**Abstract**

**Introduction**

Patellar instability is most common among adolescent female athletes, although anyone can be affected. The aetiology of patellar instability is multifactorial and often the result of abnormal patellofemoral biomechanics and anatomy, as well as traumatic injury or overuse in origin. Diagnosis and management begin with physical examination and imaging such as radiographs, computed tomography or magnetic resonance imaging. The management of patellar instability is non-operative for primary dislocations, reserving operative management for patients with recurrent patellar instability. There are a variety of operative procedures including osseous realignment procedures as well as soft-tissue procedures aimed to correct predisposing factors contributing to patellar instability. The approach to patellar instability should be individualised and tailored to each patient’s symptoms, anatomy and physical demands to obtain the highest levels of success in this patient population.

This article discusses patellar instability.

**Conclusion**

Patients with recurrent instability may benefit from operative management consisting of proximal or distal realignment procedures. Tailoring a patient’s treatment to symptoms, osseous morphology and specific injuries with patellar instability will lead to the best outcome and highest levels of satisfaction with this complex problem.

**Introduction**

Patellar instability encompasses a range of injuries including patellar subluxation, dislocation and symptomatic instability. The incidence of patellar instability is 7/100,000. While among adolescents aged 10–17 years, the incidence is higher and estimated to be 29/100,000 with females affected 33% more often than males in this age group. It has been reported that 61%–72% of patella dislocations occur during athletic activity. Among dislocations that occur during sports, basketball (18.2%), soccer (6.9%) and football (6.3%) are most commonly associated with episodes of patellar instability. Patellar instability is also common among runners and represents 16%–25% of all injuries to runners.

Recurrent patellar instability occurs in 15%–44% patients. Risk factors for recurrent instability include female gender, initial dislocation at a younger age, family history of patellar instability and a history of developmental dysplasia of the hip. Among patients with recurrent patellar instability, 47% of primary episodes of patellar dislocation occur during sports with the majority of recurrent episodes occurring during less strenuous activity such as rising from a seated position. This article discusses the anatomy and biomechanics of patellar instability, as well as the presentation, examination, imaging and management of this disorder.

**Discussion:**

**Anatomy and Biomechanics**

Patellofemoral stability is principally influenced by anatomic factors. Understanding the anatomy and biomechanics of the patellofemoral joint provides insight into the aetiology and management of patellar instability.

The patella is the largest sesamoid bone in the human body. It is triangular in shape with the narrowest margin found distally. The articular surface of the patella is composed of a medial, lateral and odd facet. The medial and lateral facets are separated by a vertical ledge. The odd facet is medial to the medial facet. In type II, the patella has a smaller medial facet that is flat or slightly convex. In type III, the medial facet is convex and significantly smaller than the lateral facet. A type II patella is most common and Wiberg believed that a type III patella was most prone to chondromalacia and pain.

The trochlea is the distal portion of the femur that articulates with the patella, comprising the patellofemoral joint. The trochlea is divided into two facets: medial and lateral. The lateral facet is larger and extends more proximally than the medial facet, providing an osseous restraint to the patellofemoral joint.

At full extension, the patella is not in direct contact with the trochlea. As the knee increases in flexion, different portions of the patella’s articular surface contact the underlying trochlea. From full extension to approximately 90°, the area of the patella in direct contact with the femur...
shifts gradually from the distal to the proximal pole; however, the odd facet has no contact at this point. From 90° to 135° of flexion, the patella rotates and a ridge between the medial and odd facet engages the trochlea. From 120° to 135° of flexion, the odd facet is in contact with the femoral condyle and there is less contact between medial and lateral facets with the trochlea.

In addition to the osseous anatomy of the patellofemoral joint, soft tissue structures also provide stability to the patellofemoral joint. On the lateral side of the knee, the iliotibial (IT) band originates from the distal aspect of the tensor fascia lata and inserts onto Gerdy’s tubercle in the proximal tibia. The IT band also has insertions onto the patellar and quadriceps tendons thus influencing the patella to track in a more lateral position.

Among the quadriceps muscles, the vastus medialis obliquus (VMO) and vastus lateralis also confer patellofemoral stability. These muscles insert with a deviation from the anatomic axis that pull the patella medially and laterally, respectively. Atrophy or weakness of either muscle may cause the patella to track in a more lateral or medial position. It has been found that the VMO is the first muscle group in the quadriceps to weaken and the last to strengthen when function is impaired. Goh et al. reported that absence of the VMO resulted in a 30% reduction in lateral stability at 20° of flexion and increased loading on the lateral facet. Similarly, Senavongse et al. found that releasing the VMO resulted in a 30% reduction in the amount of force required to displace the patella 10 mm laterally.

The medial patellofemoral ligament (MPFL) is the primary medial stabiliser of the patellofemoral joint. The femoral origin of the MPFL is found in a ‘saddle’ region between the medial epicondyle and the adductor tubercle. The MPFL has a tensile strength of 208N and is found approximately 6.2 mm distal and 8.9 mm anterior to the adductor tubercle. On an anteroposterior radiograph, the MPFL origin is 42.3 mm proximal to the femoral joint line and 6.2 mm distal to the adductor tubercle. On a lateral radiograph, the distal femur may be divided into quadrants with a line continuous with the posterior cortex of a femur and a second line perpendicular to the first line at the most proximal aspect of Blumensaat’s line. The femoral origin of the MPFL is found 8.8 mm anterior to the line continuous with the posterior cortex of the femur and 2.6 mm proximal to a perpendicular line at the level of the proximal aspect of Blumensaat’s line (Figure 1). The ‘40%–50%–60%’ rule may also be used to define the MPFL origin. Following this rule, the MPFL is 40% from the posterior, 50% from the distal and 60% from the anterior outline of the medial condyle. The MPFL inserts onto the superomedial aspect of the patella, 6.1 mm from the superior pole, with a 17 mm width extending distally to the midpoint of the patella, approximately at the junction of the superior one-third and inferior two-thirds of the patella (Figure 1). The MPFL provides 50%–60% of lateral restraint from 0° to 30° of flexion.

In a cadaveric study, Senavongse et al. reported that rupturing the medial retinaculum, including the MPFL, resulted in a 49% decrease in the force required to move the patella 10 mm laterally.

Anatomic Risk Factors for Instability

There are multiple anatomic characteristics that place a patient at higher risk for patellar instability. Anatomic factors such as limb malalignment, shallow trochlear morphology and patella alta increase a patient’s risk of developing patellar instability. The Quadriceps (Q) angle is a measure of limb alignment. It is the angle formed between a line drawn from the anterosuperior iliac spine to the centre of the patella and a second line drawn from the centre of the patella to the tibial tubercle. The Q angle changes based on knee flexion and is largest in extension as the tibia externally rotates in terminal extension. The patellofemoral joint is at greatest risk of instability at full extension when the Q angle is largest and the patella is not in contact with the trochlea. Femoral anteversion and external tibial torsion also increase the Q angle and are risk factors for patellar instability.

Abnormal trochlear morphology increases a patient’s risk of developing patellar instability. A shallow depth or hypoplastic lateral trochlear facet decreases the osseous restraint the trochlea provides to prevent lateral subluxation. Senavongse et al. found that removing a wedge from the lateral condyle, representative of a hypoplastic lateral trochlear facet, reduced lateral patellar stability by 70% at 20° of flexion. Dejour et al. reported a trochlear depth of less than 4 mm to be an independent risk factor for patellar instability and concluded that trochlear dysplasia is the single most important factor in patellar instability because it prevents the femoral sulcus from providing...
sufficient osseous restraint capable of avoiding patellar dislocation\textsuperscript{19}. Dejour et al. also found trochlear dysplasia to be present in 85% of patients with recurrent patellar instability\textsuperscript{19}. Patella alta reduces patellofemoral stability because the patella does not engage the trochlea until higher degrees of flexion when compared with a normal knee. As a result, there is less osseous stability conferred by the trochlea at full extension and early flexion. Multiple studies have found patella alta to be a risk factor for patellar instability\textsuperscript{2,19-21}. In one such study, Dejour et al. compared radiographs and computed tomography (CT) scans in 143 patients treated operatively for symptomatic patellar instability to contralateral asymptomatic knees. Patella alta, quadriceps dysplasia, abnormal tibial tubercle–trochlear groove (TT–TG) distance and trochlear dysplasia were all found to be independent risk factors for patellar instability\textsuperscript{19}. Ligamentous laxity is also a risk factor for patellar instability\textsuperscript{22}. Ligamentous laxity allows a larger knee range of motion and greater degrees of ligamentous translation. When discussing the patellofemoral joint, this can result in knee hyperextension as well as excessive lateral patellar translation thus predisposing the patient to dislocation and instability.

**Presentation**

Patients with an acute patellar dislocation typically report a direct trauma to the knee or a twisting type injury with a planted foot. An audible pop is often heard at the time of injury. Patients will note anterior knee pain and swelling localised to the knee. Patients may or may not be able to bear weight and will note a restricted range of motion due to pain, particularly if the dislocation has not spontaneously reduced.

Patients with recurrent patellar instability note episodes of the knee ‘giving way’. Recurrent dislocations are less likely to occur during athletic activity than primary dislocations and may result from low-energy activities such as rising from a chair.

**Physical Examination**

Physical examination begins with inspection of the involved knee. An effusion is typically present. After the patella is reduced, either spontaneously or with a medially directed force, knee range of motion is assessed. Concomitant ligamentous injury should be carefully assessed as ligamentous injuries to the knee, such as an anterior cruciate ligament (ACL) rupture, may have a similar presentation.

The area of maximal tenderness along the MPFL is evaluated with palpation. Tenderness is used to assess MPFL injury and to identify the location of the torn area, if present. This is typically located along the femoral origin of the MPFL.

The Q angle may be assessed clinically by measuring the angle between a line drawn from the anterosuperior iliac spine to the centre of the patella and a second line drawn from the centre of the patella to the tibial tubercle. The mean Q angle for males is 11.2°, in females it is 15.8°\textsuperscript{23}. A larger Q angle is abnormal and representative of limb malalignment.

Patellar translation is assessed by passively moving the patella with the knee in full extension. The patella is divided into quadrants and the amount of lateral motion the patella translates past midline is recorded. Normal motion is less than two quadrants of patellar translation. Lateral translation of the medial border of the patella to the trochlear groove is defined as two quadrants and represents an abnormal amount of laxity. It is imperative to compare both sides as what may be abnormal for one patient is normal for another.

The patella apprehension test is performed by holding the knee in 20°–30° of flexion and applying a laterally directed force. This test is positive if the patient develops pain or exhibits apprehension. The patellar tilt test is done at 20° of flexion while the examiner holds the patella between the thumb and index fingers and pushes down in an attempt to flip the lateral edge of the patella upward. Zero to 20° of elevation is normal. Elevation to less than neutral is abnormal and indicative of an excessively tight lateral retinaculum.

The patellar grind test is performed by applying posteriorly directed pressure to the patella while displacing the patella medially, laterally, superiorly, and inferiorly in the trochlear groove. This test is positive if it reproduces anterior knee pain. The J sign is assessed by having the patient actively range the knee from flexion to full extension. The J sign is positive if the patella deviates laterally during terminal extension.

Clinically, the TT–TG distance is assessed by measuring the distance between two lines drawn vertically from the tibial tubercle and the estimated trochlear groove. The trochlear groove may be palpated medially or laterally along its articulation with the patella. A distance of greater than 20 mm is considered abnormal\textsuperscript{20}.

Joint hypermobility or ligamentous laxity, a significant risk factor for patellar instability, is assessed using Beighton’s criteria, focusing on thumb to forearm flexibility as well as hyperextension of the knees and elbows. Femoral rotation is measured with the patient prone and the examiner measuring passive range of motion with internal and external rotation. Internal rotation greater than 70° or external rotation less than 20° is indicative of femoral anteverision. Tibial torsion is assessed with the patient prone with the knee flexed to 90°. The thigh-foot axis then measured. A thigh-foot axis of 10°–15° of external rotation is normal in adults. A value greater 20° is suggestive of external tibial torsion.

A thorough examination is mandatory in these patients as there are a
variety of treatment options and a 'one size fits all' approach should not be used. Each patient should receive individualised treatment based on the presentation, detailed physical examination and imaging.

Imaging
In patellar instability, imaging begins with radiographs. Standard evaluation includes weight-bearing posterolateral, lateral and merchant views. These images are used to assess reduction, detect osteochondral or avulsion fractures, and evaluate for anatomic abnormalities predisposing to patellar instability that help guide management.

Patella alta may be defined using several different measurements on a lateral radiograph with the knee in 30° of flexion (Figure 2a–e). The Insall–Salvati ratio is the length of the patella divided by the length of the patellar tendon. This ratio is 0.9 to 1.1 in males and 0.94 to 1.18 in females. Patella alta is a value greater than 1.2 and baja is less than 0.8. One of the criticisms of the Insall–Salvati ratio is that it lacks sensitivity for patellar morphology. As a result, patients with a long distal nonarticulating facet have a higher rate of false negative readings for patella alta. This led to the Modified Insall–Salvati ratio, which is the length of the articular surface of the patella divided by the length of the patellar tendon. A normal Modified Insall–Salvati ratio is 1.25 and patella alta is a ratio greater than two. Patella baja is not defined with this measurement.

Another measure of patella alta, the Caton–Deschamps Index, is the distance from the inferior border of the patella to the most proximal aspect of the anterior articular surface of the tibia divided by the length of the articular surface of the patella. A ratio higher than 1.3 is suggestive of patella alta and patella baja is a value less than 0.6. The Blackburne–Peel ratio is the length of the articular surface of the patella divided by the distance of its inferior margin from the tibial plateau. A normal Blackburne–Peel ratio is 0.8. Patella alta is a value greater than 1.0 and baja is less than 0.5. In a study comparing the Insall–Salvati ratio, Modified Insall–Salvati ratio, and Caton–Deschamps Index, the Blackburne–Peel ratio was found to have the lowest inter-observer variability for patellar height.

More recently, the plateau-patella angle has been described to assess patellar height. The plateau-patella angle is formed between a line tangential to the subchondral bone of the medial tibial plateau (the same line used for the Blackburne–Peel measurement) and a second line drawn from the posterior extent of the plateau to the inferior articular border of the patella. The mean angle is 25° and patella alta is greater than 30°. Patella baja is less than 20°. Advantages of the plateau-patella angle include assessment using only a goniometer and that no calculations are required. In the study describing it, the plateau-patella angle was found to have high inter-observer reliability and compared favourably with the Insall–Salvati, Blackburne–Peel, and Caton–Deschamps indices.

The Merchant view is performed with the knee flexed to 45° over the end of a table with the legs supported. The X-ray beam is then inclined 30° from the horizontal. The Merchant view may be used to assess the sulcus, lateral patellofemoral, and congruence angles (Figure 3a–c). The sulcus angle is defined by two lines from the highest points of the medial and lateral femoral condyles to the lowest point of the intercondylar sulcus. An average sulcus angle is 138° and greater than 145° is indicative of trochlear dysplasia.

Patellar tilt may be assessed using either the congruence or Lateral Patellofemoral (Laurin) angles. The congruence angle is formed by a line bisecting the sulcus angle and a second line drawn from the lowest point of the intercondylar sulcus to the apex of the patella. This angle measures the relationship of the patellar articular ridge to the intercondylar sulcus with values greater than 16° being abnormal and indicative of lateral patellar subluxation. The Lateral Patellofemoral angle, or Laurin angle, is formed by a line connecting the femoral condyles and a second line following the lateral patellar facet. Abnormal is defined as parallel lines or a negative angle while in a normal population, the angle is greater than zero.

The lateral radiograph is also very useful to assess trochlear dysplasia. Dejour categorised the amount of trochlear dysplasia based on the lateral radiograph. He described four types of dysplasia in increasing severity. In all four types, the crossing sign is present on a lateral radiograph. The crossing sign is a radiographic finding in which the femoral sulcus crosses the anterior border of the two condyles. This is representative of a flat trochlea. In Type A, a crossing sign is present and trochlear morphology is otherwise normal; Type B has a crossing sign, supra-trochlear spur and flat or convex trochlea; Type C has a crossing sign, double contour sign (projection on the lateral view of a hypoplastic medial facet), and Type D has a crossing sign, supra-trochlear spur; double contour, asymmetry of the trochlear facets and a cliff pattern (vertical link between medial and lateral facets). It is not mandatory to classify each patient into his/her specific category; however, it is important to look for the radiographic signs, focusing on a trochlear bump and a positive crossing sign.

In a comparison of patients with and without recurrent patellar instability, Charles et al. found significant differences in the Insall–Salvati ratio (1.26 vs. 1.08), Caton–Deschamps ratio (1.29 vs. 1.13), and the Sulcus Angle (165 vs. 148°). This suggests that patella alta and trochlear dyspla-

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**Figure 2:** (a) Insall–Salvati ratio: patellar tendon length (61 mm) divided by patella length (55.2 mm) is 1.10. (b) Modified Insall–Salvati: patellar tendon length (61 mm) divided by patellar articular surface length (55.2 mm) is 1.10. (c) Caton–Deschamps Index: distance from inferior pole of patella to anterior articular surface of tibia (61 mm) divided by length of patellar articular surface (55.2 mm) is 1.10. (d) Blackburne–Peel ratio: length from inferior pole to perpendicular line at tibial plateau (32.7 mm) divided by length of patellar articular surface (55.2 mm) is 0.59. (e) Plateau–patella angle: the angle formed by a line following the tibial plateau to the inferior border of the patellar articular surface is 18.5°.

**Figure 3:** (a) Sulcus angle: formed by two lines from trochlear groove to the highest point of the medial and lateral facets on the trochlea. (b) Congruence angle: the sulcus angle is bisected and a second line is drawn to the deepest portion of the patellar articular surface. (c). Lateral patellofemoral angle: an angle formed by a line connecting the highest point of the femoral condyles and a second line following the lateral patellar facet.
sia play a significant role in patellar instability. Dejour et al. found trochlear dysplasia to be the single most important factor in predicting patellar instability. Dejour et al. defined dysplasia as a trochlear depth less than 4 mm, trochlear bump greater than 3 mm, or a positive crossing sign. Based on these measurements, Dejour classified patellar instability into three groups: Major patellar instability defined as more than one documented dislocation; Objective patellar instability defined as one dislocation with associated anatomic abnormalities; and potential patellar instability consisting of patients with patellar pain and associated anatomic abnormalities but no episodes of instability.

CT and magnetic resonance imaging (MRI) are often used as an adjunct to radiographs to better evaluate bony and soft tissue constraints of the patellofemoral joint. CT may be used to assess for femoral anteversion, external tibial torsion, patellar tilt, trochlear morphology, as well as other anatomic factors associated with patellar instability. In comparison to radiographs, CT has been shown to have improved sensitivity in measuring patellar tilt.

CT is also used to measure the TT–TG distance. TT–TG distance is defined as a measurement from the bottom of the most proximal part of the trochlear groove to the proximal part of the tibial tubercle. It was originally described on an axial radiograph with the knee flexed to 30°, but is more commonly assessed on CT and now with MRI. On CT, the TT–TG is measured on two superimposed CT sections with the intercondyalar sulcus and central part of the tibial tubercle projected on a line tangential to the posterior femoral condyles. TT–TG is normally 12 mm with abnormal defined as greater than 20 mm.

MRI is often helpful in evaluating patients with patellar instability. MRI may be used to detect osteochondral fractures, loose bodies, tearing of the VMO, or injury to the medial retinaculum and MPFL. MRI typically shows characteristic bone bruises on the medial facet of the patella and lateral femoral condyle in the acute setting, suggestive of patellar instability. While not originally described on MRI, the TT–TG angle, femoral version, and tibial torsion can also be calculated, often precluding the need for a CT scan.

In a review of 42 patients with MRI completed within 1 week of injury, Sillanpää et al. reported osteochondral fractures in 28% and MPFL tears in 100% [11]. Around 60% of MPFL tears were at the femoral origin, 26% were midsubstance and 14% were torn from the patellar insertion. Among patients followed for an average of 7 years, recurrent instability was most common among patients with MPFL tears at the femoral origin (32%) with fewer subsequent dislocations among midsubstance (9%) and patellar insertion tears (0%) [12].

Atkin et al. evaluated radiographic characteristics in 74 patients with acute patellar dislocations. In this population, the average sulcus angle was 144°, the average congruence angle was 9.6°, the mean Laurin angle was positive, lateral patellar overhang was positive in all knees, and 50% of patients had evidence of patella alta. On MRI, 71% of patients had an effusion or haemarthrosis, 63% had medial retinacular injuries, 57% had a contusion at the lateral femoral condyle or medial patellar facet, 21% had patellar osteochondral defects and 4% had osteochondral defects of the lateral femoral condyle.

Non-operative Management

Non-operative management typically begins with immobilisation in extension. Immobilisation may be recommended for up to 6 weeks for comfort and soft tissue healing. As symptoms allow, patients may progress out of immobilisation and begin a range of motion exercises to prevent stiffness and maintain articular cartilage health. Physical therapy is utilised with particular attention to VMO and gluteal strengthening. Abnormal patellar tracking has been linked to an imbalance in activation of timing of the VMO and vastus lateralis. Physical therapy consisting of isometric VMO and gluteal exercises has been shown to correct this imbalance and improve pain in a randomised comparison of patients undergoing targeted physical therapy and placebo therapies. Closed chain exercises have also been found to be more effective than open chain exercises in managing patellar instability.

Weight loss reduces patellofemoral loads and may decrease anterior knee pain in patients with patellar instability. Patellar taping has been shown to decrease pain, allow increased quadriceps activity, and improve function following patellar dislocation. It has also been shown to improve VMO activity onset, which may improve patellar tracking and subsequent risks of dislocation; however, the mechanism of this remains unknown.

Mäenpää et al. followed 100 patients treated non-operatively for an average of 13 years following an initial dislocation. Patientes were immobilised in a plaster cast (60%), posterior splint (17%) or brace (23%) for 6 weeks following a primary dislocation. Redislocation rates were highest in the brace (0.29 dislocations/year) with fewer recurrent dislocations in the plaster cast (0.12 dislocations/year) and posterior splint (0.08 dislocations/year) groups. However, there was a significant reduction in knee range of motion among patients treated in a plaster cast.

Atkin et al. reported outcomes of 74 patients treated non-operatively following primary patellar dislocations. At 6 months, 53% of patients reported difficulty kneeling and 58% reported difficulty squatting. A 58% of patients also noted limitations in

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strenuous activity such as jumping or sharp turns while running and 42% noted limitations in straight line running or jogging. However, 69% of patients returned to sports at 6 months and baseline range of motion returned to normal by 6 weeks after the patellar dislocation.

Among patients treated non-operatively, Sillanpää et al found that pre-injury activity level was regained by fewer patients when the MPFL tear was at the femoral origin when compared with midsubstance tears or tears at the patellar insertion. Subsequent dislocations and operative management are also more probable when the MPFL tear is at the femoral origin than when it is midsubstance or at the patellar insertion.

**Operative Management**

There have been over 100 procedures described for the management of patellar instability. Operative management is indicated in patients with osteochondral fracture following a patellar dislocation or in patients with recurrent instability. Procedures may be primarily soft-tissue proximal realignments (lateral release, medial placket, MPFL repair or reconstruction) or osseous realignments (tibial tubercle transfer, derotational femoral and tibial osteotomies, trochleoplasty).

**Lateral Release**

Lateral release has been shown to have no benefit when used in isolation for the management of patellar instability. In a review of 117 patients treated with isolated lateral release for patellar instability, 37% were classified as ‘complete failures’ because of subsequent surgery for recurrent instability and pain. Latermann et al. recommended that isolated lateral retinacular release has no role in the treatment of patellar instability and should be reserved for cases of lateral patella compression syndrome caused by a decreased lateral tilt. However, lateral release may be used as an adjunct to proximal or distal realignment procedures.

One complication of isolated lateral release is medial patellar instability. An over-release of the lateral retinaculum may cause the patella to track excessively medially and potentially subluxate or dislocate in that direction. Other complications of lateral release include post-operative infection, haematoma formation, and paradoxical worsening lateral instability.

**Medial Repair**

MPFL tears may be addressed with a repair. Repair is typically utilised in the acute setting when there is probably a higher capacity for healing. However, studies investigating MPFL repair have had less favourable outcomes than other procedures. In a prospective randomised trial comparing patients treated with immobilisation to MPFL repair, Christiansen et al. found no significant differences in re-dislocation rates, knee function, or pain after a primary dislocation.

Among patients with recurrent patellar instability, Camp et al. reported a 28% re-dislocation rate in patients after a medial repair. A 17% of patients required a second procedure, most commonly for instability following MPFL repair. The authors recommended careful patient selection when utilising this procedure. Complications of MPFL repair include recurrent instability, post-operative infection, or arthrofibrosis. Repair is most commonly performed in the paediatric population with the worry of growth disturbance following MPFL reconstruction.

**MPFL Reconstruction**

MPFL reconstruction has been found to be significantly stronger than repair. In a biomechanical study, Mountney et al. reported the tensile strength of the native MPFL (208 N) was closest in strength to reconstruction with a through-tunnel tendon graft (195 N). Weakener constructs included repair with sutures alone (37 N), repair with bone anchors and suture (142 N) and reconstruction with blind-tunnel tendon graft (126 N).

MPFL reconstruction utilises a soft-tissue graft such as an ipsilateral semitendinosus tendon or a soft-tissue allograft. A longitudinal incision is made from the superior pole of the patella to the distal pole of the patella on the medial side with dissection to the native MPFL. Either a bone tunnel or suture anchors can be used for fixation to the patella. The reconstruction should be anatomic, typically placed at the junction between the superior 1/3 and inferior 2/3 of the patella proceeding distally to the midpoint of the patella. Fluoroscopy is useful to confirm anatomic placement. For the femoral tunnel, an incision is made anterior to the palpable ridge connecting the medial femoral condyle and adductor tubercle. Typically a tunnel is used on the femoral side, which must be placed using fluoroscopic guidance as non-anatomic femoral placement of the graft is the most common cause of post-operative complications. As discussed earlier, the anatomic femoral insertion radiographically corresponds to 8.8 mm anterior to a line continuous with the posterior cortex of the femur and 2.6 mm proximal to a perpendicular line at the level of the posterior aspect of Blumensaat’s line. The appropriate amount of flexion at which to tension the graft is controversial. Tensioning is typically done at 60°–90° to avoid overtightening.

Nomura et al. followed 12 patients after MPFL reconstruction for an average of 4.2 years. An 83% of patients were classified as excellent or good and there were no cases of patellar instability following surgery. Authors found fair results only among patients with pre-existing chondromalacia of the patella. Panagopoulos et al. followed 25 patients after MPFL reconstruction for an average...
of 13 months. There was one case of patella fracture but no cases of post-operative patellar instability. Panagopoulos reported significant improvements in pain function after MPFL reconstruction in this series. To our knowledge, there are no studies evaluating the long-term outcomes following MPFL reconstruction.

MPFL ligament reconstruction is particularly prone to technical errors that may limit the range of motion or stability. Elias et al. used computational knee models to simulate knee function in an intact knee and knees after MPFL reconstruction. The MPFL reconstruction groups were divided among reconstructions performed anatomically, with a graft 3 mm shorter than the intact MPFL, and with a malpositioned graft. Proximal malpositioning and using a shortened graft was found to significantly increase graft tension during flexion. A combination of proximal malpositioning and using a shortened graft increased peak medial contact pressures by 50%. Elias et al. concluded that small errors in MPFL reconstruction may lead to significant pain and joint degeneration.

Bollier et al. reported a series of five patients in which femoral tunnel malpositioning led to disabling symptoms and revision surgery. In all five cases, the graft was positioned too anteriorly leading to iatrogenic medial patellar instability in three patients and recurrent lateral instability in two.

In a retrospective review of 179 knees in patients younger than 21 years of age, Parikh reported a 16% incidence of complications. The most common complications were recurrent instability (4.5%), decreased knee flexion (4.5%) and patella fracture (3.3%). The authors concluded that nearly half of the reported complications were due to technical factors and probably preventable.

Other complications of MPFL reconstruction include recurrent lateral instability due to lack of appropriate tension, medial instability from overtensioning, knee stiffness from overtensioning or more common improper tunnel placement, or post-operative patella fracture from bone tunnels in the patella. Thaunat et al. reported three cases of patella fracture at the tunnel site of an MPFL reconstruction, all occurring more than 4 years after surgery. Drez et al. reported one superficial wound infection and one case of arthrofibrosis among 19 patients after MPFL reconstruction. In a review of 44 patients, Chrisiansen et al. reported three cases of symptomatic hardware requiring removal, one iatrogenic fracture, four cases of recurrent instability and four cases of chronic pain. Hardware has been found to be most symptomatic at the femoral fixation site, with a higher incidence when the graft is fixed with staples.

Distal Realignment

Distal realignment procedures include a variety of tibial tubercle transfers. The Elmslie–Trillat procedure is a medial transfer and the Fulkerson procedure is an anterior medial transfer of the tibial tubercle. Both of these osteotomies aim to improve the Q angle and TT–TG distance, thus lowering the risk of subsequent patellar dislocation. The Fulkerson procedure also causes the patella to engage earlier in flexion, improving stability, while offloading the distal articular cartilage of the patella, which may be damaged with episodes of instability. These procedures are more commonly performed in the setting of anatomic abnormalities, namely high Q angles and TT–TG distances. Anteromedialisation, that is Fulkerson-type osteotomy, is performed almost exclusively today while straight medialisation is of mostly historical significance.

Ramappa et al. compared anteromedial and medial tibial tubercle transfers in a cadaveric model and found that both procedures corrected elevated patellofemoral contact pressure and resulted in normal patellar tracking. However, neither procedure proved to be superior to the other.

Koeter et al. performed a tibial tubercle osteotomy in two groups of patients. Group 1 consisted of 30 patients with patellar instability and group 2 included 30 patients with painful lateral tracking of the patella, defined on CT and physical examination. After tibial tubercle transfer, 97% of patients had no subsequent episodes of patellar instability and both groups had significant and similar improvements in pain and function.

Nakagawa et al. performed tibial tubercle medialisation in 39 patients with recurrent patellar instability. At 45 months, 91% of patients reported excellent or good outcome. However, at final follow-up, only 64% of patients had an excellent or good outcome. In this series, six patients reported a patellar dislocation after the procedure. Nakagawa also found that patients who underwent surgery less than 1 year after the first dislocation had better outcomes than those that waited longer than 1 year.

Pidoriano et al. retrospectively reviewed 36 patients after anteromedial tibial tubercle transfers and found correlations between clinical outcome and location of patellar articular lesions. Outcomes were superior among patients with distal patellar (90% good to excellent) and lateral facet lesions (85% good to excellent). Outcomes were less favourable with medial facet (55% good to excellent) and proximal patella lesions (20% good to excellent). Pidoriano et al. recommended patient selection for this procedure based on the presence and location of articular defects as this has been shown to correspond to clinical outcome. This is particularly important as articular lesions have been reported in up to 96% of patients with recurrent patellar instability.
In a comparison of cadaveric knees undergoing MPFL reconstruction or medial tibial tuberosity transfer, Ostermeier et al. reported a more significant reduction in lateral displacement with MPFL reconstruction\textsuperscript{55}. It is unclear whether this reduction in lateral displacement would have clinical significance, however, suggests MPFL reconstruction may be a more powerful tool for realignment.

Tibial tubercle distalisation may also be performed in patients with significant patella alta, but is more commonly combined with anteromedialisation. Increased patellar length has been identified as a potential risk factor for patellar instability\textsuperscript{56}. This is evident in cases of patella alta where there is an increase in patellar motion in the coronal plane\textsuperscript{56}. One method to address patellar length is with tibial tubercle distalisation which may limit patellar motion and improve stability by allowing the patella to engage the trochlea at lower flexion angles in patients with patellar dislocations.

Mayer et al. performed patellar tendon tenodesis and tibial tubercle distalisation in 22 patients with patellar instability. The mean Caton–Descamps index and Insall–Salvati ratios decreased from 1.22 to 0.95 and 1.42 to 0.91, respectively\textsuperscript{56}. There were no cases of patellar dislocation following the procedure\textsuperscript{56}. Pritsch et al. followed 66 patients after tibial tubercle osteotomy for patellar instability. A 90% of patients in this series underwent tibial tubercle distalisation procedures\textsuperscript{57}. At an average follow-up for 6 years, 72% of the patients reported good-to-excellent results\textsuperscript{57}. There was a significant decrease in the Insall–Salvati ratio from 1.25 to 1.0 and there were five cases of recurrent instability\textsuperscript{57}. Pritsch et al. found better outcomes in males and patients with intact patellar articular cartilage\textsuperscript{57}.

Although it is a powerful tool for distal realignment, tibial tubercle osteotomy also has several significant complications. In a cadaveric study, Kuroda et al. found that medial tibial tubercle transfer with the Elmslie–Trillat procedure significantly increased contact pressure in the medial patellofemoral joint and medial tibiofemoral compartments\textsuperscript{58}. Kuroda et al. recommended against using this procedure in patients with pre-existing medial compartment osteoarthritis, varus knees, or in patients with a prior medial meniscectomy\textsuperscript{58}.

In addition to increasing contact pressures in the patellofemoral and tibiofemoral compartments, another potential complication of tibial tubercle osteotomy is non-union. Pritsch et al. reported one case of non-union in 66 patients\textsuperscript{57}. Mayer et al. found a 15% complication rate including two superficial wound infections, one case of symptomatic hardware and one pseudoarthrosis\textsuperscript{56}. Post-operative tibia fracture is also possible following tibial tubercle osteotomy. To prevent this complication, patients are made non-weight bearing or limited-weight bearing on the affected leg to decrease the likelihood of fracture. However, patient falls and aggressive tibial tubercle cuts predispose patients to such fractures. Arthrofibrosis may also occur following tibial tubercle transfers. Significant patient pain following this procedure and/or restricted range of motion following the surgery increase a patient’s risk of developing arthrofibrosis. In a series of 36 patients, Piodarino et al. reported one case of tibia fracture requiring 2 months in a long leg cast and one case of arthrofibrosis that improved followed closed manipulation under anaesthesia 5 months after surgery\textsuperscript{53}. Symptomatic hardware requiring removal and compartment syndrome may also develop after tibial tubercle osteotomy.

Trochleoplasty

Trochleoplasty may be used to correct trochlear dysplasia with an elevating osteotomy of the lateral trochlear facet. However, the use of trochleoplasty is limited because of concerns of cartilaginous injury and changes to contact pressures potentially leading to patellofemoral arthritis\textsuperscript{1}. It is for this reason that contraindications to trochleoplasty include articular cartilage defects of the patellofemoral joint and patellofemoral osteoarthritis\textsuperscript{59}. There are several different techniques of trochleoplasty popularised by Dejour including proximal open trochleoplasty, deepening trochleoplasty, trochlear thinning osteotomy and arthroscopic deepening trochleoplasty\textsuperscript{59}.

Fucentese et al. reviewed 44 knees in 38 patients with patellar instability treated with deepening trochleoplasty and no other procedures performed at that time. A 37% of patients reported no improvement in pain and 8% reported worse pain following surgery than before\textsuperscript{60}. There were six cases of recurrent instability and 18% of patients said they would not repeat the surgery\textsuperscript{60}. Fucentese et al. concluded that pain relief following trochleoplasty is not predictable but that this procedure does improve stability in most patients. We currently do not advocate trochleoplasty for fear of pain and cartilaginous damage following the procedure. However, there is a subset of patients with severe dysplasia who benefit from this procedure.

Ntagiopoulos et al. followed 27 patients for an average of 7 years after sulcus deepening trochleoplasty for recurrent patellar instability. Sulcus angles decreased from an average of 152°–141° and there were no cases of patellar dislocation following the procedure\textsuperscript{60}. At latest follow-up, no patients had radiographic evidence of patellofemoral osteoarthritis and knee pain and function improved significantly from pre-operative measures\textsuperscript{60}.

Neitz et al. combined trochleoplasty and MPFL reconstruction in a cohort of 23 patients with recurrent patellar instability. Post-operatively,
there were no cases of recurrent instability and 96% of patients were satisfied or very satisfied with the procedure.

Derotational Osteotomies
Tibial and femoral derotational osteotomies may be performed for those patients with patellar instability and external tibial torsion or femoral anteversion, respectively. These procedures are typically reserved for the paediatric population although they can be performed in the adult population in certain situations. Paulo et al. compared patients who had undergone a derotational high tibial osteotomy or tibial tubercle transfer for management of patellar instability. Paulo et al. found better function and gait among patients treated with a derotational high tibial osteotomy.

Similar to tibial tubercle osteotomies, complications with derotational osteotomies include symptomatic hardware, iliotibial band fracture, wound infection and compartment syndrome. Peroneal nerve palsy may also develop following a lateral closing wedge osteotomy due to the peroneal nerve’s proximity to the tibial cuts for this procedure.

Non-operative versus Operative Outcomes
Nikku et al. randomised 125 patients to operative or non-operative management following a primary patellar dislocation. Operative management consisted of lateral release and/or medial retinacular repair with suturing, duplication or additional augmentation of the MPFL. At 2 years, patients had similar functional outcomes and no improvement in dislocation recurrence when treated operatively. This same cohort was re-evaluated at 7 years. Among those treated non-operatively, 81% of patients reported excellent or good outcomes. This figure was 67% in the operative group. Redislocation rates were similar with 30% of those treated non-operatively and 36% of patients treated operatively reporting subsequent episodes of patellar instability. The operative procedures utilised in this study are not commonly performed today but this study highlights that many patients may have good outcomes with non-operative management following a primary dislocation.

Sillanpää et al. randomised 40 patients with primary patellar instability to operative and non-operative management. Patients treated operatively underwent several different procedures including medial reefing and distal realignment procedures. Patients treated non-operatively were placed in a knee orthosis; however, four patients in this group underwent arthroscopy for removal of an osteochondral fragment without a stabilisation procedure. In the operative group, there were no episodes of redislocation. However, in the non-operative group, 29% of patients reported recurrent episodes of instability. Outcome measures were similar between the two groups and there were no significant differences in either group’s ability to return to pre-injury activity levels.

Petri et al. randomised patients to operative and non-operative management following traumatic patellar dislocation. Surgery consisted of diagnostic arthroscopy followed by soft-tissue repairs with or without a lateral release. MPFL reconstruction was not performed. In the non-operative group, patients were placed in a range of motion brace locked in full extension for 3 weeks followed by progressive range of motion increases. Outcome scores were similar between the two groups but there was a 38% redislocation rate in the non-operative group at 24 months. In the operative group, the redislocation rate was 17%. However, Petri et al. noted the study to be probably underpowered because of a study population of 20 patients, and recommended larger randomised studies and meta-analyses to better evaluate the role of operative management after a primary patellar dislocation.

Our Approach
The patient presenting with patellar instability is initially managed with closed reduction if the dislocation has not spontaneously reduced. Physical exam is then performed with assessments of limb alignment, patellar translation and patellar apprehension. Palpation is utilised to assess for MPFL tenderness and the Q angle and TT-TG distance is measured on exam and through radiographic studies. Radiographs include weight-bearing PA, lateral, andMerchant views to assess for reduction, patella height, trochlear dysplasia, as well as avulsion fractures and loose bodies.

Patients are initially treated with a removable brace in full extension. The brace is worn at all times for 4 weeks, at which time the patient may begin range of motion exercises. Patients are either sent for physical therapy or given exercises to focus on strengthening with emphasis on the quadriceps tendon and VMO. The patient is progressed to full activity in a stepwise fashion with first returning to walking and jogging. Running, jumping and kneeling are delayed until there is an absence of pain with less strenuous activity. Patellar bracing may be used to help with a feeling of apprehension or instability but is not mandatory.

After a primary dislocation, MRI is utilised in patients with mechanical symptoms of locking or clicking or in cases where pain fails to improve. It is used to assess for MPFL injury, osteochondral fracture or other injuries sustained during dislocation. Currently, we do not offer surgery for primary dislocators barring the need to address associated injuries.

Operative Management
In patients with recurrent instability, defined as more than one episode of...
patellar subluxation or dislocation, exam, radiographs and MRI are included in the evaluation. Patients are counselled about the risk of future episodes of instability and offered surgery as an option for symptomatic recurrent instability.

The authors cater the surgery to the individual patient depending on the circumstances. In those patients with malalignment, tibial tubercle anteromedialisation (AMZ) is performed. We typically use the TT–TG distance rather than the Q angle for this determination as the Q angle is more subject to examiner error than the TT–TG angle which can be measured on MRI. For those patients with TT–TG greater than 20 mm, AMZ is performed either in isolation or combined with MPFL reconstruction. In the uncommon patient with significant patella alta, distalisation is often added to AMZ with care not to move the tubercle too distal for fear of increasing patellofemoral contact pressures and capturing the knee. A good rule of thumb is to avoid shifting the tubercle greater than 2 cm. Patients with significant femoral anteversion or tibial torsion receive an AMZ as well, rather than derotational osteotomies unless the deformity is severe.

For AMZ, we use a fairly long cut to provide the most surface area for healing although violation of the tibia distal to the tubercle itself should be avoided. The bone block is fixed with two 4.5 mm cortical screws in a lag fashion. The amount of anteriorisation or medialisation depends on the patient’s deformity as well the status of the cartilage of the patella. More significant cartilaginous lesions are addressed with more anteriorisation. A lateral release is combined with AMZ if the lateral structures are tight following AMZ and/or if the patient has abnormal patella tilt.

For those patients with normal TT–TG distances, MPFL reconstruction is the preferred treatment method. We typically use a soft tissue allograft as the reconstruction is extra-articular and will reliably heal, although semitendinosus autograft can be used as well. We use two suture anchors on the patella side in the location of the anatomic MPFL. The graft is placed in an upside triangular configuration (Figure 4) with the base of the triangle anchored to the patella at two locations: the junction of the superior 1/3 and inferior 2/3 of the patella and the midpoint of the patella. The two ends of the graft are then passed between layers 2 and 3 on the medial aspect of the knee. A femoral tunnel is drilled using fluoroscopy to verify the anatomic location of the tunnel. The two free ends are then pulled out laterally and the graft is fixed with an interference screw. The graft is initially tensioned at full extension, but brought up to 90° of flexion to loosen the graft slightly. It is then fixed at 90° of flexion. The key to a successful reconstruction and good long-term outcomes is anatomic placement of the tunnels verified by fluoroscopy and avoidance of overtensioning the graft. Improper tunnel placement is the number one cause of problems, that is pain or stiffness.

In patients with significant trochlear dysplasia, MPFL reconstruction is performed, however, often is combined with AMZ if there is any questionable alignment issue. This addresses the ligamentous injury that has occurred and provides another barrier to dislocation. The osteotomy is performed prior to MPFL reconstruction.

Patients that have failed previous surgeries are typically treated more aggressively with combination procedures. However, each patient is different and must be evaluated not only by examination and imaging, but also based on previous procedures performed.

Conclusion
Patellar instability most commonly affects adolescent female athletes. Although most cases of patellar instability are isolated episodes, 15%–44% of patients may develop recurrent patellar instability. There are multiple anatomical considerations that may contribute to patellar instability and, in cases of recurrent instability, must be addressed to prevent subsequent episodes of instability. Non-operative management has good outcomes in most patients after a primary dislocation. Patients with recurrent instability may benefit from operative management consisting of proximal or distal realignment procedures. Tailoring a patient’s treatment to symptoms, osseous morphology, and specific injuries with patellar instability will lead to the best outcome and highest levels of satisfaction with this complex problem.

Abbreviations
CT, computed tomography; IT, iliotibial; MRI, magnetic resonance imaging; MPFL, medial patellofemoral ligament; Q, Quadriceps; TT-TG, tibial...
tubercle–trocchlear groove; VMO, vastus medialis obliquus.

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