groups (*P* < .05). BMI, body mass index; MOI, mechanism of injury; MPFLR, medial patellofemoral ligament reconstruction; MRP, medial retinacular plication/reefing/repair; TT-TG, tibial tubercle–trochlear groove; TTO, tibial tubercle osteotomy.

characteristics of a large population of patients with PFI who underwent surgery over the course of a decade at a single tertiary-care center. While the children's hospital study location may have skewed the population toward a younger age bracket than the overall PFI population, previous methodologically rigorous epidemiologic studies on PFI have shown that adolescents represent the age-based subpopulation most affected by this condition.^{12,14,35} Therefore, the location may have been more appropriate than an alternative adult-based hospital or database. Moreover, the institution at which the study was performed is unique among pediatric centers in that the maximum surgical age for patients is 35 years and that existing patients may be seen up to any age. Thus, an important young adult population—particularly young adult athletes—is accounted for in the current study, with critical age-based analyses explored, such as comparisons of skeletally immature with mature patients.

Among the associated age-based findings, a higher BMI and higher rates of bony realignment surgery in skeletally mature patients were not surprising. However, a relatively higher proportion of male patients within the skeletally immature subgroup than the mature subgroup was somewhat surprising and may speak to the degree of changes to the male musculoskeletal system during puberty, particularly the decrease in laxity, which can be a major risk factor for PFI. A significantly higher Caton-Deschamps value

among the skeletally immature PFI group suggests that patella alta may have a greater influence in the younger age group. This may simply be reflective of incompletely ossified patellae and tibial tubercles allowing for longer distances (ie, higher values) between the bony portions of 2 bony prominences, which serve as tendinous attachment points. Alternatively, skeletally mature patients may compensate better for true patella alta, on a relative scale, with more developed extensor musculature keeping the patella centered in the groove in older patients, despite being in the slightly more shallow, proximal aspect of the groove.

More than 70% of surgical cases in the current cohort were performed on female patients, which is consistent with prior literature suggesting that patellar instability is significantly more prevalent in women than in men.¹⁴ An analysis of active-duty military personnel by Hsiao et al¹⁸ revealed higher rates of patellar dislocation in female servicemembers. Similarly, Mitchell and colleagues²⁵ found that in sex-comparable sports, women were at higher risk of PFI. The female patients in our study also demonstrated higher levels of patellar tilt, consistent with a higher prevalence of patellofemoral pain previously reported in these patients.^{3,31} Ultimately, while an array of PFI risk factors may be at work in the majority of patients with PFI, trochlear dysplasia and patellar dysplasia may be stronger influences in men, while laxity and patellar tilt may be more influential factors in women.

TABLE 5
Clinical and Radiologic Parameters by Number of Preoperative Instability Events^a

Characteristic ^b	Single Event (n = 49 knees)	Multiple Events (n = 507 knees)	P
Sex, female	29 (59.2)	363 (71.6)	.073
BMI, kg/m ²	22.5 [20.6-25.4]	22.7 [20.2-26.3]	.591
Age at presentation, y	14.7 [13.6-16.1]	14.6 [13.1-16.3]	.373
MOI, noncontact	33 (73.3)	274 (81.1)	.234
Athlete, yes	46 (93.9)	437 (87.4)	.250
Dejour classification			.239
A	19 (44.2)	172 (41.0)	
B	14 (32.6)	114 (27.1)	
C	3 (7.0)	70 (16.7)	
D	1 (2.3)	29 (6.9)	
No dysplasia	6 (14.0)	35 (8.3)	
Wiberg classification			.654
A	3 (7.0)	45 (10.7)	
B	34 (79.1)	300 (71.4)	
C	6 (14.0)	75 (17.9)	
TT-TG, mm	16.4 [14.2-19.1]	16.9 [13.7-20.0]	.543
Sulcus angle, deg	162.0 [155.0-167.5]	161.0 [154.0-167.6]	.733
Patellar tilt, deg	20.0 [16.0-25.5]	24.0 [17.9-31.0]	.020
Caton-Deschamps Index	1.23 [1.08-1.34]	1.24 [1.12-1.37]	.373
Physeal status			.498
Open	22 (46.8)	177 (37.5)	
Closing	12 (25.5)	145 (30.7)	
Closed	13 (27.7)	150 (31.8)	
Age at surgery, y	14.8 [13.7-16.4]	15.2 [13.8-17.2]	.346
Surgery type			<0.001
MPFLR	5 (10.2)	126 (24.9)	
MRP	39 (79.6)	220 (43.4)	
TTO	5 (10.2)	142 (28.0)	
MPFLR+TTO	0 (0.0)	19 (3.7)	
Presence of osteochondral/chondral fracture	29 (59.2)	97 (19.1)	<0.001

^aData are presented as n (%) or median [interquartile range]. ^bPercentages for each characteristic are based on the number of knees over the denominator of male or female knees in which a given characteristic was reported in the electronic medical record. Due to inconsistency in reporting of each variable, denominators vary by characteristic. Boldface P values indicate a statistically significant difference between groups ($P < .05$). BMI, body mass index; MOI, mechanism of injury; MPFLR, medial patellofemoral ligament reconstruction; MRP, medial retinacular plication/reefing/repair; TT-TG, tibial tubercle–trochlear groove; TTO, tibial tubercle osteotomy.

The current study also indirectly explored the controversial concept of surgery for first-time PFI. Classically, surgery for PFI has been reserved for those with recurrent dislocations or a large loose-body or osteochondral fracture warranting repair or resurfacing to slow progression toward arthritis. Notably, despite the study methods excluding patients with larger osteochondral fractures or fragments >1 cm, 9% of surgeries in the cohort were performed after a first-time patellar instability event. Because approximately 59% of these procedures did involve an osteochondral or chondral fracture or fragment that underwent an arthroscopic loose-body removal, it appears that even a smaller loose body can be a driver for early surgery in this population, although the degree to which these loose bodies were symptomatic, or the actual rate of those with first-time dislocations who underwent surgery, cannot be derived from the study, which did not investigate patients who underwent nonoperative treatment. However, this substantial number of procedures performed for patients with first-time dislocations may be reflective of some evolution in thinking regarding PFI, in that some authors have

suggested better outcomes and lower recurrent instability rates after surgery for a 1-time event, compared with nonoperative treatment. For example, a recent prospective, randomized investigation of adolescents by Regalado et al²⁸ reported increased rates of redislocation in a cohort treated nonoperatively compared with a cohort treated operatively.

Knee function 6 years after primary dislocation was also superior in the operative cohort. The current study surgeons may be responding in kind, in that the percentage of patients who were treated surgically after a primary dislocation increased in each of the past 3 years of the study window. Notably, however, almost 80% of the operations on patients with first-time dislocations in the current cohort consisted of MRP alone for patellar stabilization. While the current study did not explore outcomes of the various procedures performed, MRP or its variations—sometimes referred to as “MPFL repair”—have been shown to have relatively high rates of recurrent instability, at times no better than nonoperative measures. For example, a prospective, randomized study by Palmu et al²⁷ of patients

after a primary instability event compared 28 knees treated nonoperatively with 36 knees treated operatively. These authors found that the treatment method or existence of osteochondral fracture had no significant impact on patient outcomes. Thus, when loose-body removal or osteochondral fragment fixation may need to be performed, a number of authors have moved toward utilizing more definitive or invasive patellar realignment techniques, such as MPFLR, rather than simple MRP or retinacular repair. Notably, the latter years of the current study period reflected this increase in MPFLR surgery relative to MRP. Nevertheless, it is critical that the upcoming outcome studies that will be derived from the current study cohort explore recurrence rates between techniques and between patients with first-time and recurrent dislocations to help elucidate the intricacies of the effectiveness of primary surgical treatment for patients with PFI.

The results of this study have also revealed significant changes in the preferred surgical procedures applied to recurrent PFI over the course of the 10-year study period, which was by far the more common indication for surgery. Specifically, a marked increase in both MPFLR and TTO procedures was seen over the latter 5 years (Figure 1), with the period of 2012-2013 marking a tipping point, of sorts, in technique selection. This may reflect the addition of 1 more surgeon to the division, with sports medicine fellowship training outside of the study institution. However, it may also be indicative of the steady accumulation of literature demonstrating the effectiveness of the TTO and a new body of literature introducing the MPFLR as an alternative technique. Although early MPFLR studies reported relatively high rates of complications, a better understanding of the anatomy and physiology of the ligament and corresponding structures has led to improved outcomes.³² One recent study by Erickson and colleagues¹³ prospectively studied 90 patients who underwent isolated MPFLR for patellar instability. Reported outcomes were favorable, with 96% of patients reporting no instability at 1 year postoperatively, and 100% at 2 years. Importantly for skeletally immature patients with PFI, who represented 40% of the current cohort, unlike the TTO, the MPFLR can be performed in nearly the full spectrum of skeletally immature patients with careful technique and consideration of the distal femoral physis.^{11,34}

In contrast to the proximal soft tissue procedures such as MPFLR, which are often performed in isolation, the TTO, a form of distal realignment most commonly paired with MRP in our series, is designed to alter the Q angle and eliminate or decrease the lateralizing forces of the extensor mechanism, thereby serving as a powerful tool for treating patellar instability. In their initial report on anteromedial tibial tubercle transfer, Fulkerson and colleagues¹⁶ demonstrated good or excellent subjective outcomes in 93% of patients. Similarly, Bellemans et al⁵ demonstrated improved functional scores in 28 of 29 patients treated with Fulkerson anteromedial transfers. While outcomes after medialization have been favorable overall, concerns about long-term functional outcomes remain.^{6,26} Because the study of adolescent patients has been limited to date, more robust comparative studies assessing the effectiveness of

such bony realignment techniques, relative to isolated soft tissue realignment techniques, are warranted.

Limitations

There are several important limitations to this study. Despite investigating a large cohort of young patients, the single study institution may not reflect the geographic variation in patient characteristics or surgical preferences. As previously mentioned, a pediatric hospital may skew the study population toward younger ages than is representative of the overall condition. Most importantly, the retrospective nature of the investigation inherently relies on incomplete documentation, such as recording of physical examination findings like ligamentous laxity. Focused prospective studies with uniform data collection and patient-reported outcomes will help better inform future care. Finally, the study design excluded several important PFI subpopulations, such as those with large osteochondral fractures or significant coronal plane abnormalities, which are the subjects of other ongoing studies from the study institution. Because the study was created to primarily understand patellar stabilization surgeries that were not confounded by chondral resurfacing or osteochondral fixation techniques and their implications, it was felt that this exclusion allowed for a purer investigation of the central pathology, specifically PFI.

CONCLUSION

In the current study, most adolescent and young adult patients undergoing surgical treatment for PFI were athletes, and female patients were more commonly affected than male patients within this subpopulation. Approximately 90% of patients who underwent surgery for PFI were indicated because of recurrent instability episodes, while a small proportion had sustained only a single instability event, most of whom had osteochondral fractures. Physician choice of surgical treatment has changed significantly over the past decade, with sharp increases in the utilization of MPFLR and TTO seen in parallel with a steep decline in the utilization of MRP and LR/LRL.

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