Special Considerations for Pediatric Patellar Instability

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Take-Home Points

- Patellofemoral joint stability is dependent on a complex interplay of musculotendinous units, ligaments, and the osteocartilaginous morphology of the patellofemoral joint.
- Varied patterns of patellar instability in the pediatric population should be recognized. Habitual dislocation in flexion and permanent dislocation are the more severe types.
- Assessment of major risk factors and, if required, their correction would influence management decisions and would have prognostic value related to outcomes.
- Physeal-sparing MPFL reconstruction can suffice for most children and adolescents with recurrent patellar dislocation.
- Distal stabilization techniques and quadricepsplasty are an important part of surgical armamentarium, especially for the more complex patellar instability patterns.

Epidemiology

In a prospective 2-year study of Finnish children, the annual incidence rate of patellar instability was 43/100,000 pediatric population. In patients 9 to 15 years of age, the incidence was approximately 1/1000. In another study, patients at highest risk for a first-time patellar dislocation were females aged 10 to 17 years. In a study in patients with traumatic hemarthrosis, 36% in the younger age group (10-14 years) and 28% in the older age group...
(15-18 years) had sustained patellar dislocation. In contrast, 22% in the younger age group and 40% in the older age group had sustained an anterior cruciate ligament tear.\(^3\)

Approximately one-half of patients who dislocate their patella suffer from long-term complications.\(^4,5\) These complications include recurrent instability, patellofemoral pain, osteochondral lesions, and eventual arthritis.\(^1,4,5\) Young, active individuals are more prone to these issues.\(^6\) Also, 39% or more of patellar dislocation patients have an associated osteochondral fracture that might influence the management.\(^1\) Thus, patellar instability in young patients is an area of concern.

### Developmental Anatomy

At 4-week gestation, the patellofemoral joint is an ectodermal sac filled with mesenchyme of the somatic mesoderm.\(^7\) Mesenchymal condensations then appear at 4 to 5 weeks gestation, followed by chondrification of both the femur and patella.\(^7\) The joint space is present by 6 weeks, and the patellar and distal femoral condyles are present at 7 weeks gestation.\(^7\) By 8 weeks gestation, the basic knee anatomy resembles that of an adult with the chondroepiphysis forming the articular surfaces of the femur, tibia, and patella.\(^7\) By this time, the extensor mechanism is formed, and active joint motion has begun, facilitating the development of the trochlear sulcus.\(^7\) The secondary ossification center in the distal femoral epiphysis forms around 36 weeks gestation.\(^8\) Postnatally, both the patella and distal femur grow through endochondral ossification.\(^9,10\)

The patella is the largest sesamoid bone in the human body.\(^11\) The patella begins as a dense consolidation of cells that differentiate as the quadriceps mechanisms develop.\(^12,13\) The patellar anlage becomes distinguishable within the quadriceps tendon around 7.5-week gestation.\(^12\) The morphology of the patella conforms to the distal femur.\(^12\) The patella molds or re-models as the knee begins to move in response to mechanical stresses.\(^7\) The patella increases in relative size during the first 6 months of gestation, then enlarges proportionately to the rest of the bones.\(^7\) Ossification begins around 3 years of age for females and 4 to 5 years of age for males.\(^8,14\) The ossification center may appear irregular as it rapidly expands.\(^14\) Ossification proceeds in a proximal to distal direction, thus giving a spurious estimation of patellar height on radiographs in children. The overall morphology of the cartilaginous patella during development is comparable to the final mature shape.\(^14\) Abnormal contact stresses on the articular surface of the patella during skeletal immaturity can lead to deformation.\(^7\)

Ultrasonographic measurements in normal patients show that trochlear groove (TG) morphology is present early and becomes more radiographically apparent as distal femoral ossification is completed.\(^15\) Anatomic dissections of aborted fetuses have verified the morphology of the TG as it remains constant during growth and the groove morphology is the same for both fetuses and adults.\(^16\) An ultrasound study performed on patients aged 12 to 18 years showed the cartilaginous sulcus angle (CSA) remained constant throughout all age groups (146°).\(^17\) The CSA however, differed in patients who suffered a patellar dislocation (average, 164°; range, 154°-195°) compared with normal knees (average CSA, 145°; range, 131°-158°).\(^15,17,18\) The osseous sulcus angle, on the other hand, appears flat at birth and the TG deepens with age. This increase in depth is more of a reflection of progressive ossification of a well-formed cartilaginous trochlea, rather than a true deepening of the sulcus.\(^17\) Thus, the axial radiographic view of the patella provides misleading information about the sulcus angle in children and should not be used to define trochlear morphology.
**Medial Patellofemoral Ligament Anatomy**

The medial patellofemoral ligament (MPFL) functions to limit the lateral translation of the patella.\(^{19}\) The attachment sites on the femur and patella for the MPFL have been studied in children.\(^{20-23}\) Cadaveric dissections in specimens aged 2 to 11 years have noted the patellar attachment to be an average of 12 mm in length with the midpoint approximately 5 mm superior to the mid-pole of the patella.\(^{22}\) The patellar footprint of the MPFL insertion was a mean 41% of the entire patellar length.\(^{22}\)

It is important to be aware of the characteristic anatomy of the MPFL, as fixation points should mimic the anatomic insertion as best as possible while also avoiding violation of the nearby physis. The MPFL originates between the adductor tubercle and the medial femoral epicondyle just distal to the distal femoral physis and attaches to the superomedial aspect of the patella.\(^{20-25}\) In relation to the physis in pediatric patients, the midpoint of MPFL insertion has been measured to be 4 mm to 9 mm distal to the femoral physis.\(^{21,24,25}\) These measurements represent averages as cadaveric studies have reported that some part of MPFL femoral insertion extends proximal to the distal femoral physis.\(^{21}\) A recent report of physeal injury to the posterior distal femoral physis during MPFL reconstruction leading to femoral flexion deformity highlights the importance of physeal-respecting surgery.\(^{26}\)

**Trochlea and Anterior Distal Femoral Physis**

The relationship between the proximal aspect of the trochlea and the anterior distal femoral physis has been recently studied in 175 knees with dysplastic trochlea.\(^{27}\) Based on magnetic resonance imaging evaluation, the lateral aspect of the trochlea extended proximal to the anterior distal femoral physis in 13% of patients and was at the level of the anterior physis in another 13% of patients (Figure 1).\(^{27}\) Hence, a cautious approach is recommended for any surgery to address trochlear dysplasia or trochlear bump in younger patients to prevent iatrogenic injury to anterior distal femoral physis and resultant genu recurvatum. The distance between the trochlea and the physis increased with increasing age.

**Limb Alignment**

Physiologically, the quadriceps angle (Q angle) changes through the course of growth. As children begin standing and walking, they stand with their feet wider apart and in genu varum.\(^{28}\) Physiologic genu varum can reach 15°.\(^{28}\) This degree lessens during the first 1.5 to 2 years of life, transitioning to physiologic valgus of nearly 12° by 3 years of age.\(^{28}\) Genu valgum, thereafter, gradually decreases to reach the adult value of around 7° to 8° by age 7 years.\(^{28}\) Increased genu valgum is a risk factor for patellar instability. In skeletally immature patients, correction of genu valgum through guided growth may be desirable in patients undergoing patellar stabilization surgery (Figures 2A, 2B).\(^{29}\)

**Pathophysiology of Pediatric Patellar Dislocation**

**Trochlear Dysplasia**

Trochlear dysplasia is an abnormal shape and depth of the TG.\(^{30}\) Up to 96% of patients with patellar dislocation have trochlear dysplasia.\(^{30,33}\) In a study of patellar instability in children, at least 1 of the 3 signs of trochlear
dysplasia (the crossing sign, supratrochlear bump, and double contour sign) was present on lateral radiographs. In another study on the growth of trochlear dysplasia in children and adolescents, all grades of trochlear dysplasia were present at all ages (ie, the dysplasia was most likely present at birth and did not necessarily worsen with age and growth). The linear dimensions of lateral and medial condylar height as well as trochlear bump increased with age but both the sulcus angle and shape of the trochlea did not change significantly. Remodeling of a dysplastic trochlea can happen if the patella is stabilized and appropriately located at a younger age, preferably before 10 years of age.

**Patellar Height**

The role of patellar height in patellar instability has been well established. In patients with patella alta, the patella remains proximal to the TG during the greater arc of knee motion, which predisposes it to patellar instability. Calculation of patellar height in children could be challenging due to incomplete ossification, as well as asymmetric ossification of the patella and the tibial tubercle (TT). Since the patella ossifies from proximal to distal, most radiographic methods that measure the patellar height from the distal aspect of the patella provide a spurious elevation of the measurement.

The Caton-Deschamps (CD) method measures the length of the patellar articular surface and the distance from the inferior edge of the articular surface to the anterosuperior corner of the tibial plateau. A ratio >1.3 signifies patella alta. The CD ratio has been verified as a simple and reliable index for measuring patellar height in children. Two other methods have been described for determining patellar height in children. Based on anteroposterior (AP) radiographs of the knee in full extension, Micheli and colleagues calculated the difference between the distance from the superior pole of the patella to the tibial plateau and the length of the patella. A positive difference signified patella alta. The Koshino method involves the ratio between a reference line from the midpoint of the patella to the midpoint of the proximal tibial physis and a second distance from the midpoint of the distal femoral physis to the midpoint of the proximal tibial physis on lateral knee radiographs. Normal values range from 0.99 to 1.20 with the knee in >30° flexion, in children 3 to 18 years of age.

**Hyperlaxity**

In contrast to adults, children have increased levels of collagen III compared with collagen I, which is responsible for tissue elasticity. Tissue elasticity leads to increased joint mobility, which is more common in children. Joint hypermobility or hyperlaxity has to be differentiated from symptomatic instability. The traditional Beighton score identifies individuals as having joint hypermobility with a score of 5/9 or higher in school-aged children. Smits-Engelsman and colleagues suggested using stricter criteria with scores of 7/9 or higher being indicative of hyperlaxity in school-aged children. A study of 1845 Swedish school children noted that females have a higher degree of joint laxity. Maximal laxity was noted in females at 15 years of age. Hyperlaxity has been demonstrated to be greater on the left side of the body and can be part of generalized syndromes including Down’s syndrome, Marfan’s syndrome, or Ehlers-Danlos syndrome.

**Limb Torsion**

Staheli and colleagues described the normative values of a lower extremity rotational profile, including femoral anteversion and tibial torsion. Children normally have increased femoral anteversion, which decreases with growth. Miserable malalignment is a term used to denote increased femoral anteversion and increased external
tibial torsion.\textsuperscript{48,49} These rotational abnormalities can increase the Q angle and the lateral forces on the patella. Femoral anteversion or internal rotation of the femur of 30° significantly increases strain in all areas of the MPFL.\textsuperscript{48} This increased strain may lead to MPFL failure and patellar instability.\textsuperscript{48} Increased internal rotation of the femur also increases contact pressure on the lateral aspect of the patellofemoral joint.\textsuperscript{48} Miserable malalignment frequently manifests following a pubertal growth spurt and may require femoral and tibial osteotomy.\textsuperscript{50}

**Syndromic Associations**

Several syndromes have patellar instability as a part of their manifestation. The more common syndromes include nail-patella syndrome, Kabuki syndrome, Down’s syndrome, and Rubinstein-Taybi syndrome.\textsuperscript{51-54} Other syndromes less commonly associated with patellar instability include Turner syndrome, patella aplasia, or absent patella syndrome. Since many patients with syndromic patellar instability are functionally limited, they may not require an aggressive approach to treatment. When treating these patients, it is important to recognize the unique features of a specific syndrome, which may affect the anesthesia risk profile, management decisions, rehabilitation, and prognosis.

**MPFL Tear Pattern**

The MPFL serves as an important constraint to the patella to prevent lateral dislocation, primarily during the first 20° to 30° of knee flexion.\textsuperscript{55,56} Injury to the MPFL is noted in over 90% of patients who suffer a patellar dislocation.\textsuperscript{57} The location of MPFL tears in pediatric patients is variably reported at the patellar attachment (10%-61%), femoral attachment (12%-73%), both (12%-35%) or mid-substance (2.5%-15%).\textsuperscript{25,57} The most common tear patterns in pediatric patients are tears at the patellar attachment.\textsuperscript{25,57} This tear pattern may be accompanied by an avulsion fracture of the medial rim of the patella, though this fracture, being extra-articular, seldom needs treatment.

**Classification**

While several authors have established extensive classification systems of patellar dislocation based on both clinical and radiographic presentation and reviews of the literature, a single classification system has not been recognized as the gold standard. In this section, in addition to presenting our preferred methods of classification, we will review some of the more recent and extensive classification systems for patellar dislocation and patellar instability.

Dejour and colleagues\textsuperscript{31} initially used both the presence of patellofemoral anatomic abnormalities and pain to define 3 types of patellar instability: major, objective, and potential patellar instability. Major patellar instability indicates that the patient has experienced more than 1 documented dislocation, objective instability involves one dislocation in addition to an associated anatomic abnormality, and potential patellar instability refers to cases in which the patient has radiographic abnormalities and patellar pain.\textsuperscript{31} Garin and colleagues\textsuperscript{58} more simplistically divided patellar dislocation patients into 2 groups: major (permanent or habitual) dislocation of the patella and recurrent dislocation. Sillanpaa\textsuperscript{59} stressed the distinction between first-time dislocation and recurrent dislocation specifically in the context of acute injuries. These classification systems were formulated with adults as the most relevant population; however, classifications targeted specifically to pediatric patients have recently been presented in the literature.
Historically, pediatric patella dislocations were simply categorized as traumatic or congenital. In 2014, Chotel and colleagues focused on classifying patellar dislocation by extensively reviewing anatomic, biomechanical, pathophysiological, and clinical patterns seen most commonly in children. They included 5 categories: congenital dislocation, permanent dislocation, habitual dislocation during knee flexion, habitual dislocation during knee extension, and recurrent dislocation; however, they did not address traumatic dislocations. Congenital dislocation is a rare condition, typically presenting at birth, which produces a pattern of functional genu valgum. Permanent dislocation typically presents after the child has started walking, but before the age of 5 years. The 2 variations of habitual dislocation typically present between ages 5 and 8 years. The final category is the most common and typically occurs during pre-adolescence or adolescence as a result of an atraumatic or trivial traumatic event or sports injury. Using more specific terminology, Hiemstra and colleagues modeled a classification system based on the traumatic, unilateral, bankart lesion, surgery (TUBS)/atraumatic, multidirectional, bilateral, rehabilitation, inferior shift (AMBRI) for shoulder dislocation classifications. The patellar dislocation system is used to identify 2 distinct subsets of patients in the patellofemoral instability population. One subset is defined by the acronym WARPS (weak, atraumatic, risky anatomy, pain, and subluxation), the other is STAID (strong, traumatic, anatomy normal, instability, and dislocation). Patients categorized by the WARPS acronym tend to experience atraumatic onsets of patellofemoral instability and demonstrate anatomic issues that increase this instability. These underlying anatomic issues include valgus alignment, ligamentous laxity, rotational abnormalities, shallow and short TG, and patella alta. On the other hand, STAID patients describe a traumatic dislocation event and do not have underlying anatomic abnormalities that predispose them to instability.

Taking into account these previous classifications, Frosch and colleagues added specific pathologies including “instability,” “maltracking,” and “loss of patellar tracking,” in addition to both clinical and radiographic factors to define 5 types of patellar dislocation and their specific treatment recommendations. Type 1 involves simple dislocation with neither maltracking nor instability and a low risk of redislocation. Type 2 is defined as primary dislocation followed by subsequent high risk of dislocation and no maltracking. Type 3 is divided into 5 subcategories of instability and maltracking issues involving soft tissue contracture, patella alta, pathological tibial tuberosity, and TG distance. Type 4 is defined as the highly unstable “floating patella,” and type 5 involves patellar maltracking without instability. In terms of treatment, conservative rehabilitation is recommended for type 1 whereas MPFL reconstruction tends to show positive outcomes for both types 2 and 3.

Parikh and Lykissas recently published a comprehensive classification system of 4 defined types of patellar dislocation in addition to voluntary patellar instability and syndromic patellar instability (Table). The 4 types are Type 1, first-time patellar dislocation; Type 2, recurrent patellar instability; Type 3, dislocatable; and Type 4, dislocated. Type 2 is further subdivided into Type 2A, which presents with positive apprehension signs, and Type 2B, which involves instabilities related to anatomic abnormalities. A distinction is also made between Type 3A or passive patellar dislocation and Type 3B habitual patellar dislocation.

The classification system proposed by Green and colleagues is more simplified with 3 main categories (Table) of pediatric patellar dislocation: traumatic (acute or recurrent), obligatory (either in flexion or extension), and fixed laterally. The acute traumatic categorization refers to patients who experienced an initial dislocation event due to trauma whereas recurrent traumatic involves repeated patella dislocations following an initial incident. Studies report that between 60% to 70% of these acute traumatic dislocations occur as a result of a sports-related incident. Obligatory dislocations occur with every episode of either knee flexion or extension, depending on the subtype. Obligatory patella dislocation in flexion typically cannot be manipulated or relocated into the trochlea while the knee is fixed but does reduce into the trochlea in full extension. Fixed lateral dislocations are rare, irreducible dislocations in which the patella stays dislocated laterally in flexion and extension. These dislocations...
often present with other congenital abnormalities. Each of these categories can be further specified as syndromic if the dislocation is associated with genetic or congenital conditions including skeletal dysplasia, Ehlers-Danlos syndrome, cerebral palsy, Marfan disease, nail-patella syndrome, Down syndrome, Rubenstein-Taybi syndrome, and Kabuki syndrome.

Surgical Techniques in Skeletally Immature Patients

While nonsurgical, conservative treatment involving physical therapy and activity modification is recommended for most patients who experience first-time traumatic patellar dislocations, many patients experience complicating factors that indicate them for surgery. These factors include recurrent dislocation, risk factors for patellofemoral instability, underlying malalignment issues, and congenital deformities. When evaluating these factors, particularly patellofemoral instability, the authors recommend assessing osteochondral lesions, age, skeletal maturity, number of previous dislocations, family history, and anatomic risk factors. Extra care should be taken when considering surgical treatment for skeletally immature patients at elevated risk for recurrent instability as the risk of cartilage damage in these cases is high.

Recently, there has been a reported increase in surgical treatment for patellar instability in the skeletally immature. This finding may be attributed to heightened awareness of factors that indicate patients for surgical treatment and increased familiarity of surgeons with newer techniques. Many surgical techniques have been described to address patellar instability involving both soft-tissue procedures and bony corrections. In this article, we discuss the various surgical techniques for MPFL reconstruction, quadricepsplasty, and distal realignment. These procedures can be paired with any number of additional procedures including, but not limited to, lateral retinacular release or lengthening, chondroplasty, TT osteotomy (in skeletally mature patients), and removal of loose bodies.

There is a need for more comprehensive studies, particularly randomized controlled trials, to evaluate the outcomes for both surgical and nonsurgical treatments for first-time dislocations. In the current literature, only very recently have surgical treatments shown outcomes that are more positive. In 2009, Nietosvaara and colleagues conducted a randomized controlled trial of nonoperative and operative treatment of primary acute patellar dislocation in both children and adolescents. After a long-term mean follow-up of 14 years, there was not a significant difference between the groups in recurrent dislocation and instability, subjective outcome, or activity scores. In a subsequent review of 5 studies including 339 knees, Hing and colleagues also found similar results in both the operative and nonoperative cohorts at risk of recurrent dislocations, Kujala scores, and reoperations. However, a recent systematic review comparing redislocation rates and clinical outcomes between surgical and conservative management of acute patellar dislocation reported more positive outcomes for the surgical cohort. This review included 627 knees, 470 of which received conservative management, 157 of which received operative treatment. The conservative cohort was followed for an average of 3.9 years and had a 31% rate of recurrent dislocation while the surgical group was followed for a mean 4.7 years and experienced a 22% redislocation rate. This study indicates that operative management for acute first-time dislocations may be the preferred treatment option.

A potential reason some of these studies did not show any significant difference between the operative and nonoperative cohort could be that the surgical cohorts included a wide range of procedures including lateral releases and MPFL repairs. Recent publications have indicated that these techniques do not produce overall positive outcomes. While each surgical treatment plan is unique depending on the patient; recently, MPFL reconstruction has been shown to have better outcomes than both nonoperative management and simple medial repair and/or lateral
MPFL Reconstruction

Indications/Overview

The MPFL is an important stabilizer for the knee that primarily resists lateral translation of the patella. Damage to the MPFL is very common in acute patellar dislocations with up to 90% of first-time dislocations resulting in injury to the MPFL. Historically, simple medial and/or lateral MPFL repairs have not been shown to improve patellofemoral kinematics significantly and often result in recurrence. To address this issue, during the past few decades, numerous MPFL reconstruction techniques have been developed to reconstruct a stronger ligament with the same kinematics as the anatomic MPFL. The ultimate goal of MPFL reconstruction is to reestablish the anatomic “checkrein” to guide the patella into the trochlea between 0° and 30° of knee flexion. An essential secondary surgical goal in skeletally immature patients is to avoid damaging the distal femoral physis.

There are many variations in both the grafts used to replace the MPFL and the means by which to secure them. The ones discussed below include free semitendinosus or gracilis autografts or grafts constructed from a pedicled adductor, patellar, or quadriceps tendon. While not used as frequently, allografts have also been used. Methods to secure these grafts in osseous tunnels include suture anchors or tenodesis screws. Incomplete osseous sockets or medial-sided bone tunnels have also been used as a method to decrease patellar fractures as they preserve the lateral patellar cortex.

Double-Bundle Hamstring Autograft

The technique most often used by the author is a double-bundle hamstring autograft harvested from either the semitendinosus or the gracilis secured by short patellar and femoral sockets. After harvesting the hamstring graft from a posteromedial incision, an approximately 90-mm graft is prepared with Krackow stitches to secure 15 mm of the tendon in each socket. Lateral radiographs are used intraoperatively to ensure the guidewire for the femoral drill hole falls along the posterior cortex of the diaphysis of the femur while AP radiographs confirm placement distal to the physis. It is important to take both AP and lateral radiographs intraoperatively due to the concave curvature of the distal femoral physis. This unique anatomy can make a point that is located distally to the physis on the AP view appear on or proximal to it on the lateral cross reference view. For the patellar socket, 2 short sockets are made in the superior half of the patella. Once the sockets have been drilled, the graft is adjusted so that the patella stays seated in the center of the trochlea between 20° and 30° of flexion. This anchoring is accomplished by securing the graft while the knee is kept at 30° of flexion. Proper tension is confirmed by ensuring that the graft does not allow lateral patella movement over one-fourth the width of the patella in extension while crepitation must not appear throughout the ROM.

Quadriceps Tendon Transfer

A combination of techniques by Steensen and colleagues, Goyal, Noyes and Albright, and Pinkowsky and Hennrikus describe an MPFL reconstruction in which the proximal end of a small medial portion of the quadriceps tendon is released and then attached to the medial epicondyle through a subcutaneous tunnel. This technique is particularly useful for cases in which the extra strength provided by the bone-quadriceps
tendon is necessary to correct more severe dysplasia. Leaving the distal end of the quadriceps tendon intact at its patellar insertion, a graft of about 8 mm x 70 mm thickness is harvested from the tendon. The free distal end of the tendon is then run anatomically through the synovium and retinaculum to be either sutured to the medial intermuscular septum at the medial femoral epicondyle or fixed in femoral tunnel using interference screw. The placement of the femoral fixation point is essential to ensure positive surgical outcomes. If the graft is secured too anteriorly, it may be too loose in extension and too tight in flexion, both of which can lead to postoperative pain, loss of normal kinematics, and overload of the medial patellofemoral cartilage. Once the ideal placement of the femoral fixation point has been confirmed by intraoperative radiographs, the graft is secured with a small absorbable suture. While this technique has good clinical results, the longitudinal scar that results from graft harvesting is cosmetically unappealing, and it is technically challenging to harvest a consistent strip of the quadriceps tendon. To address some of these concerns, Fink and colleagues described a new harvesting technique that produces more consistent grafts and requires a smaller incision.

**Adductor Magnus Tendon Transfer**

This technique is a double-bundle MPFL reconstruction that uses a pedicled graft of the distal adductor magnus tendon and suture anchors or incomplete osseous sockets to recreate the MPFL anatomically (Figure 5). Avikainen and colleagues and Sillanpää and colleagues described this procedure as a progression from the original single-strand adductor magnus transfer technique. First, maintaining the distal insertion, a graft of approximately 14 cm to 18 cm is harvested from the adductor tendon and then passed through a subcutaneous tunnel between the distal vastus medialis obliquus and the superficial joint capsule. The graft is then looped at the medial patella so that the distal bundle runs back to the adductor tubercle. With the knee at 30° of flexion to assure proper tension, the graft is secured at both the patella and near the adductor tubercle with suture anchors. Hambridge and colleagues compared a similar adductor magnus transfer with other pedicled techniques including bone-quadriceps tendon autograft and bone-patellar tendon allograft and found positive results for all 3 methods of reconstruction.

**Hemi-Patella Tendon Transfer**

In a similar technique to the adductor tendon transfer, the medial section of the patellar tendon is harvested from the TT and run from its proximal insertion at the medial patella to the medial femoral attachment via a subcutaneous tunnel. The free end of the graft is then secured with suture anchors or incomplete osseous sockets with the knee at 30° of flexion.

**Hamstring Graft With Adductor Tendon as a Pulley**

Several techniques opt to use a more dynamic model of MPFL reconstruction in which the adductor tendon or medial collateral ligament (MCL) is used as a pulley for the hamstring graft (Figure 6). The site of the pulley approximates the normal attachment of the MPFL to the femur and so acts as an effective anatomic replica of the MPFL origin. A semitendinosus graft is harvested and is prepared with continuous sutures, and 2 tunnels to secure the graft are drilled into the patella. The graft is then run subcutaneously from the medial side of the patella to the adductor magnus tubercle into which an osteoperiosteal tunnel is drilled at its distal femoral insertion. The graft is looped through the adductor tunnel and secured with sutures. Proper knee kinematics was ensured by placing the knee at 30° of flexion as the ends of the tendon are secured to the patella.
Hamstring Graft With MCL as a Pulley

The MCL can also be used as a pulley rather than the adductor tendon. The semitendinosus graft is harvested and prepared and the patella drilled as it is in the previous technique. The MCL was fashioned into a pulley by making a slit in its posterior one-third. The semitendinosus graft is looped through this slit, and both ends of the graft are held in place with suture anchors on the surface of the patella.129

Additional Procedural Combinations

Depending on the needs of the individual patient, MPFL reconstruction, and other patellar stabilization techniques can also be combined with additional procedures. Arshi and colleagues83 conducted a review of 6190 adolescents surgically treated for patellar instability and reported the most common additional procedures performed at the time of the stabilization. They found 43.7% of the population underwent lateral retinacular release, which while not effective as an isolated technique to treat patellar instability, has often been used in combination with MPFL reconstruction.131-133 There is currently a lack of consensus regarding the success of adding a lateral release to the reconstruction. Some studies report no difference while others report a decrease in stability after lateral release.98,134-136 While lateral retinacular release has been shown to decrease the force required to displace the patella, it can be surgically indicated in certain patients undergoing MPFL reconstruction.131 The authors advocate that if the lateral retinaculum is tight such that centralized patellar tracking is inhibited following the reconstruction, or if the patella cannot be pushed passively from a laterally tilted position to the neutral horizontal position, lateral retinacular lengthening should be performed to improve kinematics.132

Arshi and colleagues83 also reported a high rate of cartilage procedures, with chondroplasty performed in 31.1% and chondral fragment/loose body removal in 10.2%. These statistics suggest that a significant level of cartilage damage has occurred by the time of surgery.83

Complications

As MPFL reconstruction techniques have only recently been popularized and developed, there are not many comprehensive studies evaluating the outcomes and complications associated with these procedures. However, in the current literature, there is a general consensus that patients usually experience positive short-term clinical outcomes and relatively low complication rates.68,77 In one of the largest retrospective cohort studies of pediatric patients undergoing MPFL reconstruction, Parikh and colleagues114 reported both the type and rate of complications. They found complications occurred in 16.2% of patients, and the most common complications were recurrent patellar instability, patellar fractures, patellofemoral arthrosis, motion deficits, and stiffness with over half classified as avoidable. Most of these complications were due to technical errors with episodes of recurrent instability only reported in 4.5% of patients.114 In a comprehensive meta-analysis of MPFL reconstruction studies, Shah and colleagues137 reported a complication rate of 26% in both pediatric and adult patients. The cohort was not stratified by age, yet complications were similar to those reported by Parikh and colleagues,114 including pain, loss of knee flexion, wound complications, and patellar fracture.137

As indicated by the frequency of technical complications reported by Parikh and colleagues,114 extra caution should be taken in the operating room to minimize potential errors. In techniques that require drilling of femoral sockets, proper length for and placement of the graft is essential to reestablish proper kinematics. Studies have reported that placing the femoral socket too proximally can result in loss of ROM during flexion and increased compressive forces across the patella.138 A graft that is too short can have similar negative outcomes, and a graft
that is too long can result in recurrent instability. Positioning the graft while the knee is in 30° of flexion can help ensure the proper length and tension is achieved. Once the graft is in place, it is important to ensure the ROM and isometry before completing the fixation. It is also essential to be vigilant about potential violation of the physis and subsequent growth disturbances. To establish the safest angles for drilling the distal femoral epiphysis for graft placement, Nguyen and colleagues conducted a study using high-resolution 3-dimensional images of cadaveric distal femoral epiphyses. By recording which tunnels disrupted the physis before reaching 20 mm of depth, the authors concluded that it is safest to drill distally and anteriorly at an angle between 15° and 20°. This technique should minimize damage to the physis, notch, and distal femoral cartilage and decrease potential complications.

### Outcomes

In general, the literature reports positive outcomes for MPFL reconstruction—in both studies that address a specific technique and all-encompassing studies. Outcomes are typically reported as Kujala and Tegner scores, results from clinical examinations, and rates of subsequent recurrences. Several recent studies have also evaluated the ability of MPFL reconstruction to restore proper kinematics. Edmonds and colleagues evaluated the difference in patellofemoral joint reaction forces and load experienced by 3 groups of adolescents: a cohort treated with MPFL reconstruction, a cohort treated with soft-tissue realignment of the extensor mechanism (the Insall method), and controls. While both surgical techniques were able to restore medial constraints to the patella, the study showed that only the MPFL reconstruction cohort experienced joint reaction forces that were analogous to the control group. In comparison, the cohort that was treated with soft-tissue realignment alone experienced higher patellofemoral joint reaction forces and did not regain normal joint mechanics. These results can be used to advocate for the further use of MPFL reconstruction as an effective anatomic replacement of the native ligament. Radiographic studies have similarly reported MPFL reconstruction as an effective means to restore anatomic normality. Fabricant and colleagues conducted a radiographic study in which patella alta was corrected to normal childhood ranges in patients who underwent MPFL reconstruction technique using a hamstring autograft. Lykissas and colleagues corroborated these results with another radiographic study that reported small but significant decreases in the Blackburne-Peel index and CD index following MPFL reconstruction in 25 adolescents. As correction of patella alta allows the patella to rest in a deeper, more secure position in the TG, these results indicate that effective early MPFL reconstruction can correct for patellar anatomic abnormalities that could be future risk factors. Several studies have also reported outcomes addressing specific MPFL techniques; these are reported and discussed in this article.

### Outcomes by Technique

#### Hamstring Autograft

Reports on outcomes following MPFL reconstructions using hamstring autografts have been particularly promising. A cohort of 21 skeletally immature patients who underwent MPFL reconstruction was evaluated pre- and postoperatively with an average of a 2.8-year follow-up. The authors of the study reported no redislocation events and significant improvement in the Kujala scores, and patients were able to return to athletic activities safely. Previous studies report similar positive increases in Kujala scores, subjective patient reports, and lack of subsequent redislocation for patients who underwent either semitendinosus or gracilis autograft MPFL reconstructions. One such study further documented an average patellar inclination angle decrease from 34.3° to 18.6° following MPFL reconstruction. However, while the literature typically reports positive Kujala scores and
subjective outcomes for the hamstring autograft procedure, a study arthroscopically evaluating patellar tracking immediately following surgery and then at 6 to 26 months follow-up found that patellar tracking correction was not maintained for all patients who underwent this type of MPFL reconstruction.147

**Quadriceps Tendon Transfer Outcomes**

Studies specifically evaluating the quadriceps tendon transfer technique for MPFL reconstruction in children are sparse, but authors have reported positive clinical outcomes and low complication rates in adults. After following 32 young adults who underwent this MPFL reconstruction technique for 3 years, Goyal109 reported a significant increase in mean Kujala scores from 49.31 to 91.25 and no complications or redislocation. He argues this type of quadriceps graft has a high success rate because it is anatomically more similar to the MPFL than other grafts and does not require additional patellar fixation.101,109 Similar positive Kujala scores and minimal complications have been reported in adult patient populations.148 Abouelsoud and colleagues149 conducted one of the few studies in skeletally immature patients and reported similarly positive results with no redislocations and significantly improved Kujala scores at a mean follow-up of 29.25 months in their 16-patient cohorts.

**Adductor Magnus Tendon Transfer**

After initially describing this technique in 14 adult patients, Avikainen and colleagues96 followed this cohort and reported positive subjective results and only 1 redislocation. In a more recent study in which the adductor tendon transfer technique was compared with the quadriceps tendon transfer described above and the bone-patellar tendon allograft, Steiner and colleagues89 reported similarly significant improvement in all cohorts in Lysholm, Kujala, and Tegner scores with no redislocations. Additionally, Malecki and colleagues150 followed a cohort of 33 children with 39 knees diagnosed with recurrent patellar dislocation, who underwent MPFL reconstruction using the adductor magnus tendon. After evaluating this cohort functionally and radiographically, the authors reported improvements in Lysholm and Kujala scores, patellar tilt and congruence angles, and peak torque of the quadriceps muscle and flexor.150 However, this cohort did report postoperative redislocations in 36.4% of patients (4 of 11).150

**Hemi-Patella Tendon Transfer**

In 2012, in the first randomized controlled trial, Bitar and colleagues67 compared the outcomes of patients who underwent MPFL reconstruction via the hemi-patellar tendon technique with those who were managed nonoperatively with immobilization and physiotherapy after first-time patellar dislocation. At 2-year follow-up, the surgical cohort presented positive results with a significantly higher mean Kujala score (88.9 to 70.8) and no redislocations or subluxations. In contrast, 35% of nonoperative cases presented with recurrences and subluxations over the 2-year period.67

**MCL or Adductor Tendon as a Pulley**

Studies have reported good postoperative results and low complication rates for these dynamic techniques.128,129 In terms of kinematics, while hypermobility and patellar height were not fully corrected, improvements in patellar tilt and lateral shift were reported in a cohort of 6 patients with a minimum 4-year follow-up.129 To further evaluate whether the more dynamic pulley reconstruction technique resulted in better outcomes, Gomes and colleagues128 compared the subjective reports, clinical evaluations, and complication rates of patients who underwent MPFL reconstruction with a rigid adductor magnus fixation vs a semitendinosus tendon dynamic femoral fixation. One
case in the rigid cohort experienced a subsequent subluxation, while patients in the semitendinosus group had better subjective reports and a higher rate of return to sport. More recently, Kumahashi and colleagues specifically studied the outcomes of the MCL tendon as a pulley in 5 patients aged 14 to 15 years. They reported similar successful results as no patients experienced recurrence, and all patients exhibited improvement in radiographic measures of patellar tilt and congruence angle, lateral shift ratio, and both Kujala and Lysholm scores.

While there has yet to be a randomized controlled trial comparing all of these different techniques, there is a general consensus in the literature that patients tend to perform better following MPFL reconstruction vs MPFL repair.

**Other Stabilization Procedures, including Distal Realignment**

Patients with additional underlying deficits and malalignment issues such as significant trochlear dysplasia, increased TT-TG distance, patella alta, increased Q angle, and/or positive J sign may require stabilization procedures beyond MPFL reconstruction. TT osteotomies are often used to correct alignment issues in the adult patient population; however, these procedures are typically contraindicated in skeletally immature patients. Alternative realignment procedures for the pediatric population include both proximal and distal realignment, with proximal realignment performed primarily in children under the age of 12 years. Many variations on these procedures exist, some of which are no longer regularly performed due to poor reported outcomes. In this article, we discuss several of the techniques, focusing primarily on those that have demonstrated higher success rates.

**Galeazzi Technique**

One of the first and most famous soft-tissue techniques to address patellar instability was the semitendinosus tenodesis, published by Galeazzi in 1922 (Figure 7). This technique stabilizes the patella without altering the TT. In the original technique, a portion of the semitendinosus tendon is harvested with its tibial insertion left intact. The free end of the tendon is then secured with sutures at the periosteal groove of the medial patella. Fiume modified this technique by adding a lateral release and medial retinacular reefing. The most recent addition to this procedure was introduced by Baker and colleagues, in which a tunnel is drilled from the medial to the lateral border of the patella. Tension placed on the grafted tendon is used to reposition the patella medially and draw it downward. Preliminary literature on this modified procedure reported fair clinical results with success rates of approximately 75%. A recent study evaluating both the clinical and radiographic outcomes of this technique also indicated that while clinical results were excellent in 62.5% of patients, this technique alone was unsuccessful in fully addressing patellar instability in patients with underlying anatomic abnormalities such as patellar alta. In light of these less than ideal reports, the authors no longer recommend this technique for patellofemoral instability cases.

**Roux-Goldthwait Procedure**

The Roux-Goldthwait procedure, first described by both Roux and Goldthwait in 1888 and 1895 respectively, was later modified in 1985 to involve a lateral release, plication of the medial retinaculum, medial transfer of the lateral patellar tendon without advancement, and advancement of the vastus medialis (Figure 8). More recently, Marsh and colleagues introduced an addition to aligning the extensor mechanism with the femoral
shaft better. In this technique modification, the patellar tendon is split longitudinally, and its lateral half is detached and transferred distally beneath its medial half. The free end is then sutured to the periosteum on the medial side of the tibia. With a mean long-term follow-up of 6.2 years, Marsh and colleagues reported excellent results in 65%, good in 11%, and fair in 3% of the knees operated on with this modified technique. Of the patients in this cohort whose strength was evaluated, 80% had their strength returned to 90% of preoperative levels in the operated leg. While this study and others report improved outcomes, an increasing body of literature has found high rates of recurrence, patella infera, and other complications following the modified Roux-Goldthwait procedure. Also, a study comparing MPFL reconstruction using adductus magnus transfer with the Roux-Goldthwait procedure reported that patients in the MPFL cohort reported less pain postoperatively. In addition, whereas the Kujala and Lysholm scores, recurrence rates, patellofemoral angles, and apprehension test results did not demonstrate significant differences between these 2 groups, the MPFL group had significantly fewer abnormal congruence angles, better patellar medialization, and higher peak torque of the hamstring.

**Combined MPFL and Medial Patellotibial Ligament Reconstruction**

While the medial patellotibial ligament (MPTL) has not received much attention with regard to patellar stability, recent studies have indicated its role during higher degrees of both flexion and extension. The MPTL acts as a secondary restrictor ligament which helps release stress on the MPFL by decreasing the Q angle and further normalizing patellar kinematics. Patients who present with hyperlaxity or knee hyperextension combined with extension subluxation and flexion instability could be indicated for this additional stabilizing procedure. Both Nietosvaara and colleagues and Brown and Ahmad have described a dual MPTL and MPFL reconstruction technique using a semitendinosus hamstring graft. More recently Hinckel and colleagues described a combined MPFL and MPTL reconstruction, using a graft from the quadriceps tendon to reconstruct the MPFL and one from the patellar tendon to reconstruct the MPTL. In this technique, once the respective grafts have been harvested, a femoral insertion for the graft recreating the MPFL is fluoroscopically established so that an anchor can be inserted distal to the femoral physeal growth plate. For the MPTL insertion, attachment to the tibia below the joint line and 2 cm medial to the patellar tendon is established fluoroscopically just above the physeal growth plate on the proximal epiphysis. The MPTL graft is sutured first with the knee at 90° of flexion to establish tension similar to that of the patellar tendon. Then, the knee is placed in 30° of flexion to fix the MPFL graft to the medial patella to prevent excessive lateral translation of the patella.

**Patellar Tendon Transfer**

Patellar tendon transfer with proximal realignment is a technique used in particularly young patients to address cases of patellofemoral instability involving concomitant bony or anatomic abnormalities. This procedure is effective for young children with substantial amounts of remaining growth as it better mimics native anatomy than other realignment procedures and does not require bony remodeling. It is important to familiarize with surgical techniques to address malalignment issues in young patients as neglected alignment issues can lead to worsening of trochlear dysplasia and instability, which are very difficult to treat later on when patients are older.

The patellar tendon transfer technique (Figure 9), as described by Gordon and Schoenecker, starts with an extensive lateral retinacular release. The patellar tendon is then released from its distal insertion at the TT so that it can be moved medially without moving it inferiorly. After confirming patellar tracking and alignment by flexing the knee from 0° to 90° with the graft in place, the patellar tendon graft is secured with multiple nonabsorbable horizontal sutures. Of note, in skeletally mature patients, a TT osteotomy is used to accomplish the same goal. This osteotomy has been shown to improve both patellar height and TT-TG distance in skeletally mature patients,
but is contraindicated in skeletally immature patients.\textsuperscript{92,178}

Initial studies conducted on patellar tendon transfer have positive outcomes.\textsuperscript{179} At a mean follow-up of 5.1 years, patients reported a decrease in pain and increased the ROM and activity, and only 1 reported a postoperative redislocation.\textsuperscript{179} In more recent studies, both Benoit and colleagues\textsuperscript{36} and Garin and colleagues\textsuperscript{58} reviewed cases of patellar instability treated with patellar tendon transfer to address concomitant patellar alignment and anatomic abnormalities. They reported good functional, clinical, and radiographic outcomes with 12.5\% and 16\% recurrence rates, respectively.\textsuperscript{36,58} They also noted radiographic improvements in femoral sulcus angle, particularly in younger patients, which indicate this procedure is effective in addressing bony abnormalities that can result from neglected malalignment issues.\textsuperscript{36,58,154}

**Quadricepsplasty**

Quadricepsplasty is a lengthening and remodeling technique not frequently used in the pediatric population. The goal of this procedure in patients with significant amounts of growth remaining is to reposition the patella to ameliorate trochlear remodeling and prevent worsening symptoms and anatomic abnormalities.\textsuperscript{36} A quadricepsplasty accomplishes this by de-rotating and/or lengthening the extensor mechanism and may or may not involve a concomitant MPFL reconstruction. This procedure is particularly effective in young patients who experience obligatory dislocation.\textsuperscript{60,72} Several quadricepsplasty techniques have been described including Thompson, Curtis and Fisher, Judet, Stanisavljevic, and V-Y technique.\textsuperscript{180-186} Most techniques initially involve sharp dissection of the vastus medialis and lateralis from the rectus femoral tendon. A tongue is then fashioned out of the rectus femoral tendon. Once the vastus medialis and lateralis are detached from the margins of the patella, the knee is extended, and the distal ends of the vasti are sutured to the tongue of the rectus tendon. Effective extension facilitates flexion to 90°.\textsuperscript{184} The authors recommend a modification of this technique in which a Z lengthening of the quadriceps tendon is performed after the vastus lateralis is removed distally from the patella and the quadriceps tendon.

Several series and case reports evaluating quadricepsplasty in adult patients report positive outcomes with most patients achieving good or excellent flexion with minimal complications.\textsuperscript{183,185,187-189} Reports on quadricepsplasty used to treat conditions other than patellofemoral instability in children have reported similar positive outcomes.\textsuperscript{190-192} As quadricepsplasty for patellar instability is relatively rare in pediatric patients, there is not much relevant literature. However, Kocon and colleagues\textsuperscript{193} reported results of quadricepsplasty and quadricepsplasty combined with the modified Galeazzi procedure in 8 children (10 knees) with a mean follow-up of 3.25 years. Seventy percent of cases resulted in stabilization and correction of patellar position, and only 2 postoperative redislocations were noted.\textsuperscript{193} Additionally, in a study evaluating 6 patients suffering from patellar instability, 2 of whom were obligate dislocators, quadricepsplasty resulted in patellar stability, satisfaction, and near normal gait patterns.\textsuperscript{194}

**Figure 10** shows the surgical algorithm used for patellar instability characteristics.

**Conclusion**

Patellofemoral joint stability relies on a complex interplay of musculotendinous units, ligaments and the osteocartilaginous morphology of the patellofemoral joint. Patellar instability in pediatric patients is different from adults. Having an in-depth understanding of the remodeling potential, the insertion sites for the MPFL and its relationship to the physis are of utmost importance when planning surgery. Reducing and maintaining the patella
within the patellofemoral joint early enough can allow for remodeling of the patella and/or the trochlea to provide for lasting stability. Appropriate surgical principles, such as tensioning, can help both prevent continued pain and minimize future complications.

Key Info

Figures/Tables

Figures / Tables:

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Figure 1. Sagittal magnetic resonance imaging shows the lateral trochlear cartilage (yellow arrow) extends just above the anterior distal femoral physis (white arrow).

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Figure 2. (A) Preoperative and (B) 1-year follow-up full length radiographs show correction of genu valgum after simultaneous medial patellofemoral ligament reconstruction and transphyseal screw medial distal femur hemiepiphyseodesis. Solid line represents the anatomic axis, dotted line represents the mechanical axis.

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Figure 3. Double bundle hamstring autograft that uses patellar and femoral sockets.
Figure 4. Quadriiceps tendon transfer.

Figure 5. Adductor tendon transfer.

Figure 6. [Image not provided]
Figure 6. Hamstring graft that uses the adductor tendon as a pulley.

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Figure 7. Representation of the Galeazzi technique.

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Figure 8. Illustration of the Roux-Goldthwait procedure.

Figure 9. Graphic of the patellar tendon transfer.

Figure 10. Graphic of the patellar tendon transfer.
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