Patellar Instability in Young Athletes

Shital N. Parikh, MD[a,*], Matthew Veerkamp, BA[a], Lauren H. Redler, MD[b], John Schlechter, DO[c], Brendan A. Williams, MD[d], Moshe Yaniv, MD[e], Nicole Friel, MD[f], Sofia Hidalgo Perea, BS[g], Sara Rose Shannon[g], Daniel W. Green, MD, MS[g]

KEYWORDS

• Pediatric • Patellar instability • Patellar dislocation • Children • Physis • MPFL • Quadricepsplasty • Skeletally immature

KEY POINTS

- Besides patellofemoral anatomic risk factors, the rotational and coronal plane alignment of entire lower extremity should be evaluated.
- Prediction models should be used to estimate the rate of recurrent dislocation in young patients.
- Medial patellofemoral ligament reconstruction in skeletally immature patients is safe and effective for recurrent episodic patellar dislocation.
- Quadricepsplasty is necessary to address fixed or obligatory patellar dislocation.

INCIDENCE AND EPIDEMIOLOGY

Lateral patellar dislocation (LPD) is common during adolescence and represents one of the most frequent knee injuries in this age group.[1] The annual incidence of primary (first-time) LPD is estimated to range from 2.3 to 77.4 per 100,000 person-years, peaking during adolescence and young adulthood (**Fig. 1**). Longitudinal studies over several years have suggested that the incidence of injury is either stable or slowly rising in the adolescent age group (**Fig. 2**).[2–13] A recent report from 3 national administrative databases suggests increased rates of admission and surgical intervention for patellar instability.[13–15] These findings may be attributable either to trends toward earlier surgical

[a] Cincinnati Children's Hospital Medical Center, 3333 Burnet Avenue, Cincinnati, OH 45229, USA; [b] Columbia University, New York, NY, USA; [c] Children's Hospital of Orange County, Orange, CA, USA; [d] Children's Hospital of Philadelphia, Philadelphia, PA, USA; [e] Dana-Dwek Children's Hospital - Tel Aviv Sourasky Medical Center, Tel Aviv, Israel; [f] Shriners Hospital for Children Northern California, Sacramento, CA, USA; [g] Hospital for Special Surgery, New York, NY, USA
* Corresponding author.
E-mail address: Shital.Parikh@cchmc.org

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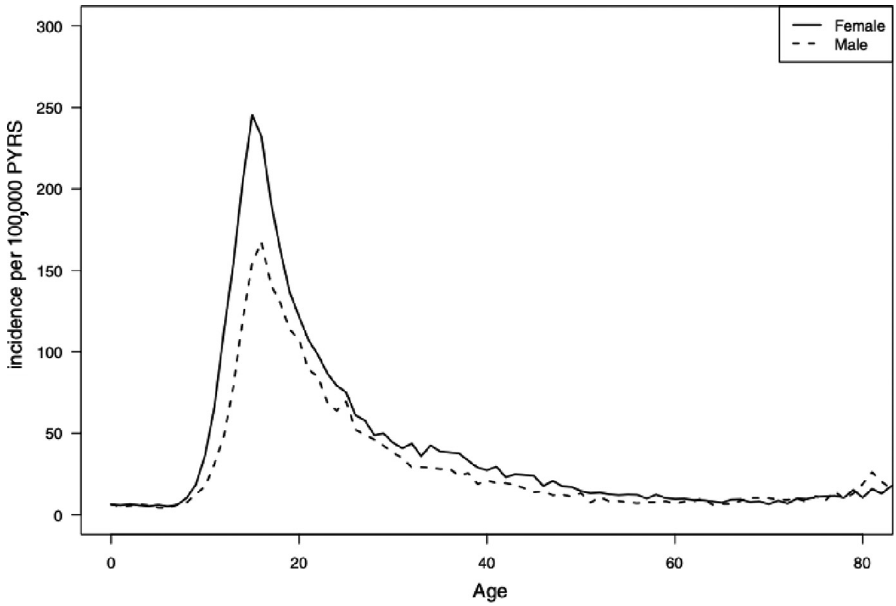

Fig. 1. Incidence of primary patellar dislocation. The figure shows the average, age-related incidence of suffering a primary patellar dislocation for the period 1994 to 2013. A primary patellar dislocation was defined as a patient with no earlier incidents in the same knee; hence, the calculation included the *International Classification of Diseases*, 10 the edition, code DS 83.0, and each individual could only be included in the analysis once with each knee. Incidence rates are reported per 100,000 person-year risk. (*From* Gravesen KS, Kallemose T, Blønd L, Troelsen A, Barfod KW. High incidence of acute and recurrent patellar dislocations: a retrospective nationwide epidemiological study involving 24.154 primary dislocations. Knee Surg Sports Traumatol Arthrosc. 2018;26(4):1204–1209. doi:10.1007/s00167-017-4594-7.)

management for this condition or perhaps a true increasing incidence of injury in response to increased youth sports participation or early sports specialization.[16]

More than one-half (55%–61%) of primary LPD events occur during sport participation in adolescents.[2,5,17,18] Much of our current understanding of the epidemiology of LPD injuries occurring during sport participation is derived from Mitchell and colleagues' study of high school athletes in the United States using the Reporting Information Online Athletic Trainers Injury Surveillance system. These researchers identified an overall LPD injury rate of 1.95 per 100,000 athletic exposures (AEs) over a 6-year period.[19] The majority (75.1%) were primary LPD events, whereas recurrent injuries from the same or prior academic year occurred in 5.7% and 17.8% of athletes, respectively. The highest rate of injury occurred during gymnastics in females (6.19/100,000 AEs) and during football (4.10/100,000 AEs) and wrestling (3.45/100,000 AEs) in males. The most common injury occurring concomitantly with LPD episodes were medial collateral ligament injuries (3.3%).

Although the overall rates of LPD seem to be similar between the sexes across numerous studies, females in the late adolescent period seem to be at greatest risk for first-time LPD with an estimated incidence as high as 100 to 150 per 100,000 in some cohorts.[2,3,8,11] Female predisposition to LPD is believed to be most attributable to sex-based anatomic differences including greater ligamentous laxity and increased

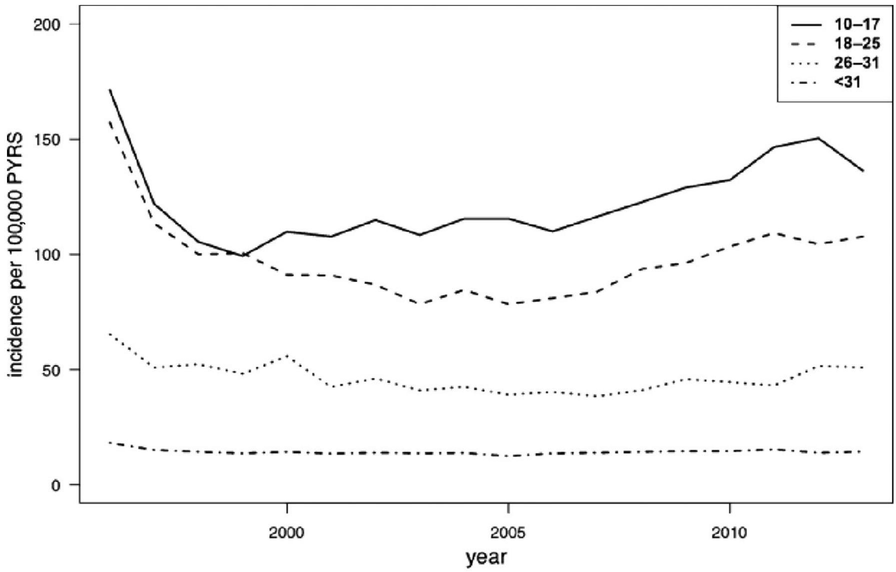

Fig. 2. Incidence rate in primary patellar dislocation from 1996 to 2013. The figure shows changes in the incidence of suffering a primary patellar dislocation from 1996 to 2013. A primary patellar dislocation was defined as a patient with no earlier incidents in the same knee; hence, the calculation included the *International Classification of Diseases*, 10 the edition, code DS 83.0, and each individual could only be included in the analysis once with each knee. Incidence rates are reported per 100,000 person-year (PYRS) risk. (*From* Gravesen KS, Kallemose T, Blønd L, Troelsen A, Barfod KW. High incidence of acute and recurrent patellar dislocations: a retrospective nationwide epidemiological study involving 24.154 primary dislocations. Knee Surg Sports Traumatol Arthrosc. 2018;26(4):1204–1209. doi:10.1007/s00167-017-4594-7.)

Q-angle owing to pelvic width and limb alignment. In their epidemiologic review of high school patellofemoral injuries, Mitchell and colleagues[19] found that the overall injury occurrence rate was lower for girls than boys (1.66 vs 2.15 per 100,000 AEs), but rates were higher for females in sex-comparable sports. Contact injuries occurred nearly twice as frequently as noncontact injuries, with contact injuries more common in male athletes and noncontact injuries more common in females. Together, these data indicate that the higher percentage of male participation in contact sports may explain gender differences in incidence of primary LPD, and that the female sport-related LPD events may be more related to their anatomic differences.

TYPES OF INSTABILITY AND CLASSIFICATION

Several classification systems for LPD have been proposed. Chotel and colleagues[20] focused on classifying patellar dislocation by extensively reviewing the anatomic, biomechanical, pathophysiological, and clinical patterns seen most commonly in children. It differentiated habitual dislocation during knee flexion from habitual dislocation during knee extension.

Parikh and Lykissas[21] published a comprehensive classification system of 4 types of patellar dislocation in addition to voluntary patellar instability and syndromic patellar instability. The 4 types were type 1 or first time patellar dislocation; type 2, or recurrent patellar instability; type 3, dislocatable; and type 4, dislocated. The classification system proposed by Green and his colleagues [1] is useful for surgical indications and

Table 1
Classification of patellofemoral instability

Type	Features
Syndromic	Connective tissue disorders predisposing to instability
Obligatory	Dislocates with every flexion
Fixed	Irreducible
Traumatic	First time vs recurrent

planning (**Table 1**). This classification system notes syndromic, obligatory (either in flexion or extension), fixed lateral, and traumatic types. Traumatic LPD represent the typical episodic dislocations seen in the majority of adolescent athletes.

Traumatic LPD by definition have an inciting event which disrupts the medial patellofemoral ligament (MPFL). Traumatic dislocations can be further subdivided into first-time (primary) or recurrent dislocations. Repeated traumatic LPD typically involve less energy with subsequent episodes owing to weakened medial supporting structures. Obligatory (habitual) patellar dislocations means that the patella dislocates with every episode of knee flexion and reduce when the knee is extended. This phenomenon is typically associated with a malpositioned and shortened quadriceps mechanism and tight lateral retinacular structures.[22,23] There is a rare subset of patients with obligatory patellar instability in extension that decreases in flexion; this finding is similar to an exaggerated J-sign. This subtype presents one of the more challenging cases to treat surgically. Fixed lateral dislocations remain laterally dislocated throughout the entire range of motion and are irreducible. This type is the rarest and is often associated with other congenital limb deficiency, but can be seen in patients with normal anatomy (**Fig. 3**). Treatment for both obligatory and fixed dislocations often requires a more extensive open reconstruction with a wide lateral release or lateral lengthening to address the tight lateral retinacular structures that are tethering the patella.[22] V–Y or other forms of quadriceps lengthening is often required for these cases as well.[23]

Syndromic dislocators have a genetic syndrome that predisposes the patient to recurrent instability, such as Marfan syndrome, Ehlers–Danlos syndrome, Down syndrome, nail–patella syndrome, or skeletal dysplasias.[1] Syndromic dislocators are predisposed to frequent or fixed patellar dislocations owing to connective tissue laxity, incompetent collagen supporting structures, trochlear dysplasia, and lower extremity deformity.[24] These patients will often present with falls during gait. Historic literature referring to cases of congenital dislocations have included cases of syndromic, obligatory, and fixed dislocations.

PATHOANATOMY

There are several pathoanatomic risk factors for patellar instability, including trochlear dysplasia, lateralization of the tibial tubercle or medialization of the trochlear groove represented by an increased tibial tubercle to trochlear groove (TT–TG) distance, patella alta, lower limb malalignment, excessive femoral anteversion and tibial torsion, hyperlaxity, and syndromic associations.

Trochlear Dysplasia

Trochlear dysplasia is an abnormal shape and depth of the trochlear groove. Dejour and colleagues[25] classified trochlear dysplasia into 1 of 4 different categories based upon a lateral radiograph and axial imaging on a computed tomography scan or MRI. Type A denotes a shallow trochlea with a sulcus angle greater than 145°, type

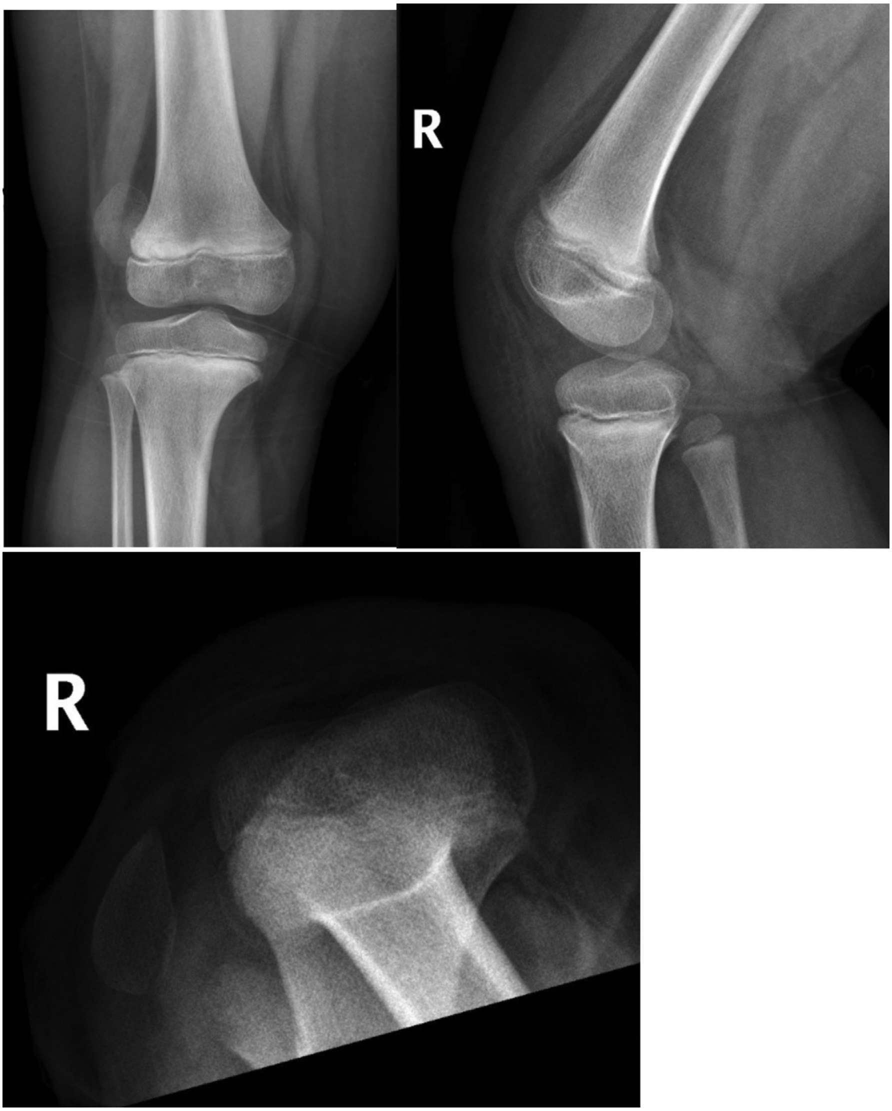

Fig. 3. Anteroposterior, lateral, and sunrise view of a fixed irreducible right knee patellar dislocation.

B has a flat trochlea, type C has a convex trochlea, and type D has a cliff pattern with a convex lateral trochlea and significantly hypoplastic medial femoral condyle. There are now more than 30 unique measurements to assess trochlear dysplasia, including lateral trochlea inclination, trochlear depth, and the ventral trochlea prominence (bump).[26] Trochlear dysplasia is most often cited as the greatest anatomic risk factor for recurrent patellar dislocation.[18,27,28]

Elevated Tibial Tubercle to Trochlear Groove Distance

An increased TT–TG distance predisposes one to patellar instability. A TT–TG of 20 mm measured on MRI has frequently been used as a cutoff value to direct surgical treatment towards a tibial tubercle osteotomy in adults, although this decision is multifactorial. In the pediatric and adolescent populations, the normative values of TT–TG distance increases with chronologic age. Thus, a growth chart type of representation may be an appropriate way to describe normal TT–TG distance, and correspondingly an abnormal TT–TG distance, for a given age.[29] Some of the drawbacks of TT–TG, including changing values with knee flexion, difficulty in identifying the trochlear groove in patients with trochlear dysplasia, and difficulty in identifying the site of anatomic abnormality, can be addressed by an alternative measurement described as the tibial tubercule-to-posterior cruciate ligament (TT–PCL) distance.[30] The TT–PCL measurement has been validated in children and its value increases with patient age.[31]

Correction of an increased TT–TG in an adult can be accomplished by an osteotomy of the tibial tubercle and medial, anterior, and/or distal transposition of the tubercle. Management in the skeletally immature patient is more challenging owing to the risk of injury to the physis, but soft tissue realignment procedures such as the Roux–Goldthwait procedure or complete patellar tendon transposition have been utilized to avoid growth plate disruption.

Patella Alta

An increased patellar height is associated with patellar instability. With the knee in full extension, the patella remains proximal to the trochlear groove, and thus the patella alta keeps the patella away from the groove through a larger arc of knee range of motion. Multiple measurements are used to measure patella height; the Caton–Deschamps index is a simple and reliable index measure on lateral radiographs of the knee for evaluating patellar height in adults and also has been validated in children (**Fig. 4**).[32] A Caton–Deschamps index of greater than 1.2 predisposes to patellar instability in children.

Lower Limb Malalignment

Genu valgum is a risk factor for patellar instability, because it produces an increased Q angle and an increased lateral force on the patella. At 3 to 4 years of age, children can have up to 20° of genu valgum, but this should normalize and be no greater than 8° by

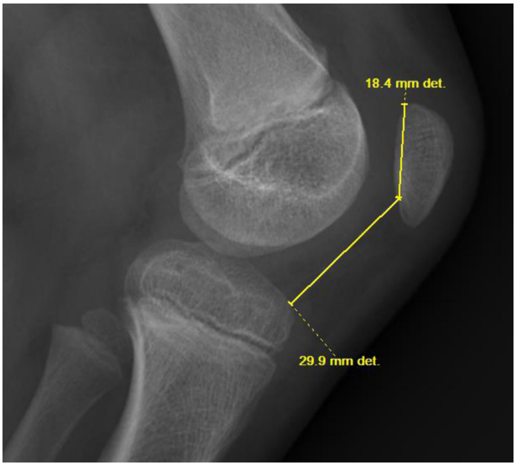

Fig. 4. Caton–Deschamps Index of 1.6 (29.9/18.4) in a 7-year-old girl with habitual patellar dislocation. As patella ossifies from proximal to distal, normative values of the Caton–Deschamps Index decrease with age.

age 12. Genu valgum in skeletally immature patients can be corrected by guided growth using a number of different methods, including a percutaneous transphyseal screw or by use of a physeal tethering device such as an 8-plate. However, the threshold value or what constitutes pathologic valgus is not known. In a recent study, guided growth of distal femur for correction of genu valgum in presence of patellar instability was performed when the lateral distal femoral angle was 84° or less, and the mechanical axis was in the lateral compartment.[33] In skeletally mature adolescents, an osteotomy, most often a lateral opening wedge distal femoral osteotomy, can achieve correction of the malalignment.

Lower Limb Torsion

The combination of excessive femoral anteversion and tibial torsion, often coupled with genu valgum, describes miserable malalignment. Excessive femoral anteversion increases strain in the MPFL, as well as increases contact pressure on the lateral aspect of the patellofemoral joint. There is no consensus regarding the acceptable tolerance of anteversion, but a derotational osteotomy can be considered in children with symptomatic patellofemoral instability and an increased femoral anteversion, based on both examination and imaging measurements.

Hyperlaxity

Hyperlaxity refers to increased joint mobility related to tissue elasticity, in which primarily type III collagen is increased. The Beighton score is a tool used to identify hyperlaxity. Traditionally, a score of 5 out of 9 or higher identifies joint hypermobility; however, it has been suggested that for children, a score of 7 out of 9 or higher should identify hypermobility. The most common diagnosis associated with hyperlaxity in this patient population is Ehlers–Danlos syndrome.

Syndromic Associations

Multiple syndromes have associated patellar instability, including Down’s syndrome, Kabuki syndrome, and nail–patella syndrome.[1] The treatment approach is individualized for each syndrome, given that children with each of these syndromes may have different functional levels.

NATURAL HISTORY OF PATELLAR INSTABILITY IN YOUNG PATIENTS

The natural history following first-time episodes of LPD in children and adolescents runs the gamut. The instability event may occur in isolation or as a 1-time phenomenon. More often, however, there tends to be a recurrence of instability that ranges from lateral maltracking of the patella with apprehension during activities to recurrent subluxations and frank dislocations. Frank dislocations may reduce spontaneously or may require formal manipulation or reduction in an emergency department setting. Ipsilateral recurrence rates after a first-time LPD range from 15% to 71%.[12,27,34–39] Contralateral dislocations may occur in 5% to 8% of patients.[12,38]

Palmu and colleagues[35] reported on 62 patients (64 knees) less than 16 years of age with primary LPD who were randomized to nonoperative treatment (28 knees) or operative treatment (36 knees). Operative treatment consisted of direct repair of the damaged medial structures if the patella was dislocatable with the patient under anesthesia (29 knees) or lateral release alone if the patella was not dislocatable with the patient under anesthesia (7 knees). The rehabilitation protocol was the same for both groups. The patients were seen at 2 years, and a telephone interview was conducted at a mean of 6 years and again at a mean of 14 years. There were 58 patients (64 knees; 94%) who were reviewed at the time of the most recent follow-up. The rates of recurrent dislocation were 71% (20/28) for the nonoperative group and 67% (24/36) for the operative group. The first redislocation occurred within 2 years after the primary injury in 23 of the 44 knees (52%) with recurrent dislocation. Instability of the contralateral patella was noted in 30 of the 62 patients (48%).

In addition to recurrent dislocation, functional limitations after an acute LPD in children and adolescents may include persistent pain, mechanical symptoms, and an inability to return to sport. The occurrence of these limitations is variable and depends on many factors, such as the nature and force of the initial inciting event, underlying pathoanatomy, ligamentous laxity, and activity level.

Depending on underlying anatomic factors, acute LPD and relocation may produce major forces at the articular surfaces.[40,41] Articular injury is best assessed with MRI and arthroscopy. Acute LPDs result in predominantly lateral femoral condylar and medial patella facet lesions.[40,42] The incidence is high and ranges from 70% to 96%.[41] Stanitski and Paletta[40] assessed 48 patients, 24 boys and 24 girls (mean age, 14 years), with acute, initial, noncontact LPD. Eleven of the 48 patients (23%) had radiologic diagnoses of articular injuries. Thirty-four of the 48 patients (71%) had arthroscopic evidence of articular damage.[40] Nomura and Inoue[42] examined 70 knees in 57 patients with recurrent patellar instability and found that 67 knees (96%) had articular cartilage lesions of the patella. In a population-based cohort study of 232 skeletally immature patients who experienced a first-time LPD with a mean follow-up of 12.1 years, Sanders and colleagues[12] reported that 20% of patients developed arthritis by 20 years after the initial dislocation.

Numerous studies have compared outcomes after nonoperative versus operative treatment after primary LPD in adolescents.[36,39,43–47] In a randomized controlled trial, Askenberger and colleagues[39] examined whether arthroscopic-assisted repair of the MPFL in patients with an acute first-time traumatic LPD would decrease the recurrence rate and offer better objective and subjective knee function compared with a knee brace without repair. They found that the redislocation rate was significantly lower in the MPFL repair group than in the knee brace group at final follow-up, but surgery did not improve subjective or objective knee function compared with a knee brace without repair. The majority of the patients in both groups were satisfied with their knee function.

The fundamentals of a nonoperative treatment algorithm after an LPD include a period of rest, cryotherapy, nonsteroidal anti-inflammatory drugs, bracing, and physical therapy. The addition of a specific patellofemoral brace may improve joint mechanics and decrease the likelihood of future instability when worn.[48] The author's preferred method of nonoperative treatment after an acute LPD in children and adolescents without chondral or osteochondral fracture is a brief period (<21 days) of immobilization in a knee immobilizer for comfort and weight bearing as tolerated with the assistance of crutches. Often, after an acute patella dislocation, there will be a large knee effusion. In patients with a large effusion, therapeutic arthrocentesis is considered to relieve pressure and pain. The initiation of a formal physical therapy regimen commences in the first 3 weeks after the injury with a focus on restoration of range of motion, normalization of gait, proprioception, and strength. Functional progression to sport-specific rehabilitation follows with an anticipated return to sport 9 to 12 weeks after the injury. A patella-stabilizing brace is used for sport and activity for the first 12 months after the initial dislocation and at the patient's discretion thereafter. It is important to recognize that poor results after nonoperative treatment of LPD may involve nonrecognition of articular injuries.[40]

PREDICTION MODELS FOR PATELLAR INSTABILITY

Several demographic and anatomic risk factors for LPD and recurrence have been identified, of which the age (chronologic age and open physes) and anatomic factors (trochlear dysplasia and patella alta) are most consistently identified.[17,18,27,34] In patients with multiple risk factors, the risk of recurrent instability increases considerably, with rates as high as 88%.[18,27] Lewallen and colleagues[18] found open/closing physes and the presence of trochlear dysplasia to be the greater risk factors for recurrence in one of the largest cohorts of adolescent patellar instability. The authors identified a recurrence rate of 68.8% in patients having both of these risk factors indicating a 3-fold increase in risk compared with skeletally mature primary dislocators without dysplasia. Individuals without these risk factors had an estimated recurrence-free survival of 85%, 73%, and 73% at 1, 3, and 5 years, respectively.

Family history is also a significant factor to consider in the epidemiology of LPD. Even in the absence of inheritable conditions of ligamentous laxity such as Ehlers–Danlos syndrome, a positive family history of LPD alone is considered to be a risk factor for dislocation events. Palmu and colleagues[35] identified that a positive family history of LPD was a risk factor for both recurrent and contralateral instability. Fithian and colleagues[2] similarly identified that patients with a family history of instability carry an increased odds of contralateral dislocation after a primary instability episode.

Depending on the duration of follow-up and the population studied, recurrent ipsilateral LPD has been reported to occur in 15% to 54% of patients after primary dislocation in adolescent and young cohorts, with a pooled rate of 41.8% in a systematic review performed by Zhang and colleagues.[2,8,12,18,27,49–51] Episodes of recurrence appear to peak during adolescence with the vast majority occurring within the first 5 years of the primary event.[12,18] Contralateral dislocation can occur in as many as 10% to 11% of pediatric and adolescent patients.[2,8,12]

Several prediction models have been developed to evaluate the risk of recurrent instability after a first-time patellar dislocation.[52] The usefulness of such models is based on the hypothesis that, if recurrent instability can be predicted after a first-time dislocation, then surgical stabilization of the patella can be considered after a first-time dislocation in selected patients. This approach would be different from the standard recommendation of conservative treatment for all first-time patellar dislocation. To date, none of the models have been validated in a prospective study.

Balcarek and colleagues[53] developed the patellar instability severity score based on age, contralateral dislocation, trochlear dysplasia, a TT–TG distance of greater than 16 mm, a patellar tilt of greater than 20°, and patellar height (**Table 2**). If the score was 4 or higher, then the odds of recurrent dislocation were 5 times higher than if the scores were less than 4.

Jaquith and Parikh[27] identified 4 risk factors based on history and lateral knee radiographs: young age, contralateral dislocation, patella alta (Caton–Deschamps index of >1.45), and trochlear dysplasia. Based on the presence of the number of risk factors, the likelihood of patellar dislocation could be estimated (**Table 3**).

Arendt and colleagues[54] reported on 3 risk factors on MRI: sulcus angle of 154°or more, an Insall–Salvati rate of 1.3 or greater, and skeletal immaturity. The probability of recurrent dislocation was 5.8% in absence of any risk factor and 78.5% if all 3 factors were present.

Recently, Ling and colleagues[55] synthesized 4 prediction models and reported on 7 variables in their multivariate model: younger age, skeletal immaturity, contralateral dislocation, trochlear dysplasia, increased TT–TG distance, increased patellar tilt, and an increased Insall–Salvati ratio. Huntington and colleagues[56] performed a

Table 2
Patellar Instability Severity Score. Odds for recurrence are 5 times higher when total score of 4 or more points

Risk Factors (Odds Ratio)		Points
Age (11.2)	>16 y	0
	≤16 y	1
Bilateral instability (3.2)	No	0
	Yes	1
Trochlear dysplasia (4.2)	None	0
	Mild	1
	Severe	2
Patellar height (1.4)	≤1.2	0
	>1.2	1
TT–TG (1.5)	<16 mm	0
	≥16 mm	1
Patellar tilt (1.9)	≤20°	0
	>20	1
	Total score range	0–7

systematic review and meta-analysis of prognostic risk factors for LPD, based on 17 studies. The overall rate of recurrent dislocations after first-time LPD was 33.6%. Recurrent rates were 7.7% to 13.8% when no risk factors were present but increased to more than 70% when 3 risk factors were present.

MEDIAL PATELLOFEMORAL LIGAMENT RECONSTRUCTION

The MPFL plays an important role as a passive restraint against lateral displacement of the patella. Owing to its important role in the patellofemoral biomechanics and the high frequency of MPFL injuries after a traumatic LPD, its reconstruction has become a mainstay for treatment of patellofemoral instability. In LPD cases where the underlying pathoanatomy is not severe enough to justify anatomic corrections, isolated MPFL reconstruction can provide satisfactory outcomes.

The femoral insertion of the MPFL has been well-described in the adult population, with most investigators agreeing that it is located anterior to a midpoint between the

Table 3
Prediction model for recurrence after first-time patellar dislocation based on number of risk factors

Risk Factors	Average Predicted Risk of Recurrence (%)	Treatment Recommendation
0	13.8	Conservative treatment
1	30.1	
2	53.6	Surgery optional
3	74.8	Surgical treatment
4	88.4	

The 4 risk factors include trochlear dysplasia, history of contralateral dislocation, skeletal immaturity, and a Caton–Deschamps index of >1.45.

medial epicondyle and the adductor tubercle.[57–59] The MPFL femoral footprint anatomic relation to the distal femoral physis is critical for its reconstruction in the skeletally immature population, owing to the risk of femoral physis injury. In a radiological study of 27 children (mean age, 14.3 years; range, 12–16 years) the center of MPFL femoral insertion was a mean of 6 mm (range, 2.9–8.5 mm) distal to the physis.[60] In a cadaveric study of 6 knees (1 month to 11 years), Shea and colleagues[61] found significant variability of the femoral foot print of the MPFL in the skeletal immature specimens. With respect to the distal femoral physis, the MPFL origin was more anterior and proximal (0.8 mm) to the physis in specimens over the age of 7 years, and posterior and distal (4.7 mm) to the physis in specimens under the age of 7 years.[61]

Different techniques have been developed for reconstruction of the MPFL in skeletally immature patients with variations in terms of graft types and fixation methods. A free or distally attached hamstring graft, quadriceps tendon pedicle graft, adductor magnus pedicled graft, allograft, and synthetic graft have all been described as options for MPFL reconstruction, with no evidence of superiority of one over the other. The need to avoid distal femoral physeal injury during MPFL femoral attachment has generated 2 main concepts. Extraosseous soft tissue fixation may use the adductor tendon insertion or medial collateral ligament origin as an anchor or a pulley. Avikainen and colleagues[62] described MPFL reconstruction with extraosseous fixation on the femoral side, using the distal adductor magnus tendon as a graft and leaving the adductor insertion in place as the femoral fixation. A hamstring graft, left attached at its tibial insertion and looped around the adductor origin and then secured to the patella, has been described.[20,63] In contrast with extraosseous fixation, intraosseous femoral fixation involves drilling a tunnel through the medial femoral condyle epiphysis. The tunnel is created distal to the distal femoral physis and under image intensifier guidance.[64] An anatomic 3-dimensional study showed a technique for safe drilling paths across the distal femoral epiphysis, such that the distal femoral physis, intercondylar notch, and trochlear articular cartilage can be avoided.[64] The location of the femoral MPFL attachment distal to the femoral physis was demonstrated to result in a more isometric graft, compared with techniques using the attachment point proximal to the physis like adductor sling technique.[65]

In a cadaveric study of MPFL patellar attachment in skeletally immature subjects, the center of the MPFL insertion was found below the midpoint of the patella in some younger specimens. In older skeletally immature specimens, MPFL insertion was found in the proximal two-thirds of the patella, similar to the location in adult anatomic studies.[66] The options for patellar graft fixation include patellar bony socket, tunnel (single or double), or longitudinal slot with anchors. Free ends or the midportion of the graft can be docked to the patella. There is a small risk of patellar fracture after tunnel or anchor placement in the patella. The use of a pedicled quadriceps tendon graft for MPFL reconstruction can help to decrease the risk of patella fracture by avoiding such patellar drill holes.[67] The MPFL graft could be looped through the periosteum and sutured to itself on the anterior aspect of the patella.[68] The graft could be looped around the quadriceps tendon and the adductor tubercle (medial quadriceps tendon–femoral ligament) to avoid any drill holes in the patella or femur.[69]

True complication rates after MPFL reconstruction surgery in the skeletal immature patient are difficult to ascertain because most of the reports focus on the adult population with multiple procedures. Recurrent patellar instability, stiffness, limited flexion, patellar fractures, pain, and arthrosis were reported in 38 of 179 knees (16.2%) of adolescents and young patients (mean age 14.5 years; range, 6–21 years) who had undergone MPFL reconstruction. One-half of the complications were attributed to erroneous surgical techniques like patellar drill placement.[70]

The cause of MPFL reconstruction failure was evaluated in 19 young patients (aged 16–27 years). The most frequent complication was redislocation associated with trochlear dysplasia or graft failure. Medial pain was associated with overtensioning of the graft or femoral tunnel malposition. Patellofemoral pain was associated with chondral damage and limb malrotation.[71]

QUADRICEPSPLASTY

Fixed and obligatory (or habitual) lateral dislocators present with pathologic morphologic anatomic risk factors, tight lateral structures, and often with a shortened extensor mechanism that contributes to patellar instability.[72] Fixed dislocation refers to an irreducible lateral dislocation throughout the knee range of motion. Obligatory dislocation in flexion refers to patients whose patella dislocates laterally every time their knee flexes. If left untreated, both types of patellar instability may lead to degenerative arthritis.[73]

Different techniques have been published to guide treatment. However, owing to the uncommon nature of both fixed and obligatory instability, there is no standard treatment algorithm in the literature. Surgical treatment must account for the variety of underlying etiologies of these conditions and the presence of open physes. Typically, MPFL reconstruction is not enough to remove the deforming forces on the patella, resulting in the need for concomitant procedures. Our approach is typically to begin with an extensive lateral retinacular release (with a lateral lengthening of the retinacular tissues when possible), which often extends into the vastus lateralis tendon, and a lengthening of the vastus lateralis tendon. If, after lateral retinacular lengthening and vastus laterals tendon lengthening the patella continues to dislocate laterally when the knee is flexed, then a formal quadriceps Z-lengthening can be performed to address the shortened extensor mechanisms and maintain the patella in the trochlear groove during knee flexion.

Various open quadriceps lengthening techniques have been described, often for congenital knee dislocations (not patella dislocations). Among these, the most frequently cited technique has been the V–Y quadricepsplasty described by Curtis and Fisher in 1969.[74] Quadriceps lengthening techniques for pediatric patellar instability are few (**Table 4**).[72,75–85] In 1976, Stanisavljevic and colleagues described a novel technique that included a proximal extensive subperiosteal realignment of the quadriceps mechanism, medial plication using the large overstretched medial capsule as a cover to the realigned patella, and an additional distal Roux–Goldthwait patellar tendon realignment procedure. At the 2-year follow-up they observed satisfactory results in 6 knees. However, there have been few, small cohort studies that have been able to replicate this technique with good outcomes, and the largest cohort to date reported an 80% recurrence of instability.[86–90]

In a study including 12 patients (15 knees), Sever and colleagues[75] performed a modified Stanisavljevic technique that included a Roux–Goldthwait distal realignment, subperiosteal quadriceps realignment, and soft tissue medial plication. One patient (8%) presented with recurrent patellar instability that occurred after a fall in the early postoperative stage. At 46.2 months of follow-up, postoperative knee extension and quality of life (measured by the Pediatric Outcome Data Collection Instrument) had significantly improved. Using a separate novel technique, Danino and colleagues[72] performed a “4-in-1” procedure on 34 patients (46 knees) that included a combination of the Roux–Goldthwait procedure, vastus medialis obliquus advancement, lateral release, and the Galeazzi procedure. Six patients presented with recurrent instability (18%). Sixteen patients (22 knees) responded to a phone interview and follow-up

Table 4
Quadriceps lengthening techniques for pediatric patellar instability

Author	No. of knees	Mean age (years)	Mean Follow-up (years)	Summarized Treatment
Williams,[77] 1968: Quadriceps contracture Obligatory dislocators Technique	NA	NA	NA	The tight lateral bands are released from the patella and the incision continued proximally, lateral to the rectus femoris tendon, thus fully releasing vastus lateralis. Vastus intermedius is inspected and divided if tight. When necessary, the rectus femoris is lengthened by extending the medial release proximally, medial to the rectus femoris tendon and dividing the rectus femoris at its musculotendinous junction. The knee is then flexed, lengthening the rectus femoris. The vastus lateralis and vastus medialis are sewn to each other and to the rectus femoris tendon in its lengthened position. If lateral dislocation is still not controlled, a medial advancement of the vastus medialis, medial plication, patellar tendon transfer, or sartorius to patella transfer is added.
Jones et al,[78] 1976: Congenital dislocation of the patella Fixed dislocators Case report	8	NA	NA	Lateral release of patella, medial transposition of patellar tendon, and plication of medial capsule or advancement of vastus medialis.
Stanisavljevic et al,[79] 1976: Congenital, irreducible, permanent lateral dislocation of the patella Fixed dislocators Therapeutic	6	NA	2	Proximal extensive subperiosteal realignment of the quadriceps mechanism, medial plication using the large overstretched medial capsule as a cover to the realigned patella, and an additional distal Roux-Goldthwait patellar tendon realignment procedure.
Gao et al,[80] 1990:	35	5	5	Extensive lateral release, medial plication, and transfer of the lateral one-

(*continued on next page*)

Table 4
(*continued*)

Author	No. of knees	Mean age (years)	Mean Follow-up (years)	Summarized Treatment
Surgical management of congenital and habitual dislocation of the patella Fixed and obligatory Therapeutic				half of the patella tendon. The vastus intermedius was released when required, and in extreme cases the rectus femoris was lengthened.
Gordon and Schoenecker,[81] 1999: Surgical treatment of congenital dislocation of the patella Fixed dislocators Therapeutic	17	7.8	5.1	Extensive procedure including lateral release and advancement of the vastus medialis obliquus. Skeletally immature children underwent medial transfer of the entire patellar tendon. Skeletally mature patients underwent medial transfer of the tibial tubercle.
Eilert,[82] 2001: Congenital Dislocation of the Patella Fixed dislocators Case report	3	NA	NA	Lateral retinaculum release, medialization of the patellar ligament followed by a Z or Z–Y quadricepsplasty and a medial plication of the quadriceps mechanism. The lengthening is done proximal to the patella through the tendinous fibers of the muscle as they insert into the patella. In older patients a Galeazzi procedure was also performed.
Martin et al,[83] 2013: Treatment of femoral lengthening-related knee stiffness with a novel quadricepsplasty Obligatory dislocators Therapeutic	6	18.7	6.2	Distal medial to proximal lateral oblique transection of the main quadriceps tendon and the transposition to the medial side of the proximal aspect of the tendon.
Inan et al,[84] 2015: A combined procedure for irreducible dislocation of patella in children with ligamentous laxity: a preliminary report Fixed dislocators Therapeutic	14	6.9	3.1	The tensor fascia was divided into 2 strips, and these strips were passed via the joint and sutured to themselves. The combined procedure additionally includes lateral capsular release, vastus lateralis resection, medial capsular plication, and Z-plasty of the rectus femoris tendon.

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Table 4
(*continued*)

Author	No. of knees	Mean age (years)	Mean Follow-up (years)	Summarized Treatment
Niedzielski et al,[85] 2015: The results of an extensive soft tissue procedure in the treatment of obligatory patellar dislocation in children with ligamentous laxity: a postoperative isokinetic study Obligatory dislocators Therapeutic	11	NA	8.1	Extensive soft tissue procedure: vastus medialis advancement, lateral release, partial patellar ligament transposition and Galeazzi semitendinosus tenodesis.
Sever et al,[75] 2019: Surgical treatment of congenital and obligatory dislocation of the patella in children Fixed and obligatory dislocators Therapeutic	15	Fixed: 7.6 Obligatory: 7.3	3.9	Modified Stanisavljevic technique; fascia lata was split rather than excised and in patients in whom the insertion of the split lateral portion of the patellar tendon over (rather than under) the medial portion eliminated patellar tilt. Moreover, did not close the lateral fascial window created by the medial mobilization of the quadriceps muscle.
Danino et al,[72] 2020: Four-in-one extensor realignment for the treatment of obligatory or fixed, lateral patellar instability in skeletally immature knee Fixed and obligatory dislocators Therapeutic	46	10.3	4.3	The 4-in-1 extensor realignment procedure uses an extensive lateral release, Roux–Goldthwait procedure, Galeazzi procedure, and vastus medialis obliquus advancement.
Ellsworth et al,[76] 2021: Stepwise lengthening of the quadriceps extensor mechanism for severe obligatory and fixed patella dislocators Fixed and obligatory dislocators Technique	24	NA	NA	Stepwise lengthening of the extensor mechanism composed of a lateral retinaculum lengthening, followed by a vastus lateralis tendon lengthening and if the patella continues to dislocate in flexion a Z-lengthening quadricepsplasty. These 3 procedures are followed by an MPFL reconstruction.

questionnaire, of which 91% returned to sports at an average of 23.1 weeks of follow-up. After using the 4-in-1 technique in 6 knees, Joo and colleagues[91] observed no recurrence of instability at 54.5 months of follow-up. Both Sever and colleagues and Danino and colleagues reported a low incidence of patellar instability recurrence and neither reported extensor lag after surgery, demonstrating that there may be multiple techniques to treat these complex cases.[72,75]

These authors' preferred technique is the stepwise lengthening of the extensor mechanism previously described by Ellsworth and colleagues[76] and characterized by an extensive lateral release or lengthening, vastus lateralis lengthening, and a separate Z-lengthening of the rectus and intermedius tendon (if needed); this procedure permits the surgeon to preferentially lengthen the lateral aspect of the quadriceps tendon more than the medial aspect.

MANAGEMENT OF ANATOMIC RISK FACTORS

Several anatomic risk factors increase the likelihood of recurrent episodes of patellar instability, including but not limited to patella alta, trochlear dysplasia, elevated TT–TG, genu valgum, femoral anteroversion, and patellar tilt.[92]

Patella Alta

Patella alta is defined as the displacement of the patella within the trochlear groove of the femur, usually in an orientation that is considered high.[93,94] This instability is most commonly the result of an injury owing to overextension, quick and unnatural changes in movements, and frequently a predisposed developmental condition.[95] Patients can develop patella alta at any age, with many displacements occurring in active teenagers and adults. This instability contributes to overall anterior knee pain, demonstrated when patients simply walk.[96] Previous studies found that subjects with patella alta compared with the control group, when walking, had incrementally smaller amounts of patellofemoral contact area at the point of maximal stress.[97]

To improve patella alta, common options are used. The transfer of the tibial tuberosity is an option for skeletally mature patients.[98] However, children who have severe displacement will most likely achieve surgical stabilization through MPFL reconstruction.[99] Partial or complete distal transposition of patellar tendon, patellar tendon imbrication and patellar tendon shortening methods have been described to address patella alta in skeletally immature patients.

An MPFL reconstruction alone has been shown to decrease preoperative patella alta in patient presenting with patella instability.[24,100] In a study performed by Fabricant and colleagues[24] that included 27 pediatric patients, the Insall–Salvati Ratio, Modified Insall–Salvati Ratio, and Caton–Deschamps measures (patella alta indices) improved significantly ($P < .001$) after undergoing MPFL reconstruction without a distal realignment procedure. Lykissas and colleagues[100] observed similar outcomes when comparing preoperative and post-MPFL reconstruction Insall–Salvati ratio, Blackburne–Peel index, Caton–Deschamps index, and plateau–patella angle in 38 pediatric patients.

Trochlear Dysplasia

Trochlear dysplasia is one of the leading causes of patella instability in which a patient possesses a slightly flat or prominent trochlea, resulting in pain within the anterior femoral cortex.[28] Trochlear dysplasia is most commonly the result of genetic risk factors with morphologic trochlea changes leading to greater instability and further injury.[101] There are several different types of trochlear dysplasia, with type A demonstrating a shallow trochlea, type B displaying a flat trochlea, type C presenting a convex trochlea, and type D showing asymmetry of trochlear facets and a vertical cliff pattern.[102]

Many surgical treatments have been explored for the various types of trochlear dysplasia, with many being performed in association with other procedures. Trochleoplasty is suggested as the most common procedure for high-grade trochlear dysplasia.[103] Deepening trochleoplasty has been found to be a safe procedure that reduces patella instability.[104] In addition to this technique, recession-wedge trochleoplasty has shown improvement in patients by reducing the bump on the trochlea.[105] This trochleoplasty procedure has essentially only been reported in adults or adolescents near the end of growth; therefore, there is little literature to support this surgical approach in skeletally immature patients.

Tibial Tubercle to Trochlear Groove Distance

The TT–TG distance is defined as the lateral distance or deviation between the tibial tubercle relative to the center of the trochlea in the axial plane.[106] An abnormal TT–TG distance, defined as greater than or equal to 20 mm in adults, has a greater than 90% association with patellar instability.[28] However, Dickens and colleagues[29] demonstrated that, similar to other pediatric orthopedic assessments, the TT–TG depends on chronologic age. In their study, skeletally immature patients with patellar instability had an average TT–TG of 12.1 mm. Thus, clinicians must use an age-based approach when measuring this distance and defer from using the adult parameters.[29]

Although the TT–TG distance is a well-established indicator for patellar instability, there are multiple limitations to this measurement; it is confounded by age, gives no information about the anatomic malformation location, and varies with the degree of knee flexion on cross-sectional imaging.[29,30,107] To overcome these shortcomings, the TT–PCL has been proposed as an alternate measurement; it quantifies the position of the tibial tubercule in respect to the tibia alone and independent of the trochlea, better describing the lateralization of the tibial tubercle.[30] However, in a study of 566 pediatric patients, Clifton and colleagues[31] showed that, similar to the TT–TG, the TT–PCL was cofounded by age and did not correlate to recurrent patellar instability. Moreover, in 2018, Brady and colleagues[107] demonstrated that the TT–TG distance was superior at differentiating patellar instability compared with the TT–PCL. However, several studies have suggested that the TT–PCL may be a useful measurement to determine surgical treatment when used in conjunction with TT–TG.[107,108]

Genu Valgum

Genu valgum, also known as knocked knees, is a prevalent orthopedic deformity in the coronal plane of the lower extremity. This condition has been associated with patellofemoral instability, because it alters the forces on the lateral aspect of the patellofemoral joint.[109,110] If left uncorrected when performing an MPFL reconstruction, genu valgum and its subsequent increased tensile forces can lead to graft failure and poor clinical outcomes.[33] Typically corrected using a distal femoral osteotomy in adults, correction in skeletally immature patients can be achieved by growth modulation, such as implant-mediated guided growth.[22,111–113] In a recent study, Parikh and colleagues[33] demonstrated that performing an MPFL and implant-mediated guided growth simultaneously could correct the angular deformity without interfering with graft placement.

Femoral anteversion

The role of rotational malalignment such as femoral anteversion in relation to patellar instability has been recognized as an important anatomic risk factor.[28,114,115] A study conducted by Diederichs and colleagues[116] that compared rotational alignment on MRI of nontraumatic patellofemoral instability with healthy controls suggested that higher femoral anteversion and knee rotation can be associated to patellofemoral instability. Moreover, in a study including 70 knees with a mean of 28 months of follow-up, Zhang and colleagues[117] showed that patients with increased femoral anteversion had inferior clinical outcomes and worse patient-reported outcomes after MPFL reconstruction and combined tibial tubercle osteotomy. Given the adverse effect of elevated femoral anteversion, clinicians should consider performing a concomitant derotational distal femoral osteotomy.[117–120]

Patellar Tilt

Patellar tilt is a static radiographic measure of patellar tracking.[121] Once believed to have been the leading cause of patellar instability, recent studies have shown it to be a consequence of other pathologic anatomic risk factors, such as elevated TT–TG, patella alta, and trochlear dysplasia, rather than an independent factor.[122–124] A continuation of these studies performed by Kaiser and colleagues[125] demonstrated that patellar tilt is mainly influenced by knee torsion, TT–TG, and trochlear dysplasia, but not by femoral or tibial torsion. An abnormal patellar tilt, defined as more than 20° on axial computed tomography images, can be corrected surgically by performing a lateral retinacular release (or lengthening), in addition to an MPFL reconstruction, and distal realignment (if needed).[126]

Other Markers

The aforementioned risk factors are well-documented in the literature. Recent studies have shifted to novel measurements that will provide clinicians with a better understanding of the degree of patellofemoral instability and guide surgical treatment alongside the standard risk factors already used. In a study including 215 pediatric patients' MRIs, Mistovich and colleagues[127] proposed using the patellar tendon lateral to the lateral trochlear ridge distance. Their study demonstrated this measurement to be similarly sensitive to TT–TG but with higher specificity for patellofemoral dislocations.[127]

Moreover, Chassaing and colleagues[128] demonstrated that TT torsion correlated with the TT–TG and patellar tilt. In a 2021 study comparing fixed and obligatory dislocators, standard patellofemoral instability patients, and controls, Lin and colleagues[129] showed that the degree of tibiofemoral rotation correlated to the severity of patellofemoral instability. Both studies introduced these 2 novel parameters as reliable patellar instability risk factors.

SUMMARY

The management of patellar instability in young patients continues to evolve. Owing to its multifactorial nature, several demographic and anatomic risk factors need to be considered during medical decision making process. The role of MPFL is increasingly recognized and physeal-respecting MPFL reconstruction can be safely performed in skeletally immature patients. On the other hand, quadricepsplasty for fixed and habitual patellar dislocation is challenging. No single procedure is appropriate for all cases and treatment should be tailored to each patient.

DISCLOSURE

The authors have nothing to disclose.

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