Review Article

Patellofemoral Instability Part I: Evaluation and Nonsurgical Treatment

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ABSTRACT

Patellofemoral instability (PFI) is a prevalent cause of knee pain and disability. It affects mostly young females with an incidence reported as high as 1 in 1,000. Risk factors for instability include trochlear dysplasia, patella alta, increased tibial tubercle-to-trochlear groove distance, abnormal patella lateral tilt, and coronal and torsional malalignment. Nonsurgical and surgical options for PFI can treat the underlying causes with varied success rates. The goal of this review series was to synthesize the current best practices into a concise, algorithmic approach. This article is the first in a two-part review on PFI, which focuses on the clinical and radiological evaluation, followed by nonsurgical management. The orthopaedic surgeon should be aware of the latest diagnostic protocol for PFI and its nonsurgical treatment options, their indications, and outcomes.

This article is part 1 in a two-part series presenting an approach to the clinical and radiological evaluation of patellofemoral instability (PFI), with a discussion on nonsurgical treatment, and part 2 of this series will discuss surgical management. PFI has a multifactorial etiology, often affecting young, active individuals.[1,2] The overall incidence of PFI in the general population is 5.8 in 100,000, whereas its incidence in female individuals between 10 and 17 years is reported at 29 in 100,000.[3] Patellofemoral disorders and patellar dislocations comprise approximately 25% and 3% of all knee injuries, respectively.[1,3] In patients with a first-time patellar dislocation, the rate of recurrence is 17% to 33%, with no difference across different age groups.[4-7] For those with recurrent dislocations, the risk of redislocation is over 50%.[2] Moreover, up to 48.9% of patients with a first-time patellar dislocation develop osteoarthritis of the patellofemoral joint after 25 years versus 8.3% in age-matched control subjects ($P < 0.001$).[8] Therefore, an algorithmic approach to diagnosis and treatment of PFI is imperative (Figure 1).

Patients with PFI often present with sensations of patellar instability, previous patellar subluxations/dislocations, and knee effusion.[2,9] They may report difficulty with weight-bearing or standing upright and difficulty straightening their knee. They may have instability while walking, climbing stairs/bending their knee, running, or jumping. It is important to distinguish

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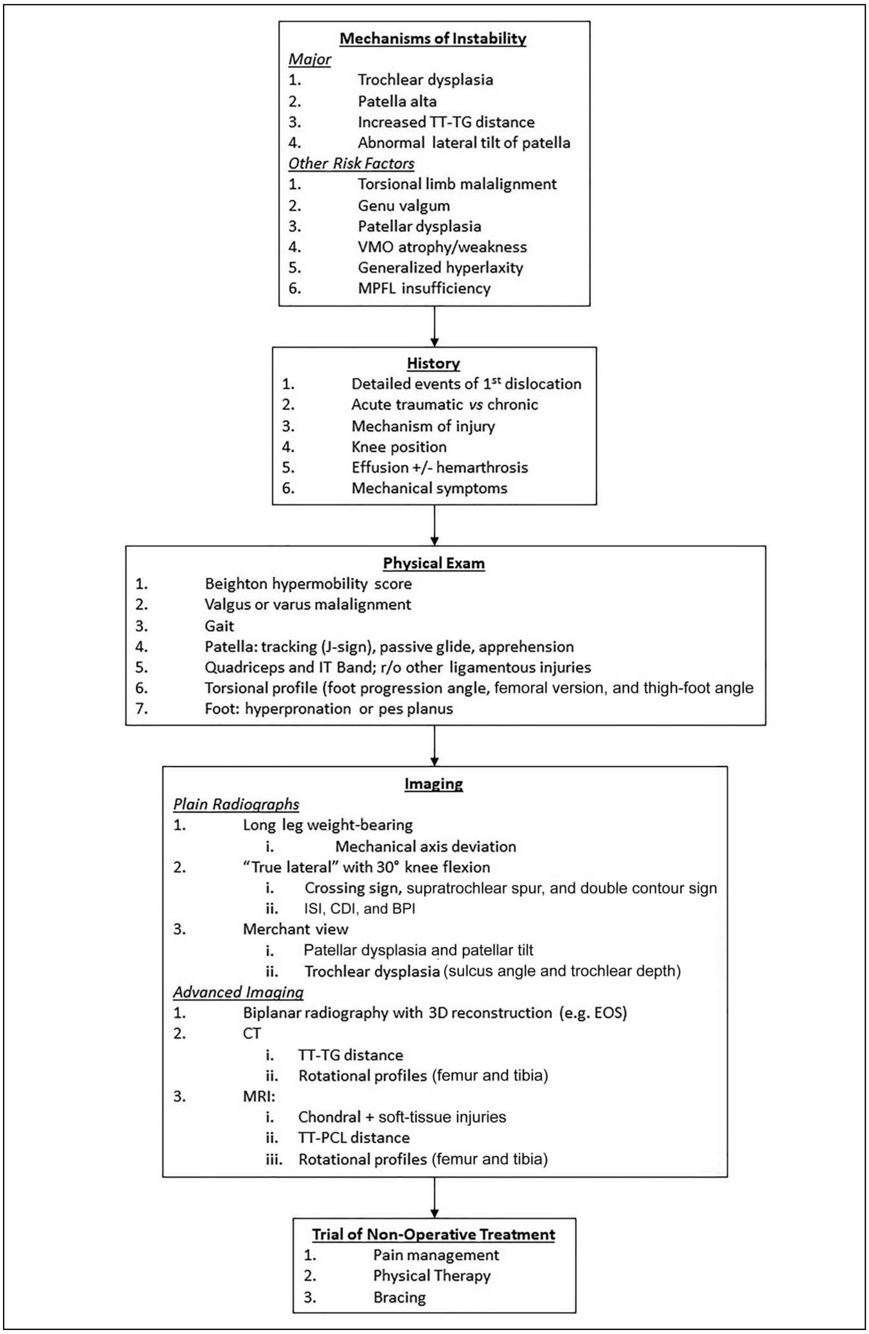
Figure 1



Flowchart showing an algorithmic approach to the diagnosis and nonsurgical management of patellofemoral instability. Characterizing the underlying mechanism(s) of instability is critical and is driven by clinical history and physical examination findings, followed by imaging modalities, including plain radiography and advanced imaging (CT and MRI). TT-TG = tibial tubercle-to-trochlear groove; VMO = vastus medialis oblique; MPFL = medial patellofemoral ligament; IT band = iliotibial band; ISI = Insall-Salvati Index; CDI = Caton-Deschamps Index; BPI = Blackburne-Peel Index; 3D = three-dimensional; CT = computed tomography; MRI = magnetic resonance imaging; TT-PCL = tibial tubercle-to-posterior cruciate ligament.

the two broad types of PFI patients: (1) PFI with a history of traumatic patellar dislocation and (2) nontraumatic PFI where patients present with a patellar dislocation with regular daily activities or noncontact sports.[2] Recurrent PFI accelerates degenerative changes of the patellofemoral joint, which can lead to anterior knee pain that worsens with activity. In more severe forms, it can be associated with chondral injuries and earlier onset of osteoarthritis of the patellofemoral joint.[4,5] Osteochondral fractures of the lateral femoral condyle and/or medial patellar facet occur in 40% to 50% of patella dislocations, which may cause acute large hemarthrosis and/or mechanical symptoms.[10]

Patellofemoral Joint

Osteology

The depth of the trochlear groove averages 5.2 mm and deepens as it extends distally.[1] The sulcus angle describes the angle between medial and lateral facets, with its normal values ranging between 132° and 144°.[6,9] The lateral facet of the patella is longer and has a flatter slope to match the lateral facet of the femoral trochlea while the medial facet is shorter with a steeper slope.[1] The Wiberg classification is used to describe the four morphologic types of patellae based primarily on the asymmetry between its medial and lateral facets.[1]

Patellar tracking is achieved through a combination of (1) the osseous constraints between the patella and the femoral trochlea and (2) soft-tissue structures that provide static or dynamic stabilization. The single most important factor for patellar stability is the trochlear morphology.[11] During the initial 20° to 30° of knee flexion, the patella migrates medially, slides into the osseous groove of the trochlea, and becomes centered in the trochlea.[2,12] Beyond 30° of knee flexion, patellar stability is achieved primarily by the medial and lateral osseous constraints.[13,14] A delayed engagement of the patella in the trochlear groove, as in the case for patella alta or trochlear/patellar dysplasia, can predispose individuals to an increased risk of PFI.[1]

Soft Tissues

The soft-tissue structures that contribute to the "neutral" patellar position include the quadriceps muscle, the patellar tendon, and the medial and lateral soft-tissue stabilizers.[1] The vastus medialis oblique (VMO) and the iliotibial band (ITB) are the primary medial and lateral dynamic stabilizers of the patella, respectively.[15,16] During motion, contractions of the VMO and ITB work simultaneously to exert forces that prevent lateral or medial patellar displacement, respectively, and maintain in-line patellar tracking. The medial retinaculum is the primary static stabilizer of the patella, which prevents lateral displacement of the patella during the initial 30° of knee flexion.[11,17] The medial retinaculum comprises the medial patellofemoral ligament (MPFL), transverse fibers of the medial retinaculum, medial patellotibial ligament (MPTL), medial patellomeniscal ligament (MPML), and the medial quadriceps tendon-femoral ligament.[2,11,17,18]

Limited literature exists on the contribution of lateral soft tissues in patellar stabilization. Excessive contracture of the lateral soft tissues, particularly the deep transverse/lateral retinaculum (LR), applies a tensile force on the patella in the lateral direction that may predispose to PFI; paradoxically, the LR also seems to play some beneficial role in preventing lateral translation of the patella and stabilizing the patellofemoral joint.[2,4,11] From full extension to 30° of flexion, the medial and lateral retinacular structures stabilize the patella.[2] The relative contributions of the soft tissues that restrain lateral displacement of the patella are MPFL 53% to 72%, MPML 13% to 22%, transverse fibers of the medial retinaculum 11%, MPTL 5% to 24%, and LR 10% to 22%.[2,11,17,19] The MPTL and MPML act as stabilizers at greater angles of knee flexion, contributing a combined 26% of resistance to lateral translation at full extension of the knee versus 46% at 90° of knee flexion.[15] The medial quadriceps tendon-femoral ligament is an anatomically distinct component of the medial retinaculum, and it originates from the adductor tubercle slightly proximal to the MPFL and inserts into the distal quadriceps tendon.[20] It is classically described as a static stabilizer; however, in some patients there is a variable insertion through the VMO, which indicates a contribution to dynamic stability.[11,18,20]

The MPFL originates 1.9 mm anterior and 3.8 mm distal to the adductor tubercle, radiologically identified as the Schottle point, and has a broad insertion into the superior medial border of the patella.[2,11] The midpoint of the MPFL insertion is located 41.2% of the length from the proximal tip of the patella along its length.[21] The MPFL is the primary medial stabilizer from zero to 30° of knee flexion.[1,11,19] The MPFL experiences maximal strain in full extension and progressively relaxes with flexion.

Mechanisms of Instability

The five major anatomic risk factors for chronic PFI are trochlear dysplasia, patella alta, increased tibial tubercle-to-trochlear groove (TT-TG) distance, abnormal lateral tilt of the patella, and torsional malalignment of the femur and/or tibia.[2,9,19,22] Other risk factors are genu valgum, patellar dysplasia, VMO atrophy, generalized hyperlaxity, MPFL insufficiency, and lateral soft-tissue contractures.[6,12] Lateral instability accounts for 95% of PFI and almost always has identifiable anatomic risk factors.[10,13] Conversely, medial instability is often due to a direct trauma or iatrogenic causes (ie, complication of a lateral retinacular release, blunt or surgical trauma causing scarring and inferomedial patella tethering, or surgical overconstraining of medial structures).[10,16]

Trochlear Dysplasia

Trochlear dysplasia describes the absence of the normal concavity (Figure 2).[1] This leads to a narrower and flatter trochlear groove that is incapable of containing the patella during knee flexion.[1] The Dejour classification is a well-known classification system for trochlear dysplasia that classifies the trochlear morphology into four types based on radiologic findings.[23] Recent studies suggest that the Dejour classification may have limited interobserver reliability and reproducibility for routine clinical use.[23]

In clinical settings, trochlear depth less than 4 mm or trochlear bump greater than 3 mm is pathognomonic for trochlear dysplasia.[2,9] Another sign of trochlear dysplasia is an abnormal sulcus angle, where angles greater than 145° are pathologic (Figure 3).[6] Dejour et al demonstrated radiologically that sulcus angles more than 145° had statistically significant instability compared with control subjects (average 130°), suggesting a shallow trochlea, which is incapable of providing sufficient osseous constraint from lateral displacement of the patella, thereby predisposing to instability.[6] Overall, 85% of patients with PFI were found to have trochlear dysplasia.[6]

Patella Alta

In patients with patella alta, the degree of knee flexion at which the patella engages with the trochlea increases beyond the normal 20° to 30°.[1] The patella remains "vulnerable" during a greater fraction of the knee range of motion, relying more on the medial soft-tissue structures preventing lateral patellar displacement.[1] In fact, there is an increased tensile stress applied to the MPFL to prevent the lateral displacement.[6] Patients with recurrent PFI have a three times higher prevalence of patella alta compared with those with a stable patellofemoral joint.[24]

Increased TT-TG Distance

The TT-TG distance is used to measure the lateralization of the tibial tubercle relative to the trochlear groove. A TT-TG distance more than 20 mm is generally considered abnormal and is thought to be indicative of lateralized insertion of the patellar tendon into the tibial tubercle (Level IV evidence), with over 90% association with PFI.[2,25,26] An increased TT-TG distance can be caused by increased femoral anteversion, which internally rotates and medializes the trochlear groove; increased external tibial torsion, which externally rotates and lateralizes the tibial tubercle; valgus malalignment of the lower limb, which lateralizes the path of patellar tracking relative to the trochlear groove; or combinations of these.[25]

Torsional Malalignment

Torsional malalignment can influence the coronal alignment of the patella within the trochlear groove.[14,27] Two classic examples include (1) increased femoral anteversion and (2) increased external tibial torsion.[28] In excessive femoral anteversion, the proximal extensor mechanism (ie, quadriceps muscle and tendon) is internally rotated relative to the distal extensor mechanism (ie, patellar tendon), resulting in a laterally directed force on the patella. Conversely, in the case of increased external tibial torsion, the patellar tendon inserts into an externally rotated tibial tubercle, also resulting in a laterally directed force on the patella. The presence of either increased femoral anteversion or increased external tibial torsion can lead to premature osteochondrosis of the lateral patellar facet and lateral femoral trochlear facet and an increased predisposition to PFI.[14,27]

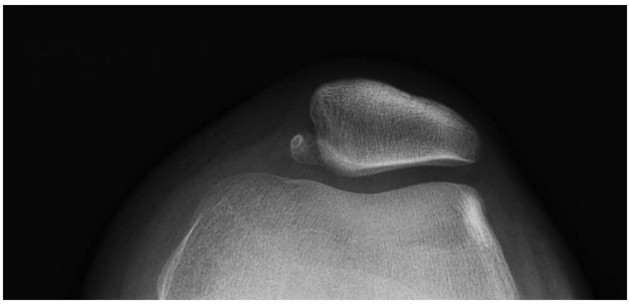
Diagnostic Approach

Clinical Evaluation of PFI

History

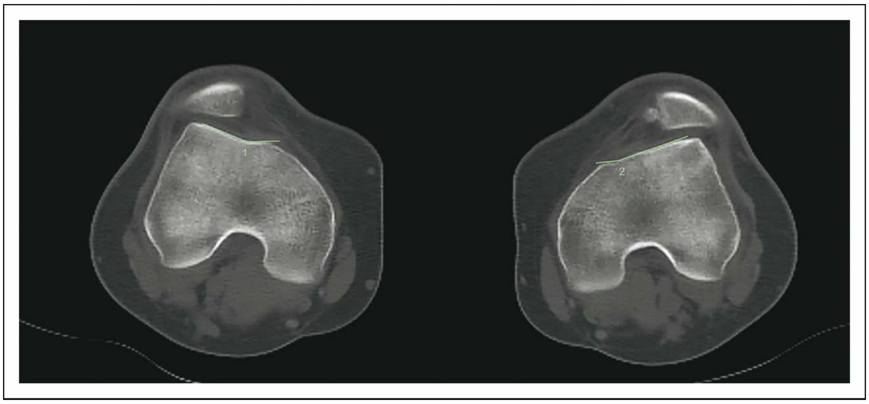
An algorithmic approach to characterizing the mechanism(s) of instability through obtaining a focused clinical history, physical examination, relevant radiological imaging, and nonsurgical management is demonstrated in Figure 1. For PFI, the following information should be obtained:

Figure 2



Trochlear dysplasia visualized on an axial radiograph of the patellofemoral joint in the left knee. Trochlear dysplasia is visualized with a flat-appearing trochlear groove. The sulcus angle in this case is measured at 162° while the depth of the trochlear groove is 1.6 mm.

Figure 3



Radiograph showing abnormal sulcus angles on CT. The sulcus angle is measured between lines drawn along the medial and lateral trochlear facets. The sulcus angle of the right knee (angle 1) is 156.2°. The sulcus angle of the left knee (angle 2) is 165.4°.

(1) detailed history of the patient's first patellar dislocation (traumatic versus nontraumatic) along with necessity of a reduction, (2) acute traumatic versus chronic instability, (3) mechanism of injury, (4) position of the knee at which instability occurs, and (5) presence of acute hemarthrosis or effusion.[3,6] The presence of a large hemarthrosis or mechanical symptoms may indicate an intra-articular loose body and warrants more emergent acquisition of advanced imaging (ie, CT and/or MRI).

Physical Examination

Physical examination can help elucidate the mechanism of instability for most patients with PFI. The presence of generalized ligamentous hyperlaxity can be assessed using the Beighton hypermobility score.[3,13] With the patient standing, overall alignments of the lower limbs can be visualized to assess for the presence of valgus or varus malalignment and malrotation of the lower limbs, which can be represented with the patella facing inward.[3,29] Subsequently, the patient's gait should be observed because it may reveal antalgic or Trendelenburg gait and/or an abnormal foot progression angle, in which the latter is indicative of malrotation.[29]

With the patient lying supine, the quadriceps muscle bulk, tone, and strength can be assessed. Patellar tracking during passive and active ROM should be examined, which can reveal the J-sign, defined as the lateral subluxation of the patella during the terminal phase of knee extension from a flexed position.[2,9] The J-sign is indicative of soft-tissue contractures or trochlea dysplasia.

Special tests can further evaluate for PFI.[2] The passive patellar glide test is conducted with the knee flexed at 20°, and the patella is translated medially and then laterally.[13] If the patella glides less than one quadrant of the patellar width medially, this suggests lateral tightness, whereas gliding more than three quadrants in either direction suggests hyperlaxity. The passive patellar glide test is a sensitive tool to screen for MPFL injuries when asymmetrical compared with the contralateral side.[13]

The patellar apprehension test is conducted by applying a laterally directed force on the patella while the knee goes from full extension to flexion.[6] Any apprehension or quadriceps muscle activation indicates a positive test. The patellar apprehension test has a very high diagnostic accuracy for PFI, with 100% sensitivity, 88.4% specificity, 89.2% positive predictive value, and 100% negative predictive value.[6]

Finally, the rotational profile should be assessed with the following four components: (1) foot progression angle during gait (measured as the angle between the line of progression during the stance phase and the line from the calcaneus to the second metatarsal to assess for the net torsion of the femur and tibia); (2) internal and external rotation of the hip in a prone position (Figure 4), which can be used to assess for the presence of increased femoral anteversion (represented by increased hip internal rotation with decreased hip external rotation); (3) quantify tibial rotation using the thigh-foot angle with the patient in a prone position (Figure 5); and (4) foot examination to assess for foot hyperpronation or pes planus.[10,13] Examination in the prone position maintains the hip extended and allows for a reliable assessment of the rotational profiles of the femur and tibia.

Radiological Evaluation

Radiographs

Plain radiographs represent a vital initial investigation in patients with PFI. Important views include the long leg weight-bearing view of the lower limbs, "true lateral" view with the knee flexed at 30°, and axial projections of the patellofemoral joint with the knee flexed at 20° (Laurin view) and at 30° to 45° (Merchant view).[3,25] The Laurin view can reveal the position of the patella with soft-tissue stabilizers engaged.

Overall limb alignment can be assessed using the long leg (hips-to-ankle) weight-bearing view of the lower limbs. The Q-angle is a critical indicator of knee alignment and the force vector of the extensor mechanism on the patella.[3,27] A normal Q-angle is 15 to 20° and 10° to 15° in women and men, respectively.[3] A larger than normal Q-angle indicates a laterally directed vector of the force applied to the patella.[3,26] In cases of valgus malalignment, when the mechanical axis of the entire limb is deviated laterally to the center of the knee, the lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA) can help identify the origin of the deformity (Figure 6). The mechanical (m) LDFA is denoted by the angle between the mechanical axis of the femur and a line drawn across the articular surface of the distal femur.[30] The MPTA is denoted by the angle between the mechanical axis of the tibia and a line drawn across the articular surface of the proximal tibia. A mLDFA of 85° to 90° and MPTA of 85° to 90° are considered normal.[30]

A true lateral view of the knee can reveal trochlear dysplasia and/or patella alta (Figure 7). The presence of a "crossing sign," "supratrochlear spur," and/or "double contour signs" on lateral radiographs are indicative of trochlear dysplasia and are components of the Dejour classification.[3,25] Patellar height is evaluated using the Insall-Salvati Index (ISI), the Caton-Deschamps Index, or the Blackburne-Peel Index, which can reveal patella alta or patella baja.[2,11,25,31] To measure patella height on radiography, ISI was shown to be the most reliable of the three (Level II evidence).[32] An ISI of 1.0 is considered normal while a value greater than 1.2 is defined as patella alta and less than 0.8 is patella baja.[14] To note, the Caton-Deschamps Index and Blackburne-Peel Index were shown to yield higher interobserver reliability than the ISI.[2]

Finally, Laurin and Merchant views, acquired with the knee flexed at 20° and at 30° to 45°, respectively, can reveal abnormal patellar tilt, trochlear dysplasia, patellar dysplasia, and/or subluxation of the patella.[2,3,25] However, up to 20% of patellar subluxations seen on the Merchant view are false-positives.[2]

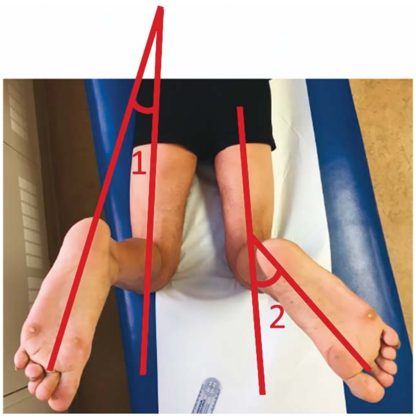
Biplanar Radiography with 3D reconstruction

Biplanar radiography with 3D reconstruction, such as the EOS Imaging System (EOS Imaging, ATEC Spine Group, 2012), may be a suitable alternative to CT imaging with the advantage of lower exposure to ionizing radiation, although its accessibility remains limited in clinical settings.[24] It allows for the measurement of femoral and tibial torsion and anatomical and mechanical assessment including the evaluation of valgus and varus alignment of the entire limb. In a retrospective study of 43 lower limbs, the EOS system

Figure 4

Photographs showing excessive femoral anteversion observed during physical examination (left lower extremity). The hip internal rotation and external rotation are measured during the physical examination with the patient positioned supine and knees flexed at 90°. In the patient photographed in the image, the hip internal rotation and external rotation are 80° and 30°, respectively, which are consistent with excessive femoral anteversion.

Figure 5



Photograph showing the thigh-foot angle measured during physical examination. Measurement of the thigh-foot angle as the intersection of the (1) axis of the thigh and (2) axis of the foot (heel bisector line) with the patient positioned prone, knees flexed to 90°, and the hindfoot in the neutral position. Here, increased external tibial torsion of the right leg is shown by its increased thigh-foot angle compared with the left leg. Angle 1 represents the thigh-foot angle of the left leg, which is 15°, and angle 2 is the thigh-foot angle of the right leg, which is 37°.

and CT measurements of femoral torsion and tibial torsion had <0.5° of difference (P = 0.5 and 0.4, respectively), and the EOS system had similar inter-observer reproducibility as CT in measuring these torsional profiles.[33]

CT

CT is the benchmark imaging modality for assessing bony abnormalities and torsional malalignment that may contribute to PFI.[27] In addition to assessing for trochlear or patellar dysplasia and/or abnormal patellar tilt, the TT-TG distance can be measured on superimposed axial cuts of the CT. The TT-TG distance is measured by drawing a line along the coronal plane between the deepest point of the trochlear groove and the most prominent point on the proximal tibial tubercle, paralleling the posterior femoral condylar line (Figure 8).[25,26]

Controversy exists for the method for measuring femoral torsion on CT.[33] This is mainly because of the difficulty in determining the true femoral neck axis, in which slice selection can influence the measured values.[33] Nevertheless, femoral torsion is measured as the angle between the femoral neck axis (a line parallel to the femoral neck and the center of the femoral head) and the posterior bicondylar axis (Figure 9).[33,34] Contrarily, tibial torsion is generally measured using the angle between a line tangential to the posterior tibial cortex on the slice just proximal to the tip of the fibula and the bimalleolar axis on the most proximal slice of the talus (Figure 10).[33,34]

MRI

The TT-TG distance can also be measured on MRI, although it may underestimate the value by up to 4 mm compared with CT.[25,31] A major advantage of MRI is the ability to characterize chondral abnormalities and soft-tissue injuries associated with PFI, such as lateral patellar facet chondromalacia, thickening of the LR, avulsion or rupture of MPFL, VMO dysplasia, and presence of loose bodies.[2,25] In addition, MRI allows measurement of the tibial tubercle-posterior cruciate ligament distance, which theoretically eliminates the potentially confounding variables introduced by the amount of knee flexion.[35] Although the inter-rater reliability of tibial tubercle-posterior cruciate ligament measurements is lower than that of TT-TG values, it may serve as a useful secondary tool for borderline TT-TG values (16 to 20 mm).[25,35]

MRI can also be used in the evaluation of patellar height (Figure 11) and torsional profiles of the femur and tibia with high reported accuracy.[33] MRI measurements of femoral and tibial torsion have inter-rater interclass correlation coefficients of 0.964 and 0.914, respectively.[34]

Classifications

PFI can be classified descriptively based on the direction of instability and degree of knee flexion at which the instability occurs. Alternatively, it can be classified based on its etiology, such as traumatic, nontraumatic, syndromic, and obligatory/habitual.[25]

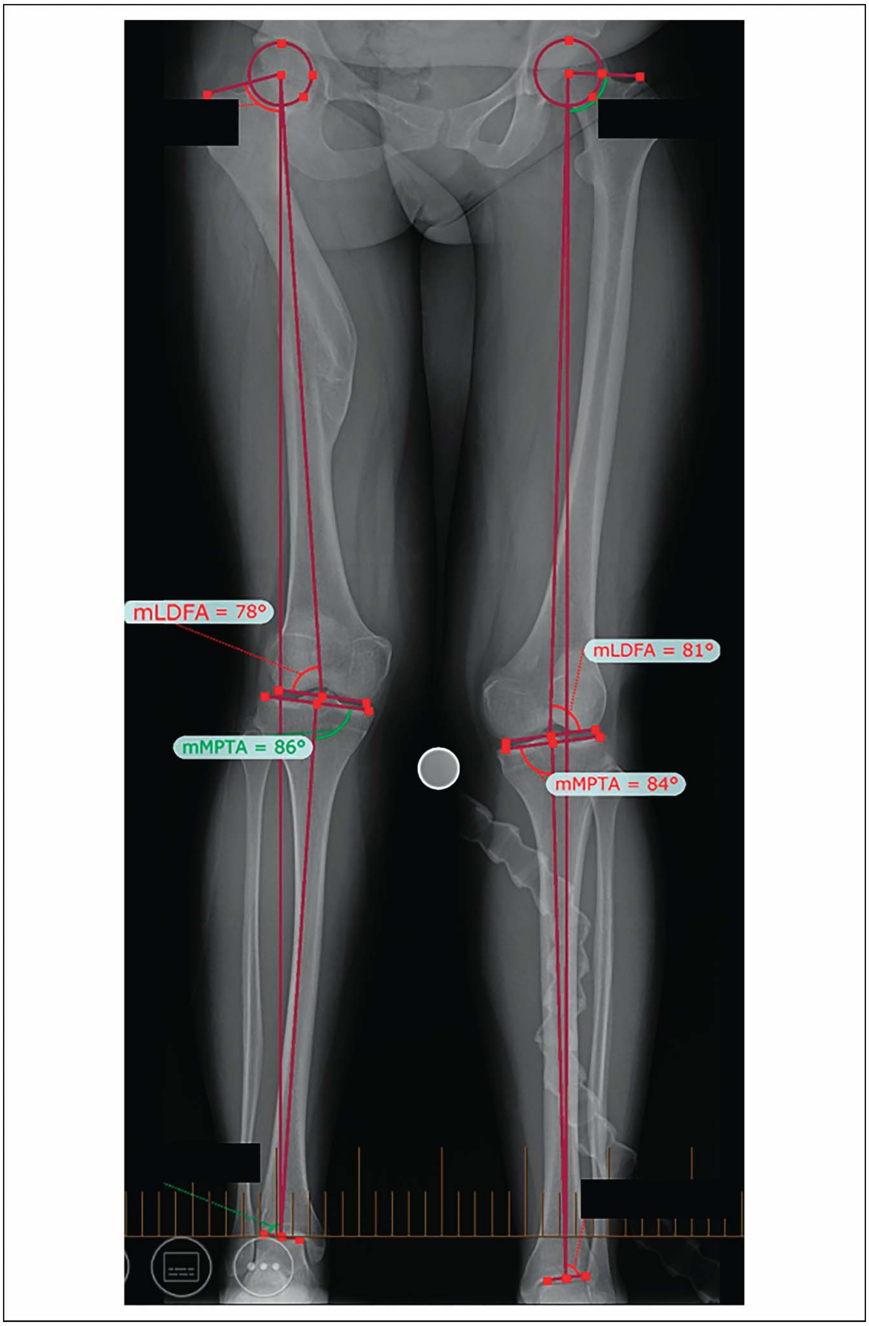
Finally, the Frosch classification is a newly proposed classification system for PFI, which considers the presence or absence of instability, maltracking, and loss of patella tracking.[36] In the Frosch classification, five types of PFI were described, each with varying contributions of different mechanisms of instability and their associated surgical strategies.[36] The Frosch classification will be covered in detail in part 2 of this review series.

Nonsurgical Management

Indications and Contraindications

Nonsurgical management is indicated in patients with a first-time patellar dislocation. All patients with PFI should begin physical therapy, coupled with adjunct modalities, although there is no strong evidence to support the use of one nonsurgical modality over another.[37] Although the exact duration of nonsurgical management remains controversial, we recommend a trial of 6 weeks to 3 months of empirical nonsurgical treatment before considering surgical interventions.[38] An

Figure 6



Mechanical axis measurement of the lower limbs on radiograph imaging. The mechanical lateral distal femoral angle (mLDFA) is formed by the intersection of the (1) mechanical axis of the femur (line from the center of the femoral head to the midpoint of the tangent to the femoral condyles) and (2) line tangent to the articular surface of the distal femur. The mechanical medial proximal tibial angle (mMPTA) is formed by the intersection of the (1) mechanical axis of the tibia (line from the center of the proximal tibial joint line to the midbimalleolar axis) and (2) line tangent to articular surface of the proximal tibia. Normal mLDFA and mMPTA range from 85 to 90°. Here, mLDFA on the right = 78° and left = 81°, and the mMPTA on the right = 86° and left = 84°.

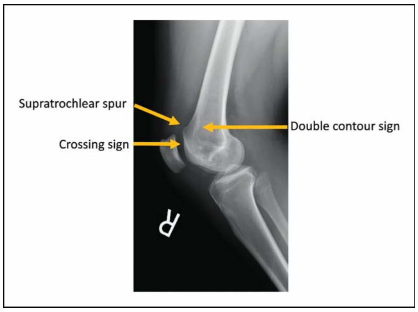
exception applies for patients presenting with mechanical symptoms and radiologically confirmed loose bodies, in which case such patients should promptly undergo an arthroscopic removal of loose bodies and surgical correction of underlying PFI etiologies.

Nonsurgical Treatment

Physical Therapy

Structured physical therapy has been shown to improve clinical outcomes in patients with PFI when initiated early.[29,37] The overall goals of physical therapy are

Figure 7



Indicators of trochlear dysplasia on the true lateral view of the knee (radiograph imaging). The "crossing sign," "supratrochlear spur," and "double contour signs" are radiograph imaging findings suggestive of trochlear dysplasia and are included in the Dejour classification for trochlear dysplasia.

quadriceps strengthening, patellar mobilization, core strengthening, and hip abductor strengthening.[29] Various techniques used in physical therapy include manual therapy to relieve ITB tightness; flexibility to target arthrogenically inhibited muscle groups; strength training to correct muscular imbalances, such as relative VMO weakness; and stability training for patients with hypermobile joints.[38]

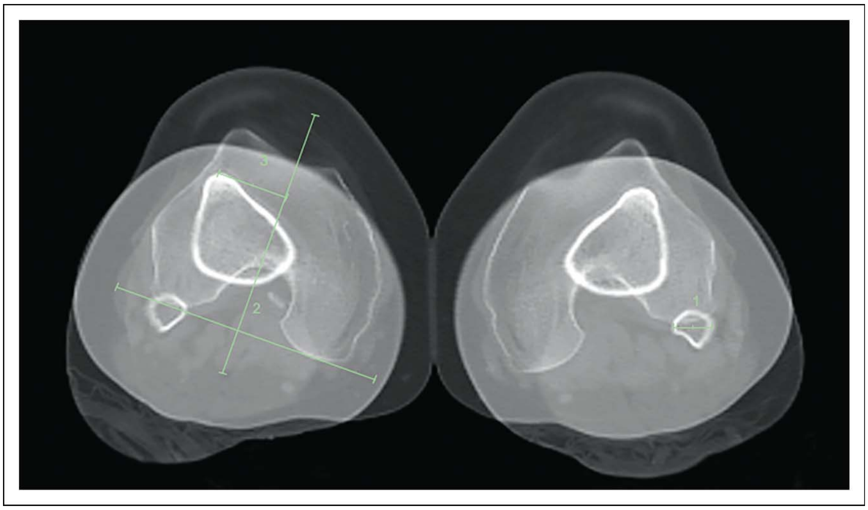
Bracing Treatment and Casting

Numerous bracing treatment options for PFI exist with some evidence to support their use for pain relief and functional improvement.[38] However, this is low-quality evidence from studies involving a relatively small number of patients. In patients with first-episode PFI, cast immobilization for 6 weeks was compared with patellar bracing treatment.[2] Although those who received cast immobilization had three times reduction in recurrent dislocations, they also had a notable increase in knee stiffness.[2] Therefore, we recommend a trial of dynamic bracing treatment in combination with early mobilization and physical therapy, and we advise against the use of cast immobilization for PFI without concomitant injuries.

Outcomes

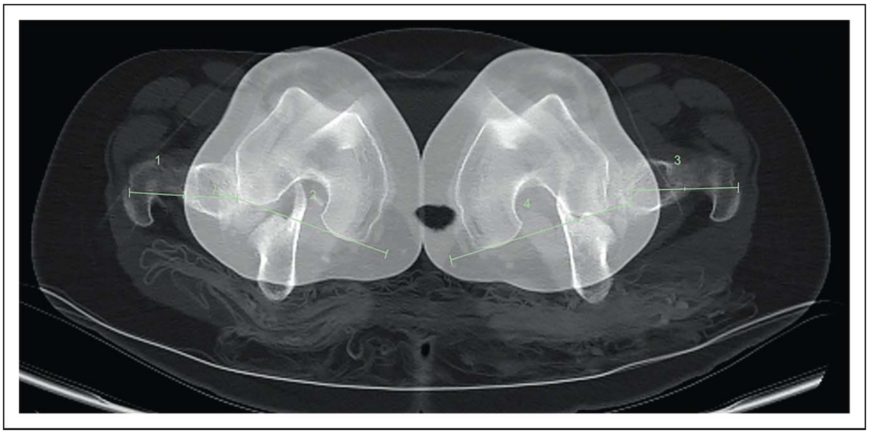
Historically, it is thought that nonsurgical management of patellar dislocation results in recurrent instability in up to 60% of patients.[39] In a 2015 systematic review of four meta-analyses (997 patients treated surgically versus 987 patients treated nonsurgically), patients who underwent nonsurgical management had a 34.6% subsequent patellar dislocation rate and a 33.0% rate of recurrent PFI. Conversely, patients who underwent surgical management had a 24.0% rate of subsequent patellar dislocation and a 32.7% rate of recurrent PFI.[7] Although notable heterogeneity in outcome measures was demonstrated, there was no consistently notable difference between the two treatment groups about patient-reported outcomes (pain, patient satisfaction,

Figure 8



Radiograph showing the tibial tubercle-to-trochlear groove (TT-TG) distance measured on CT (right knee). Line 1: Reference length for the image of 1.4 cm. Line 2: Line perpendicular to the posterior distal femoral bicondylar axis crossing the trochlear groove. Line 3: Distance between Line 2 and tibial tubercle, which gives the measured TT-TG distance of 2.6 cm. An increased TT-TG distance (>2.0 cm) is considered abnormal and suggestive of lateralization of the insertion of the patellar tendon into the tibial tubercle. Alternative causes include increased femoral anteversion, increased external tibial torsion, valgus malalignment of the lower limb, or a combination thereof.

Figure 9



Radiograph showing measurement of femoral torsion on CT. Femoral torsion is measured as the angle between (1) femoral neck axis and (2) posterior distal femoral bicondylar axis. Intersection of Lines 1 and 2 gives the right femoral torsional angle = 17.0° anteversion, and the intersection of Lines 3 and 4 gives the left femoral torsional angle = 15.9° anteversion.

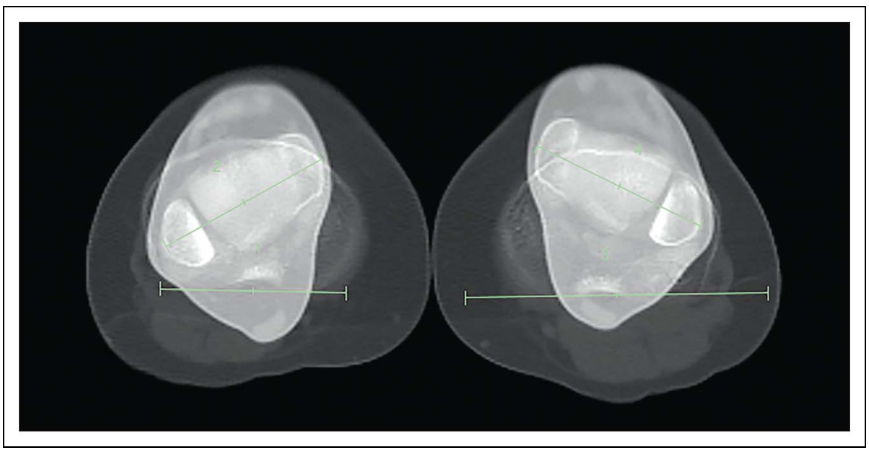
and return to preinjury level of activity) nor functional outcome scores (VAS pain score, Tegner score, and Lysholm score).[7] Interestingly, Smith et al[39] reported that surgical management of patellar dislocation was associated with a significantly higher risk of osteoarthritis of the patellofemoral joint (odds ratio = 6.4 favoring nonsurgical management; $P = 0.002$).

In a 2015 Cochrane Library review, very low-quality but consistent evidence demonstrated that patients with first-time patellar dislocation who underwent surgical management had a markedly lower risk of recurrent patellar dislocation (risk ratio = 0.53 favoring surgical management, CI = 0.33 to 0.87) at 2 to 5 years of follow-up.[40] Based on an illustrative risk, this extrapolated to 104 fewer recurrent dislocations per 1,000 patients after surgical management.[40] Unfortunately, there were no trials that compared surgical versus nonsurgical management, specifically in patients after recurrent patellar dislocation.

Conclusion

There is notable heterogeneity in the literature about patient outcomes after nonsurgical versus surgical management for patellar dislocation and PFI. Given the available evidence (keeping in mind no high-quality evidence), we recommend a 6-week to 3-month trial of nonsurgical management in patients presenting with PFI. If empirical nonsurgical management of PFI fails, surgical interventions directed at surgically correcting the

Figure 10



Radiograph showing measurement of tibial torsion on CT. Tibial torsion is measured as the angle between (1) the line tangential to the posterior tibial cortex (proximal to the tip of the fibula) and (2) the bimalleolar axis (on the most proximal talar slice). Intersection of Lines 1 and 2 gives the right external tibial torsion of 30.9°, and intersection of Lines 3 and 4 gives the left external tibial torsion of 27.0°.

Figure 11

Radiograph showing the Insall-Salvati Index (ISI) measured on MRI (right knee). ISI is measured with a lateral view of the knee flexed at 30°. Line 1 is the patellar tendon length (TL), which is the distance from the distal pole of the patella to the insertion on the tibial tubercle (TL = 5.96 cm), and Line 2 is the patellar length (PL), which is the distance between the superior and inferior patellar poles (PL = 4.45 cm). Here, ISI = 1.34 (TL/PL ratio). On MRI, an ISI of < 0.74 is considered patella baja, an ISI of 0.74 to 1.5 is considered normal, and ISI > 1.5 is considered patella alta.

underlying anatomic risk factors are imperative. Various surgical interventions and their indications will be discussed in detail in Part 2 of this review series.

Summary

PFI is a notable cause of morbidity and functional limitations. Without optimal treatment, recurrent PFI can result in chronic instability, osteochondral defects, and early-onset osteoarthritis of the patellofemoral joint. In a systematic approach to the management of PFI, of utmost importance is to characterize the underlying mechanism(s), beginning with elucidating a traumatic versus nontraumatic mechanism of their first episode of patellar dislocation/subluxation. There are multiple anatomic risk factors, namely, trochlea dysplasia, patella alta, increased TT-TG distance, abnormal patellar tilt, and torsional malalignment, which increase the risk of recurrent PFI. Various imaging modalities (plain radiographs, CT, and MRI) are used to objectively quantify these anatomic abnormalities. An initial trial of nonsurgical treatment (physical therapy and dynamic bracing treatment) is indicated in all patients with PFI, except in a subset of cases with mechanical symptoms because of intra-articular loose bodies. In patients with recurrent PFI, surgical interventions directed at correcting underlying mechanisms of instability are indicated.

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