Recurrent Patellofemoral Instability in the Pediatric Patient: Management and Pitfalls

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Abstract

Purpose of Review The purpose of the review is to discuss the relevant pathoanatomy, management, complications, and technical considerations for recurrent patellofemoral instability (PFI) in the pediatric population. Special consideration is given to recent literature and management of the patient with repeat instability following surgery.

Recent Findings Patellar stabilization surgery is in principle dependent upon restoration of normal patellofemoral anatomy and dynamic alignment. Historically, treatment options have been numerous and include extensor mechanism realignment, trochleoplasty, and more recently repair and/or reconstruction of the medial patellofemoral ligament (MPFL) as a dynamic check rein during initial knee flexion. In skeletally immature patients, preference is given to physseal-sparing soft tissue procedures. While medial patellofemoral ligament reconstruction has become a popular option, postoperative failure is a persistent issue with rates ranging from 5 to 30% for PFI surgery in general without any single procedure (e.g., distal realignment, MPFL reconstruction) demonstrating clear superiority. Failure of surgical patellar stabilization is broadly believed to occur for three main reasons: (1) technical failure of the primary stabilization method, (2) unaddressed static and dynamic pathoanatomy during the primary stabilization, and (3) intrinsic risk factors (e.g., collagen disorders, ligamentous laxity).

Summary PFI is a common orthopedic condition affecting the pediatric and adolescent population. Treatment of repeat instability following surgery in the PFI patient requires understanding and addressing underlying pathoanatomic risk factors as well as risks and reasons for failure.

Keywords Patellar instability · Patellar dislocation · Patellar stabilization · Pediatric · Revision patella surgery · Skeletally immature

Introduction

Patellofemoral instability (PFI) is a frequently encountered orthopedic condition affecting children and young adolescents. The estimated population incidence among pediatric patients has ranged from 23 to 43 per 100,000 person-years and is highest among adolescents aged 14 to 18 years [1–3]. Reasons for this adolescent predominance may include rapid skeletal growth with changes in lower extremity mechanics and alignment, ligamentous laxity, early sports specialization, and increase in high-risk activity level [4]. While first-time dislocation may be successfully managed non-operatively with proper rehabilitation, bracing, and activity modification, up to 36% of patients have ipsilateral recurrent PFI [5]. While epidemiologic studies have demonstrated a relatively consistent incidence of PFI over time [1], studies have found an increasing incidence of surgery to treat PFI reflecting the trends towards earlier operative management of this condition [6].

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The pathoanatomic mechanism of PFI is complex and in many instances multifactorial. While trauma may be a causative factor, patients often have intrinsic anatomic factors that predispose them to dislocation. The rotational and trochlear anatomy of the femur, alignment of the extensor mechanism and tibial tubercle, relative imbalance of medial and lateral soft tissue structures, and generalized ligamentous laxity are all known to be contributive factors (Table 1) [7–11]. Given these intrinsic predisposing factors, non-operative management with therapy and bracing has a limited role in the recurrent dislocation patient [12, 13].

PFI commonly presents in the adolescent years near the transition to skeletal maturity causing most of the epidemiologic and treatment literature to focus on late adolescent or young adult populations. Skeletally immature patients with open physes merit special discussion where bony surgical procedures are generally contraindicated in favor of physal-sparing soft tissue balancing and realignment techniques [10]. Numerous realignment and stabilization techniques have been described in the past century with medial patellofemoral ligament (MPFL) reconstruction recently emerging as a promising option for medial restraint in early knee flexion [14, 15]. However, recurrence rates of PFI following isolated MPFL reconstruction can be as high as 26.1% in the revision setting [16]. Despite the great number of surgical options for PFI, success rates vary widely without clear superiority of any single approach [17, 18]. In their recent systematic review, Wilkens et al. found that the rate of recurrent PFI following surgical intervention in skeletally immature patients was 13.8% among all patients and was not significantly different between patients undergoing MPFL

reconstruction versus other soft tissue realignment techniques [19].

The purpose of this review is to summarize the relevant pathoanatomy, management, complications, and technical considerations for recurrent patellofemoral instability in the pediatric population. Special consideration is given to literature emerging in the last several years and management of the patient with repeat instability following surgery. Failure of surgery for PFI is broadly believed to occur for three main reasons: (1) technical failure of the primary stabilization method, (2) unaddressed static and dynamic pathoanatomy during the primary stabilization, and (3) intrinsic risk factors (e.g., collagen disorders, ligamentous laxity).

Current Methods of Stabilization

Non-operative management is a common initial treatment for first-time patella dislocations without osteochondral injury. However, if after a trial of non-operative treatment including physical therapy, activity modification, brace wear, and strength training, the patient remains symptomatic (pain, effusions, apprehension, PFI, inability to return to sport, etc.), operative options should be considered. General non-operative management following first-time patellar dislocation includes a brief period of knee immobilization (~1 week) followed by gentle range of motion exercises, ice, anti-inflammatories, quadriceps, hamstring and core strengthening exercises, and sports-specific drills [20]. On average, patients tend to obtain full knee range of motion by 6 weeks while unrestricted return to sport can vary from 6 weeks to 3 months depending on the severity of injury, sport type, and level of athletic competition [20]. Current criteria for return to play

Table 1 Checklist of considerations for recurrent patellar femoral instability in the pediatric patient following prior surgical intervention

Reason for failure	Special evaluation	Treatment
Failure of primary stabilization procedure		
TTO: non-union, fracture, inadequate anteromedialization	XR	Revision osteotomy
MPFL repair/reconstruction: inappropriate knee flexion angle for tensioning, non-anatomic tunnel position	XR	Revision MPFL reconstruction, Schottle's point Tension at appropriate knee flexion angle
Mechanical axis evaluation		
Q angle/valgus assessment	Standing alignment XR: LDFA, MPFA CT/MRI: femoral version	Growth modulation: skeletally immature, valgus Osteotomies: skeletally mature, derotation
TT-TG and/or TT-PCL distance	CT and/or MRI	TTO to correct TT-TG and/or TT-PCL
Patella alta	XR: Insall-Salvati, Caton-Deschamps ratio	Tibial tubercle distalization
Medial PFI	Clinical assessment: iatrogenic	Lateral patellofemoral ligament reconstruction, lateral patellotibial ligament reconstruction
Trochlear dysplasia	CT/MRI: Dejour classification	Trochleoplasty Sulcus deepening Lateral facet elevation

following non-operative management of patellar dislocations proposed by the International Society of Arthroscopy, Knee Surgery and Orthopedic Sports Medicine (ISAKOS) include the following: (1) absence of pain or repeat patellar instability, (2) full range of motion, (3) no knee effusion, (4) completed neuromuscular training, (5) satisfactory core strengthening and endurance, (6) limb symmetry index > 85% on hop tests, (7) adequate performance of sports-specific drills, and (8) psychological readiness to return to sport [20, 21]. Early operative correction is recommended for patients with features of malalignment that put them at high risk for recurrent instability episodes as recurrent instability and dislocation rates in this population can be as high as 70% [22]. Additionally, if a dislocation event caused a displaced osteochondral fracture (OCF), loose body removal or possible fracture fixation is indicated [15]. Typically, OCF smaller than 1 cm² are treated with surgical excision while those greater than 2–3 cm² undergo attempts at fracture fixation [23]. Surgical alignment correction and patellar stabilization can be addressed at the same time as the OCF treatment.

With all skeletally immature patients, an integral part of the surgical plan centers around preserving the physis. Typically, patients younger than 10 years old or with greater than 2–3 years of growth remaining will require physeal sparing surgical procedures due to the increased risk of growth disturbance associated with adult techniques [24]. Preoperative assessment of bone anatomical alignment dictates if bony correction is needed in combination with soft tissue stabilization. Alignment abnormalities such as increased *Q* angle (> 15°), patella alta (Caton-Deschamps ratio > 1.3), increased tibial tubercle-trochlear groove (TT-TG) distance (> 15–20 mm), increased tibial tubercle-posterior cruciate ligament distance (TT-PCL) (> 20 mm), femoral anteversion (> 30°)/tibial external rotation (> 30–40°) (aka “miserable malalignment”), and genu valgum (> 15°) have been shown to be risk factors for PFI recurrence [13, 24]. When comparing magnetic resonance imaging (MRI) of knees with and without a history of recurrent patellar instability, adult patients with recurrent patellar dislocations had significantly higher rates of trochlear dysplasia (68.3% versus 5.8%), patella alta (60% versus 20.8%), increased TT-TG distance (42% versus 3.2%), and rotational malalignment (26.7% versus 2.5%) [25].

Osseous Deformity Correction: Guided Growth or Osteotomy

All pediatric patients with recurrent PFI should obtain standing full-length alignment films to evaluate for mechanical axis deviations contributing to PFI. CT/MRI may also be obtained in order to measure femoral anteversion and tibial torsion which if elevated can lead to the so-called miserable malalignment syndrome and a lateralized pull of the extensor mechanism. Correction of the mechanical axis abnormalities depends on the age and skeletal maturity of the patient. In

skeletally immature patients with knee valgus, growth modulation via distal femoral hemiepiphyodesis may be performed. In skeletally mature patients or those with severe rotational or mechanical axis abnormalities (e.g., excessive femoral anteversion, external tibial torsion), osteotomies may be required. Correction of the bony alignment via hemiepiphyodesis or osteotomy in conjunction with MPFL reconstruction has shown to reduce rates of recurrent dislocation and improve patient outcome scores in both adult and pediatric patients [26, 27].

In addition to the mechanical axis, it is important to analyze the position of the patella in relation to the trochlear groove. Patella alta, or increased patellar height, results in the patella existing superior to the trochlear groove requiring a greater degree of knee flexion prior to trochlear engagement. Patella alta can be determined through a variety of methods (e.g., Insall-Salvati ratio (normal 0.8–1.2), Caton-Deschamps index (normal 0.6–1.3), Blackburn-Peel ratio (normal 0.5–1.0)) by evaluating a lateral radiograph of the knee [12]. Correction of patellar height via a tibial tubercle distalization procedure helps confer stability to the patellofemoral articulation via early patellar engagement but is reserved for patients who are skeletally mature [28]. However, care should be taken with distalization procedures to avoid increasing patellofemoral contact pressures and iatrogenic early PFJ arthrosis. Technical pearls to avoid overly constraining the PFJ include limiting distalization to less than 1 cm and combining distalization with anteriorization to help off load the PFJ [29, 30].

TT-TG distance is a measure used to determine lateralization of the tibial tubercle, as a surrogate for the *Q* angle, indicating an increased lateral force of the quadriceps on the patella. Tibial tubercle posterior cruciate ligament (TT-PCL) distance has been advocated by some authors in lieu of TT-TG in cases of severe trochlear dysplasia since this measurement relies solely on tibial landmarks. However, recent studies have shown that the TT-PCL describes pure lateralization of the tibial tubercle while the TT-TG describes the path of the extensor mechanism and is therefore more pertinent to PFI [31]. Skeletally mature individuals with a TT-TG greater than 20 mm have traditionally been recommended to undergo a tibial tubercle anteromedialization in combination with MPFL repair or reconstruction. Tibial tubercle anteromedialization leads to decreased patellofemoral contact pressures as well as a decreased *Q* angle. Pritsch et al. showed that tibial tubercle anteromedialization led to significantly improved Lysholm and Karlsson scores in 48 out of 66 (72.5%) skeletally mature patients at an average of 6-year follow-up [32].

Lateralizing force vectors such as an increased TT-TG (> 20 mm) and increased *Q* angle can be addressed with patella tendon-modifying procedures in skeletally immature patients, similar to tibial tubercle osteotomies (TTO) in skeletally mature patients [24]. The goal of correction is to achieve an approximately normal TT-TG distance of 10–15 mm [33]. In

skeletally immature patients, standard TTOs such as the Trillat, Maquet, and Fulkerson are not suitable because of the risk to the proximal tibial physis and tibial tubercle apophysis. Options for physeal respecting distal realignment procedures include Galeazzi tenodesis, patella tendon shortening, modified Grammont procedure (medialization of the entire patella tendon and underlying periosteum, dissecting superficial to the open apophysis), Roux-Goldthwait (translation and fixation of lateral half of the patella tendon, anteriorly, distally, and medially to the untouched medial half of the tibia), or combination procedures such as the “4 in 1” (lateral release, medial reefing, Insall tube realignment, and Roux-Goldthwait patella ligament transfer) and “3 in 1” procedure (Vastus medialis oblique (VMO) advancement, lateral release, and transfer of the medial third of the patellar tendon medially, sutured to the MCL and secured with anchors) (Table 2) [34–36]. These aim to correct enlarged Q angles, similar to a TTO, but without threatening the physis or apophysis. The Roux-Goldthwait technique allows the surgeon to medialize and distalize the patella to improve tracking similar to what would be achieved with Trillat, Maquet, and Fulkerson osteotomies, without risk for physeal disruption [36]. Critics of the Roux-Goldthwait express concern over the increased rotation and tilt of the patella that remains uncorrected with this procedure. The addition of the MPFL reconstruction corrects this lateral rotation and tilt while providing a second restraint to lateral translation [37].

Failure to recognize and correct these bony abnormalities may lead to early failure if an isolated soft tissue procedure such as MPFL repair or reconstruction is performed.

Soft Tissue Correction: MPFL Repair and Reconstruction

Greater than 90% of children with a first-time patellar dislocation will result in injury to the MPFL [38]. Various techniques for MPFL reconstruction for patellar stabilization have been

described [39–45]. MPFL advancement, if intact but elongated, can also be performed. The VMO and the MPFL blend together and can be advanced jointly to add tension to the medial structures of the PFJ and improve patellar tracking and biomechanics. Acutely, primary repair of the MPFL can be attempted; however, reconstruction is preferred if the MPFL rupture is located in the mid-substance of the ligament and in the setting of recurrent PFI [46]. In addition, it is imperative that any bony abnormalities be corrected at the time of soft tissue correction in order to mitigate the risk of PFI recurrence.

Published techniques describe MPFL repair by separating the MPFL from the VMO and medial retinaculum and suturing the deep MPFL and capsule [47]. The MPFL and underlying deep MCL/capsule naturally blend together and provide medial stability to the PFJ. Dissection of the thinned and incompetent MPFL elucidates where to focus repair and tissue strengthening efforts. Trans-osseous sutures or suture anchors can be used to reattach the ligament to the patella and femur at anatomic insertion points that do not threaten the physis. Tightening of the repair should be performed with the knee flexed to 30° with the patella centered in the groove to ensure anatomic patellofemoral contact pressures without overtightening [48]. Excessive tension can lead to pain and potentially early arthritic changes. Bryant et al. reported on 16 pediatric patients who underwent MPFL repair for tears that were torn from the patella insertion and whose femoral origins were intact [49]. They showed success with no recurrent instability at mean follow-up time of 1.5 years, and no complications were reported in their study group. This however underscores the narrow indications for MPFL repair due to variety of tear types, as they only repaired ligaments with clear tears identified from the patella insertion. Intrasubstance or complex tears of the MPFL, especially in the setting of other anatomic risk factors for recurrent PFI, have been shown to have PFI recurrence rates as high as 30% in adult patients when treated with repair alone [50, 51].

Table 2 Soft tissue distal realignment procedure in the skeletally immature patients with increased tibial tubercle to trochlear groove (TT-TG) distance

Name	Description
Galleazi tenodesis	Rerouting of proximal semitendinosus to medial border of the patella in combination with lateral release
Modified Grammont	Medialization of entire patellar tendon and underlying periosteum with dissection staying superficial to tibial tubercle apophysis
Roux-Goldthwait	Translation and fixation of lateral half of the patellar tendon anteriorly, distally and medially to an area of untouched medial tibia creating a cross or Roux patellar tendon configuration
“3 in 1” Procedure	Vastus medialis oblique advancement, lateral release, and transfer of the medial third of the patellar tendon to the MCL
“4 in 1” Procedure	Lateral release, medial reefing, Insall tube realignment, and Roux-Goldthwait procedure

MPFL reconstruction can be performed using a harvested autograft or allograft such as a semi-tendinosis or gracilis, both of which are biomechanically stronger than the native MPFL [52]. Successful reconstruction and return to sport without recurrent instability has been reported with both autografts and allografts [53]. In a systematic review of 45 studies, McNeilan et al. reported that autograft was not superior to allograft or synthetic graft reconstruction regardless of graft type, for isolated MPFL reconstruction. However, they did note that in skeletally immature patients, use of an adductor tendon autograft led to higher PFI recurrence rates [54]. Weakening the already weaker medial structures by harvesting an adductor graft to use for reconstruction is not consistent with balancing the forces acting on the patellofemoral joint. Furthermore, in a recent retrospective review of gracilis autograft versus allograft in 56 pediatric patients from 2012 to 2015, Hendawi et al. concluded that autograft had longer operating times and higher graft failure at an average of 13.8 months when compared with allograft [55]. Larger systematic reviews have shown comparable revision rates and postoperative functional outcome scores between autograft and allograft MPFL reconstruction in adult patients [15]. When considering MPFL reconstruction, use of allograft is appropriate in mitigating patient morbidity from the donor site with equivalent outcomes.

When performing an MPFL reconstruction, anatomic positioning of the graft is critical for proper restoration of the native PFJ biomechanics. Femoral positioning is confirmed radiographically at Schottle's point (Fig. 1). In the pediatric population, Schottle's point has been shown to be on average 7 ± 2 mm from the medial distal femoral physis [56]. The patella insertion in the pediatric population has been shown to have a insertion footprint range of 8 to 18 mm along the proximal half of the patella, similar to adult insertion points (Fig. 2) [57]. MPFL reconstruction

can be achieved with suture anchors, sutures, and trans-osseous tunnels, or with suture tape and anchors [58]. The surgeon should remain cautious when instrumenting the patella as patella fracture has been noted to occur with the use of suture anchors, trans-osseous tunnels, and interference screw fixation [59]. This is especially vital in the pediatric patient with a small patella and overall decreased patellar bone stock.

Trochleoplasty

Patients with trochlear dysplasia have an abnormally shaped trochlea (e.g., shallow, flat, supratrochlear spur) which can be characterized according to the Dejour classification [60]. Trochlear dysplasia significantly increases the risk for recurrent PFI since the trochlea is the most important static stabilizer of the patellofemoral joint [61]. Past studies have suggested that greater than 80% of patients with PFI have some level of trochlear dysplasia as a primary reason for recurrence [62, 63]. Trochleoplasty works by reshaping the trochlea via the removal of subchondral bone so that the overlying cartilaginous surface may be deepened resulting in normalization of the patellotrochlear contact ratio and overall congruence [64]. Recent studies have shown that isolated trochleoplasty for recurrent PFI results in overall good long-term stability and improved functional outcomes despite an unpredictable effect on the development of patellofemoral pain and arthrosis [62]. While trochleoplasty provides a stable path for patella tracking, it risks a Salter-Harris type IV transphyseal injury to open physes and can lead to anterior epiphysiodesis and genu recurvatum deformity [44].

Different trochleoplasty techniques can be performed to address the specific Dejour type [65]. Lateral wedge augmentation to address flat trochlear grooves with minimal lateral bumper can be accomplished in a physeal

Fig. 1 Schematic showing radiographic landmarks used to determine isometric femoral insertion of the medial patellofemoral ligament (Schottle's point). A line is drawn as an extension to the posterior diaphyseal femoral cortex (PFC) distally (red). A second line is drawn from the posterior tip of Blumensaat's line perpendicular to the PFC (purple). A third line is drawn from the posterior origin of the medial femoral condyle (MFC) perpendicular to the PFC (blue). Schottle's point is located anterior to the PFC and between lines 2 and 3

Fig. 2 Schematic showing the insertions of the medial patellofemoral ligament (MPFL) on the patella and femur in relation to other bony anatomic landmarks. The MPFL inserts on the proximal half of the medial patella (yellow oval) as well as the “saddle point” (red circle) between the adductor tubercle (purple circle) and medial epicondyle (blue circle) of the distal femur

sparing manner in addition to soft tissue procedures [66]. Epiphyseal elevation can also be considered in skeletally immature patients, staying distal to the anterior distal femoral physis. Nelitz et al. analyzed the results of thin flap trochleoplasty used to protect open physes in patients after their growth spurt, but still with two or more years of predicted growth remaining [44]. They reported no growth disturbances and no recurrence of PFI at 2-year follow-up. However, they did not report on early arthritic changes or long-term follow-up outcomes, which are a concern with such a procedure [44].

Currently, this procedure is more commonly performed in skeletally mature patients in European clinical practice. At present, the narrow indications for trochleoplasty include severe trochlear dysplasia (Dejour B and D) in patients that do not have preexisting patellofemoral arthritis. Importantly, the coronal and rotational alignment should also be normal or corrected if considering trochleoplasty [65].

Complications of Stabilization

In the pediatric population, non-operative management of recurrent PFI has a high recurrence rate that can affect activities of daily life [5]. However, operative management is not without complications.

Osseous Complications

The risks of complications in distal realignment procedures are inherent to any orthopedic corrective alignment surgery. When changing the patient's anatomical axes, risks of nerve injury, fracture, delayed or non-union, over or under correction, increasing contact forces, and altering the tension of ligaments are intrinsic to the change in

force vectors. In the pediatric population, the open tibial tubercle apophysis is at risk with TTOs, which if violated can lead to growth arrest of the anterior tibia and subsequent recurvatum deformity [67]. Therefore, recommended distal realignment procedures focus on soft tissue manipulations to minimize risk to the physis. These include the Roux-Goldthwait, modified Grammont, Galleazzi, and combination procedures [34–36]. Complications of these include incomplete correction, recurrent symptoms, patella tilt, increased PFJ contact pressures, anterior knee pain, and change in sport to non-weight bearing or lower level sport.

Alternatively, bony realignment procedures such as a TTO and proximal tibial osteotomy are possible in the adolescent patient with closed growth plates. In a systematic review of 21 TTO studies, complications were reported in up to 8%, which included complications associated with the type of TTO specifically, in addition to general risks of recurrent patella dislocations, subluxations, wound complications, anterior knee pain, and infections [68]. For a lateral opening wedge proximal tibial osteotomy, specific complications include peroneal nerve injury, disruption of the proximal tibia-fibula joint, LCL disruption, compartment syndrome, non-union, and delayed union. Non-union or delayed union, tibia fractures, hematoma, advanced patellofemoral arthritic changes, and need for re-operation are also potential complications of osteotomies. Notably painful or symptomatic hardware requiring future removal had the highest rate of occurrence, reportedly 16% [68]. Technical errors resulting in intraoperative fracture, malpositioning of the osteotomy, or overly aggressive rehabilitation postoperatively leading to consequential fracture must be avoided in order to prevent iatrogenic complications and recurrent PFI.

Soft Tissue Complications

MPFL repair has been historically thought to have a greater recurrence of PFI compared with MPFL reconstruction. This is likely due to the multifactorial nature of PFI, including different MPFL tear patterns and the anatomical factors inherent to the patient. Previous studies that evaluated the success of MPFL repair reported increased recurrence of PFI and higher re-tear rates compared with reconstruction [50, 69]. However, these early studies may not have consistently accounted for differing anatomical risk factors between the patients treated with repair versus reconstruction. Notably, when MPFL repair was reviewed by Dragoo et al. in 24 adult patients they reported on patient anatomical factors and associated need for surgical correction to supplement the MPFL repair at the time of surgery [48]. They added corrections, such as TTO for patients with an increased TT-TG or a lateral retinacular lengthening for patients with a positive patellar tilt, and they assessed the location of the MPFL tears: femoral attachment versus patella attachment versus mid-substance. The final outcomes following their algorithm-directed surgical corrections showed no significant difference in recurrence or re-tear in repair versus reconstruction at 2-year follow-up [48]. However, all patients requiring a bony re-alignment procedure underwent concomitant MPFL reconstruction rather than repair. This study highlights that correction of the co-existing factors in recurrent PFI is essential for a successful MPFL stabilization surgery and may allow for the successful performance of MPFL repair rather than reconstruction in a select group of patients [70].

A major contributing factor to the failure of MPFL reconstruction is graft malposition either at its patellar or femoral insertions [50, 71]. As with any ligament reconstruction, it is essential that the ligament be placed in the appropriate anatomic location and correctly tensioned in order to correctly replicate the viscoelastic properties of the native ligament. Failure to do so results in increased risk of surgical complications including recurrent PFI and potential graft failure. Anatomic positioning on the femoral origin at Schottle's point has been shown to be safe and reproducible in the skeletally immature patient [56, 72]. Failure to adequately recreate the MPFL femoral insertion is often found in patients with recurrent PFI [73]. The broad patellar MPFL insertion as described previously is along the proximal half of the medial patella and also blends into the distal VMO.

Correct graft placement and tension is fundamental to success without increasing PFJ contact pressures. From 0 to 30° of flexion, the MPFL provides the main restraint against lateral patellar translation. It remains isometric and able to act as a checkrein through up to 90° of flexion [74]. Throughout the first 90°, the tension remains relatively low, from 2 to 10 N [75]. Beyond 90° of flexion, tension in the ligament decreases. Appropriate tensioning to allow for a checkrein through a

large arc of motion while not overtightening the ligament is important in recreating the normal anatomy. Appropriate tensioning has been demonstrated as 2 N and should be assessed along with graft isometry through the knee range of motion intraoperatively [28]. Over-tensioning can lead to stiffness, early arthritis, and tension-induced fractures at the superior pole or medial rim. Likewise, large (>4.5 mm) and convergent graft tunnels can lead to iatrogenic patella fracture.

Trochleoplasty

Common complications following trochleoplasty include arthrofibrosis, fracture of the cartilaginous surface, and the development of patellofemoral arthritis. Complications of trochleoplasty, limiting its use in the USA, include high incidence of patellofemoral (PF) cartilage damage and early arthritis. In a 5-year follow-up study of 23 pediatric patients (mean age of 12.5 years), Pesenti et al. found evidence of early osteoarthritis on follow-up CT scans in 17% of patients. They cautioned to consider other options prior to trochleoplasty in the young population [66]. Furthermore, most forms of trochleoplasty are contraindicated in skeletally immature patients as the procedure may lead to significant damage to the underlying distal femoral physis and subsequent growth disturbance.

Even in skeletally mature patients, patellofemoral arthritis after trochleoplasty has been reported from 30% up to 65% [52]. Furthermore, a review by Rouanet et al. found that at 15-year follow-up, patients had significant cartilage changes and some had undergone early total knee arthroplasty [62, 76]. Preexisting chondromalacia at the time of the index procedure was correlated with progression to early arthritis. Therefore, preexisting arthritic changes in the PFJ are now considered a contraindication to trochleoplasty.

Additional Considerations

In addition to technical errors associated with the failure of index patellar stabilization procedures, malalignment, and trochlear dysplasia, it is important to consider patient compliance with physical therapy/return to play criteria and host factors such as collagen tissue abnormalities in pediatric patients with recurrent PFI. Parikh et al. showed that younger age at time of index patellar dislocation event is a known predictor for recurrent patellar instability [13]. Increased failure of non-operative treatment in the pediatric patellar instability population is likely multifactorial with a lack of physical therapy compliance, overall worse neuromuscular control compared with adults, and increased participation in high-risk sporting activities being factors. It is vital that the clinician treating the pediatric patellar instability patient counsels the patient and his/her parents on activity modification and realistic goals for

Table 3 Beighton score for hypermobility

Finding	Unilateral	Bilateral	Negative
Hyperextension of the elbow > 10°	1	2	0
Hyperextension of the knees > 10°	1	2	0
Hyperextension of small finger MCP joint > 90°	1	2	0
Ability of thumb to flex and touch forearm	1	2	0
Palms flats on floor following forward bend with knees in full extension		1	0
Maximum possible score		9	
Minimum score to indicate BJHS		4	

MCP, metacarpal phalangeal joint, *BJHS*, benign joint hypermobility syndrome

return to sport both in patients treated non-operatively and operatively. Despite surgical treatment for pediatric patellar instability, return to preinjury level of performance varies from 60 to 87% in the literature [77–79].

Criteria for return to sport following surgery for patellar instability follow the same general principles seen with non-operative management [20]. However, adjustments to the rehab protocol may need to be made in the setting of bony procedures such as osteotomies or cartilage procedures in order to allow for sufficient healing. In general, patients may return to sport once they have a pain/effusion free knee with full range of motion, adequate neuromuscular control/endurance, complete surgical site healing, and completion of a sport-specific progressive physical therapy protocol [20].

It is also important to recognize pediatric patients with congenital (fixed) or obligatory (habitual) patellar dislocations as these patients often require extensive bony realignment and soft tissue tensioning procedures with better outcomes when performed at a younger age [80]. Furthermore, in rare cases, patients may suffer from medial patellar instability in the setting of an acute traumatic dislocation or secondary to iatrogenic damage to lateral sided structures (i.e., isolated lateral release) necessitating alternative forms of surgical intervention [81, 82].

Patients with soft tissue hypermobility and generalized ligamentous laxity have been shown in previous studies to have an increased incidence of PFI [83, 84]. Generalized joint hypermobility is more prevalent in pediatric populations and in those of female gender. Nomura et al. showed that in a case series comparing 82 patients (ages 13 to 49 years old) with recurrent unilateral patellar dislocations to age-matched asymptomatic controls that patients with a history of patellar instability had significantly increased lateral patellar mobility of the contralateral knee as well as generalized joint hypermobility [85]. Generalized joint hypermobility can be determined clinically via the Beighton score (Table 3). Patients with a score of 4 or greater out of a total of 9 are typically classified as having benign joint hypermobility syndrome (BJHS) [86]. BJHS may in fact represent a mild form of Ehlers-Danlos

syndrome hypermobile type (EDSH) based on the microscopic examination of skin samples from patients with BJHS and EDSH showing similar collagen fibril composition. Patients with EDSH have ligamentous, capsular, and tendinous laxity making them prone to joint dislocation and damage. In dealing with EDSH patients with patellar instability, it is important to consider using allograft tissue for soft tissue procedures such as MPFL reconstruction given the intrinsic mechanical problems with autograft in this patient population [87]. Moreover, EDSH patients may suffer from combined medial and lateral patellar instability requiring reconstruction of both the medial and lateral patellofemoral ligaments in order to confer adequate stability [88].

Conclusions

Recurrent PFI in the pediatric patient following prior surgical intervention is a common and difficult problem. The treating surgeon should carefully evaluate the patient for technical errors in the index procedure that may have led to recurrence. Skeletal maturity of the patient may limit surgical options making them more prone to failure. It is important to consider host factors such as a malalignment, patella alta, increased TT-TG, trochlear dysplasia, and collagen tissue abnormalities when determining reasons for failure. Soft tissue procedures are prone to failure if bony malalignment is not addressed. A thorough understanding of the evaluation, surgical options, potential complications, and associated conditions with pediatric patellar instability is paramount to the long-term success of the patient.

Compliance with Ethical Standards

Conflict of Interest The authors declare they have no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- Of importance
- Of major importance

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