Diagnosis and Management of Traumatic Patellar Instability in the Pediatric Patient

STEVEN F. DEFRODA, MD; JOSEPH A. GIL, MD; ALEX BOULOS, BS; ARISTIDES I. CRUZ JR, MD, MBA

abstract

Instability of the patella is a common cause of knee pain and dysfunction in pediatric and adolescent patients and can be due to several factors. Although some patients will recall a specific traumatic event others may not, requiring the diagnosis to be made on the basis of physical examination and imaging. Congenital dislocation and connective tissue disorders should also be considered, even in the setting of trauma. There are radiographic parameters that may identify causes of instability such as trochlear and patellar abnormalities, and magnetic resonance imaging can identify signs of trauma such as bony edema, loose osteochondral fragments, and increased tibial tubercle–trochlear groove distance. The first line of treatment for instability is most commonly nonoperative in nature; however, there are many options for operative management in the event of severe chondral injury or recurrent dislocation. Surgical management to best restore stability of the patellofemoral joint varies depending on the skeletal maturity of the patient and the source of instability (ligamentous, osteocartilaginous, or both). A combination of soft tissue, bony, and anatomic ligamentous repair or reconstruction is used to best augment patellar tracking and optimize patient outcome. [Orthopedics. 201x; xx(x):xx-xx.]

The patella optimizes the lever arm of the knee during flexion by increasing the length of the quadriceps tendon lever arm from the center of rotation of the knee.1 Patellar stability requires balanced bony and soft tissue constraints. The peak incidence of patellar dislocation occurs between the ages of 15 and 19 years, with a rate of 11.19 per 100,000 person-years compared with 2.1 per 100,000 person-years in the general population.2 The rate of acute patellar dislocation is 33% higher in females than in males, and the risk of recurrent injuries is 3 times higher in females.3

Patellar instability involves varying degrees of lateral patellar translation relative to the femoral trochlea beyond its physiologic limits.4 The etiology of pediatric patellar instability can be multifactorial, with more risk factors (genu valgum knee, increased femoral antversion, external tibial torsion, patella/trochlear dysplasia, increased tibial tubercle–trochlear groove [TT-TG] distance, and ligamentous laxity) resulting in a higher probability of acute or recurrent dislocation. The utility of surgical vs nonsurgical management depends on patient risk factors, making it necessary to consider numerous variables when diagnosing and managing instability.5

ETIOLOGY

Patellar instability is the result of structural compromise of the bony and soft tissue restraints of the patellofemoral joint. Patellar instability occurs frequently secondary to trauma, and developmental dysplasia of the trochlea and the patella may increase the risk of patellar dislocation.

The authors are from the Department of Orthopaedic Surgery (SFD, JAG, AB) and the Division of Pediatric Orthopaedic Surgery (AIC), Warren Alpert School of Medicine, Brown University, Providence, Rhode Island.

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Correspondence should be addressed to: Steven F. DeFroda, MD, Department of Orthopaedic Surgery, Warren Alpert School of Medicine, Brown University, 593 Eddy St, Providence, RI 02903 (sdefroda@gmail.com).

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For patients with patellar instability who have normal bony anatomy, soft tissue restraints should be investigated for laxity resulting from a connective tissue disorder, particularly if the instability event is atraumatic.

**TRAUMA**

Traumatic dislocation is a major cause of patellar instability. Traumatic injuries causing instability account for approximately 3% of all knee injuries and 51% of all patellar dislocations. Many of these injuries occur during sports or other physical activities, causing a partial or complete tear of the medial soft tissues stabilizing the patella. The most common mechanism of injury (accounting for 93% of all cases of traumatic patellar dislocations) results from a position of knee flexion and valgus as seen in many cutting and pivoting sports, such as soccer, basketball, and football. Many injuries occur as a result of a noncontact injury. The risk of recurrent instability after a traumatic patellar dislocation can be as high as 25% to 45%. Age at the time of first dislocation can also be predictive of recurrence risk. Conservative management of patients younger than 18 years results in recurrent instability in 40% of patients, and those younger than 14 years have a 60% risk of recurrence. These statistics may help guide optimal management and patient counseling regarding risk of recurrent instability. Other authors have identified the presence of trochlear dysplasia and open growth plates at the time of first dislocation as risk factors for recurrence.

**Patellofemoral Dysplasia**

Trochlear dysplasia and patellar abnormalities increase the risk of patellar dislocation. Up to 96% of patients who have had a patellar instability event have radiographic evidence of a dysplastic trochlea. The lateral view on plain radiographs can be used to assess the degree of trochlear dysplasia. Dejour et al described 4 types of dysplasia (Figure 1).

**Figure 1**: Dejour et al\textsuperscript{12} classification of trochlear dysplasia. Type A: crossover sign (line of the trochlear groove intersecting with the cortex of the femoral condyle) (A). Type B: supratrochlear spur (B). Type C: double contour from the trochlea articulating with the patella (C). Type D: all 3 signs—crossover, supratrochlear spur, and a double contour (D).

![Figure 1: Dejour et al\textsuperscript{12} classification of trochlear dysplasia. Type A: crossover sign (line of the trochlear groove intersecting with the cortex of the femoral condyle) (A). Type B: supratrochlear spur (B). Type C: double contour from the trochlea articulating with the patella (C). Type D: all 3 signs—crossover, supratrochlear spur, and a double contour (D).](image)

Various connective tissue disorders can cause or contribute to traumatic instability and should be evaluated. Marfan syndrome is a connective tissue disorder caused by a mutation in the fibrillin-1 gene. It is transmitted as an autosomal dominant disorder, has a prevalence of 1 per 5000 individuals in the United States, and is slightly more prevalent in females than males. The biomechanical factors associated with patellar instability in patients with Marfan syndrome appear to be general ligamentous laxity, damage to the medial patellofemoral ligament (MPFL) and patella, and trochlear dysplasia. On physical examination, Marfan syndrome can be quickly evaluated via the Ghent nosology, which defines major and minor criteria for...
the disease.\textsuperscript{21} Ehlers-Danlos syndrome is a hereditary disease characterized by a defect in collagen organization leading to hyperflexible and unstable joints. The prevalence is estimated to be 1 per 5000 individuals in the United States.\textsuperscript{22} Patients with Ehlers-Danlos syndrome present with characteristic findings of hypermobile skin and an increased tendency to bleed and bruise easily.\textsuperscript{23} Nail-patella syndrome is a rare, autosomal dominant disorder associated with an aberration in the transcription factor LMX1B on chromosome 9.\textsuperscript{24} The prevalence is estimated to be 1 per 50,000 individuals in the United States.\textsuperscript{25} In one study, 50.6\% of patients presented with a tetralogy of nail, patella, elbow, and pelvic anomalies.\textsuperscript{26} The biomechanical mechanism responsible for patellar dislocation appears to be twofold. First, there is a decrease in the size of the patella. Second, there is a marked decrease in muscle mass of the quadriceps muscle, which contributes to a lack of stability and uneven force distribution along the mechanical axis of the extensor mechanism acting across the patella.\textsuperscript{27}

\textbf{History and Physical Examination}

A detailed history should be gathered to elucidate preceding trauma, age at first instability event, number of instability events, family history of instability, and other relevant symptoms such as knee swelling or effusion. On examination, obvious deformities or soft tissue swelling, along with the size of the patella and its location relative to the femur on both the uninjured and the injured extremity, should be noted. The observation of Marfanoid features, hypermobility of joints (quantified by the Beighton score [Table]),\textsuperscript{28} or abnormalities of facial features, elbows, and nails should raise concerns for syndromic conditions that warrant further evaluation by a geneticist.\textsuperscript{18} Tracking the patella during normal flexion and extension can reveal deviations from the normal straight-line trajectory. The J-sign refers to a path the patella takes as it engages the femur in early flexion. The patella is subluxated laterally in extension and reduces as the knee is flexed. This may be a sign of habitual dislocation (ie, spontaneously dislocates with flexion and reduces with extension).\textsuperscript{29,30} The Q angle is the angle formed by a line drawn from the anterior superior iliac spine to the central aspect of the patella and a second line drawn from the central aspect of the patella to the TT. Normal values are 14° for males and 17° for females.\textsuperscript{31} Increases in this angle are associated with an increased risk of patellar instability. Standing examination can clinically reveal genu valgum with an increased Q angle and should lower the threshold to obtain full-length standing radiographs to assess overall mechanical alignment.

The knee should be assessed for effusion and tenderness. Tenderness along the patella may indicate a fracture.\textsuperscript{31} Tibial torsion can be examined in the prone position by measuring the thigh–foot angle (reference range, 5°–30°).\textsuperscript{32} Assessment for “miserable malalignment” (excessive femoral anteversion, inward facing patella, and excessive external tibial torsion) should also be performed.\textsuperscript{33} This leads to a characteristic gait pattern where the hip internally rotates more than it externally rotates (femoral anteversion) and the lower leg externally rotates more than it internally rotates (external tibial torsion).\textsuperscript{33} The integrity of the MPFL can be assessed via palpation along the medial retinaculum. The patellar apprehension test can help identify patients with excessive mobility of the patella. This involves flexing the knee to 20° and applying medial or lateral force to the patella. If the patient experiences apprehension during manipulation, the test result is positive.\textsuperscript{30} Tightness of the lateral retinaculum can be assessed using the tilt test. With the knee flexed at 20°, the examiner places pressure on the medial edge of the patella, evertting it. With the application of pressure, the patella should evert above the horizontal in healthy individuals but remain fixed in patients with an excessively tight lateral retinaculum. To assess for patellofemoral chondromalacia due to previous injuries, the examiner places pressure directly on the patella with the patient’s knee fully flexed, evaluating for tenderness. Finally, lateral transverse mobility of the patella is assessed. With the patient’s knee flexed at

\begin{table}
\centering
\caption{Beighton Score for Hypermobility$^a$}
\begin{tabular}{|l|c|c|}
\hline
Joint & Examination Finding & Score \tabularnewline
\hline
Left small finger & Passive dorsiflexion $>$90° & Yes? No? \tabularnewline
Right small finger & Passive dorsiflexion $>$90° & 1 0 \tabularnewline
Left thumb & Passive dorsiflexion to flexor aspect of forearm & 1 0 \tabularnewline
Right thumb & Passive dorsiflexion to flexor aspect of forearm & 1 0 \tabularnewline
Left elbow & Passive extensions $>$10° & 1 0 \tabularnewline
Right elbow & Passive extensions $>$10° & 1 0 \tabularnewline
Left knee & Hyperextension $>$10° & 1 0 \tabularnewline
Right knee & Hyperextension $>$10° & 1 0 \tabularnewline
Flexion of trunk with knees extended & Palms can lay flat on ground & 1 0 \tabularnewline
\hline
\end{tabular}
\end{table}

\textsuperscript{$^a$Total maximum score is 9, with 4-6 considered positive for hyper laxity.}
30°, lateral pressure is applied to the medial aspect of the patella and the degree of lateral translation is measured.30

**DIAGNOSTIC IMAGING**

Several imaging modalities can be used to assess the various causes of patellar instability. Full-length standing radiographs can be used to assess limb alignment and determine if the patient has excess genu valgum, which can contribute to an increased Q angle and TT-TG distance and patellar instability. The Caton-Deschamps index can also be used to assess for patella alta on the lateral radiograph. Although there are various ratios to assess patella alta, this method is the least dependent on the degree of knee flexion. The ratio consists of the distance from the distal patellar articular surface to the proximal tibial articular surface divided by the length of the articular surface of the patella, with a value of greater than 1.3 considered abnormal (Figure 2).34

Excessive femoral anteversion can lead to a relative increase in the Q angle and can be evaluated on computed tomography or MRI; normal femoral anteversion is 13°.35 Additionally, the TT-TG distance and the amount of patellar tilt can be determined.36 To spare the radiation associated with computed tomography, MRI is typically preferred and can be used to obtain a rotational profile or “günsight” image of the lower extremity.37 The TT-TG distance is the distance from the TT to the deepest point of the TG, with a value greater than 20 mm considered abnormal in adults (15 to 20 mm is considered equivocal by some). It can be measured by superimposing axial cuts at the center of the TG and TT (Figure 3).36 Dickens et al38 studied the TT-TG distance in a pediatric population on MRI, correlating age with distance. They found that a distance of less than 8.5 mm predicted no patellar instability in 95% of patients, and patients with instability had an average distance of 12.1 mm. Patellar tilt is measured on the axial sequence as the angle formed between the axis of the patella and the posterior femoral condyles. Values greater than 20° are considered abnormal.36

Finally, MRI can help to identify soft tissue and bony abnormalities associated with patellar instability. Goutallier et al39 described the lateral trochlear inclination angle as a radiographic measurement of trochlear dysplasia. This value is calculated by drawing a line tangent to the subchondral bone of the posterior femoral condyles and measuring the angle of a line drawn tangent to the subchondral bone of the lateral facet of the trochlea.36 Carrillon et al15 reported a difference in the lateral trochlear inclination of healthy subjects compared with those with instability and established a cutoff of 11° for dysplasia, with a sensitivity and specificity of 93% and 87%, respectively. Magnetic resonance imaging can also help identify osteochondral injury secondary to traumatic dislocation and the presence of loose bodies, which may exist following dislocation.40,41 Magnetic resonance imaging is also useful for calculating the TT-TG distance. Classically, bony edema may be present within the lateral femoral condyle and the medial aspect of the patella because of impaction at the time of patellar relocation (Figure 4).
TREATMENT

Conservative

The first line of treatment for patellar instability is nonoperative in most cases. Nonoperative management consists of a variety of techniques, ranging from brief immobilization (2 to 4 weeks) to immediate motion and swelling control as well as physical therapy. In a single institution study of first-time dislocation of 266 knees in 250 patients, 222 (83.5%) of the knees underwent nonoperative treatment with 145 not suffering a recurrent instability event. A systematic review recommended nonoperative management for all first-time dislocators, with the exception of those with associated chondral or osteochondral fractures of either the medial patellar facet or lateral femoral condyle due to impaction injury. These fractures are best visualized on MRI. Unlike adults, children generally have successful fracture healing even in the setting of delayed fixation. Some investigators argue that in the setting of fracture, surgery is indicated only in the event of a fragment larger than 5 mm or a fracture in the weight-bearing zone of the patellofemoral joint. In one meta-analysis, nonoperative management of patellar dislocation was shown to have a rate of redislocation of 34.6% vs 24% for surgical management; however, functional outcome scores were similar. More recently, Nwachukwu et al found similar rates of recurrence after nonoperative and operative treatment; however, they concluded that patients who undergo acute surgical treatment for first-time dislocation may have improved health-related quality of life and sporting function.

Operative

There are many options for surgical management of patellar instability, ranging from isolated soft tissue procedures to osteotomy and ligamentous reconstruction. To choose the appropriate surgical management, it is important to consider the patient’s skeletal maturity and determine the etiology of instability. Operative interventions can range from soft tissue balancing procedures to more invasive bony osteotomies and ligament reconstruction to balance the congruency and function of the patellofemoral joint. Depending on the degree of instability, reconstruction may be approached in an à la carte fashion. To assess patellar tracking, lateral release of the retinaculum can be performed either open or arthroscopically. This procedure is seldom done in isolation but may be the first step in soft tissue balancing if patients are found to have excessive lateral patellar tracking or if the patella does not sit within the trochlea either on preoperative examination or arthroscopically; lateral release may improve the balance of the patella. In addition to proximal soft tissue procedures, there are several distal extensor mechanism realignment procedures. These use osteotomy or patellar tendon transfer at the TT, altering the vector of force in which the patellar tendon pulls, effectively changing the Q angle. These procedures are typically used to correct abnormal TT-TG distance, Q angle, and Caton-Deschamps index, or patellar tracking due to other abnormalities in bony architecture. Tibial tubercle osteotomy is generally not performed until skeletal maturity in an effort to limit the risk of growth arrest. The Grammont procedure involves subperiosteal dissection of the patellar tendon at its insertion on the TT. The extensor mechanism is then medialized and reattached to the TT with the knee in 45° of flexion. Garin et al studied 35 patients (50 knees) who underwent this procedure with the addition of other aforementioned soft tissue procedures as needed and found that inversion of the normal

Figure 4: Coronal magnetic resonance imaging of a patient diagnosed with medial patellofemoral ligament rupture displaying edema at the lateral femoral condyle (A). Axial image depicting avulsion injury of the medial patellofemoral ligament off the patellar insertion (B).
In this technique, the femoral osteotomy is another way to address patellar instability. It decreases patellofemoral joint pressure compared with the Elmslie-Trillat procedure. One thing the two procedures have in common is that they maintain a distal periosteal hinge when transferring the tubercle. This results in a lower incidence of major complications such as nonunion compared with procedures that completely detach the tubercle. The Fulkerson osteotomy can be performed with or without a lateral release. A study of 41 knees that underwent osteotomy for patellar instability showed good results, with only 1 patient experiencing recurrent instability. Of note, 49% of the patients had symptomatic hardware, which was removed at an average of 8 months after surgery.

Although soft tissue and bony realignment are historically popular options that are still used, there has been an increase in the use of techniques attempting to address the MPFL in patients with recurrent instability and radiographic evidence of injury. One such procedure is the Galeazzi technique, which involves taking a pedicled semimembranous tendon through a patellar tunnel to serve as a reconstruction of the MPFL. This procedure can alter the patellar tilt in the coronal plane if the tendon is over-tensioned. One study reviewed this procedure in 34 knees, with 82% of knees experiencing recurrent instability and 35% requiring subsequent surgery. The Deie technique also involves transfer of one of the hamstring tendons; however, it uses the semitendinosus. As with the Galeazzi technique, in the Deie technique the semitendinosus is pedicled at its bony osteotomy that involves anteriorization and medialization of the tubercle. It decreases patellofemoral joint pressure compared with the Elmslie-Trillat procedure.

Distal bony alignment such as TT osteotomy is another way to address patellar instability due to abnormal bony anatomy. The Elmslie-Trillat technique involves elevating the TT with an osteotome, medializing it, and reattaching it with a cannulated screw. There is concern that strict medialization of the tubercle can lead to increased pressure within the patellofemoral joint and accelerated arthritic changes. Slight modification of the slope of the osteotomy may help anteriorize the tubercle in addition to medialization. The modified Elmslie-Trillat technique includes a lateral retinacular release, medial capsular reeving, and medial transposition of the TT hinged on a distal periosteal attachment. It should be performed in only the skeletally mature. The Fulkerson procedure is another distal bony osteotomy that involves anteriorization and medialization of the tubercle. It decreases patellofemoral joint pressure compared with the Elmslie-Trillat procedure. One thing the two procedures have in common is that they maintain a distal periosteal hinge when transferring the tubercle. This results in a lower incidence of major complications such as nonunion compared with procedures that completely detach the tubercle. The Fulkerson osteotomy can be performed with or without a lateral release. A study of 41 knees that underwent osteotomy for patellar instability showed good results, with only 1 patient experiencing recurrent instability. Of note, 49% of the patients had symptomatic hardware, which was removed at an average of 8 months after surgery.

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Finally, trochlear dysplasia can be addressed via groove-deepening trochleoplasty. The goal of this procedure is to
change the trochlear shape via deepening of the trochlea and to eliminate the supratrochlear spur.65 Deepening is accomplished by removal of the cancellous bone in the middle of the trochlea via high-speed burr, allowing the 2 slopes of the trochlea to collapse. This is typically done following skeletal maturity and is best indicated for Dejour type B and D deformities, which have a more prominent trochlear deformity.18 There is relatively little experience with this technique in the United States, and long-term outcome data are limited. Skeletally immature patients may be candidates for hemiepiphyseal osteotomy to correct excess genu valgum. Those with rotational deformities (mis-erable malalignment) may be candidates for hemiepiphyseodesis or femoral and/or tibial derotational osteotomy to correct excess bony torsion.18

**Conclusion**

Patellar instability in the pediatric patient is a challenging problem, which can have varying etiologies. It is important to evaluate these patients for patellofemoral dysplasia and connective tissue disorders. The first line of treatment for most pediatric patients with traumatic patellar instability is conservative in nature, unless a concomitant fracture or osteochondral lesion is present. For these injuries, or if the event of recurrent instability, several operative techniques can be used to address the instability. Proximal soft tissue balancing as well as distal soft tissue or bony procedures can be performed. Anatomic reconstruction of the MPFL is gaining popularity as more is known regarding its role in patellar stability; however, MPFL reconstruction alone in the face of bony abnormality will not treat rotational or other bony deformity, which may be addressed with concomitant osteotomy. Ultimately, there are many procedures available with numerous combinations that are determined based on the etiology of the patient’s instability and the preference of the surgeon.

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