

# Patellar Instability: A Narrative Review with an Integrated Treatment Algorithm

Joseph Mouawad<sup>1,2</sup>, Joeffroy Otayek<sup>1,2</sup>, Youssef Jamaledine<sup>1,2</sup>, Theodore Kaypekian<sup>1,2</sup>,  
Mohamad Omar Youssef Honeine<sup>1,2</sup>, Alfred Khoury<sup>1,2</sup>

<sup>1</sup>Department of Orthopedic Surgery, Lebanese American University Medical Center-Rizk Hospital, Beirut, Lebanon; <sup>2</sup>Department of Orthopedic Surgery, Lebanese American University School of Medicine, Beirut, Lebanon

Correspondence: Joseph Mouawad, Email [joeamouawad@gmail.com](mailto:joeamouawad@gmail.com)

**Background:** Patellar instability is a multifactorial condition characterized by episodic dislocation or subluxation of the patella, often affecting young and athletic populations. Patients present with patellar apprehension, swelling, and fear of having another episode. It results from a complex interplay between anatomical abnormalities, soft tissue dysfunction, and biomechanical imbalances.

**Objective:** This narrative review aims to provide a structured, up-to-date synthesis of the current understanding of patellar instability, from pathoanatomy and diagnostic evaluation to non-operative and operative management strategies, including specific considerations in skeletally immature patients.

**Methods:** A comprehensive literature review was conducted across major orthopedic databases and reference texts, focusing on key anatomical risk factors, diagnostic modalities, classification systems, and evidence-based treatment algorithms. Emphasis was placed on integrating recent findings with classical concepts such as Dejour's classification and the role of medial patellofemoral ligament reconstruction.

**Results:** The management of patellar instability requires accurate identification of contributing factors such as trochlear dysplasia, elevated TT–TG distance, patella alta, and patellar tilt. First-time dislocators without predisposing factors may benefit from conservative management, while recurrent or anatomically predisposed cases often require individualized surgical correction. Procedures such as MPFL reconstruction, tibial tubercle osteotomy, and trochleoplasty have shown favorable outcomes when tailored to the patient's anatomy. In skeletally immature individuals, physal-sparing techniques and guided growth are preferred to avoid iatrogenic growth disturbances.

**Conclusion:** A patient-specific, “à la carte” surgical approach grounded in detailed radiographic and clinical assessment yields the best outcomes in patellar instability. Integration of anatomical, biomechanical, and developmental considerations is essential for optimal treatment selection and long-term patellofemoral joint preservation.

**Keywords:** patellar instability, pediatric patellar instability, trochleoplasty, patella alta, MPFL reconstruction, tibial tubercle osteotomy

## Introduction

Patellar instability is a condition characterized by patellar subluxation or dislocation episodes as a result of injury or ligamentous laxity.<sup>1</sup> It is a disorder in which there is a pathological dislocation of the patella from the patellofemoral joint. The most common causes involved in this condition are acute trauma, long-term ligamentous laxity, bone malalignment, connective tissue disease, or anatomical pathology.<sup>2</sup> Patients with patellar instability may eventually experience severe discomfort, functional difficulties, and chronic arthritis. Patellar instability has an estimated annual incidence of 5.8 per 100,000 in the general population, with much higher rates reported in adolescents and young athletes.<sup>3</sup> The condition carries a significant socioeconomic burden, as recurrent episodes often require time away from sport or work and may predispose to early-onset patellofemoral osteoarthritis.<sup>4</sup> Over the past two decades, there has been a shift in surgical treatment philosophy, moving from soft-tissue procedures toward anatomic reconstructions that restore the medial patellofemoral ligament (MPFL) and address underlying bony abnormalities.<sup>5</sup>

## Anatomy and Biomechanics

Patellar tracking and patellofemoral stability result from highly complex interactions between static and dynamic stabilizers of the patella.<sup>6,7</sup> Patellar trajectory in the femoral trochlea is not straight, but includes tilt, glide, and rotation. Advanced imaging, including dynamic MRI, has demonstrated that patellofemoral kinematics involve a complex 3D interplay of tilt, rotation, and translation during functional movements like squatting or jumping.<sup>8</sup>

Static stability is provided by the patellar-femoral bony structure and the medial patellofemoral ligament (MPFL). Whereas the dynamic stability is provided by the vastus medialis muscle of the quadriceps.<sup>9,10</sup>

While the MPFL and vastus medialis obliquus (VMO) provide critical restraint in early flexion, the role of lateral structures such as the lateral retinaculum and iliotibial band should not be overlooked,<sup>11</sup> as they contribute to abnormal patellar tilt and maltracking when tight.<sup>9</sup> The quadriceps pull the patella proximally, while the VMO provides critical dynamic restraint by pulling it medially during early flexion. In pediatric populations, normal dynamic stabilization can be significantly impaired; quadriceps scarring or contractures in children can severely alter this muscular balance, tethering the extensor mechanism and predisposing the immature knee to lateral patellar instability.<sup>12</sup>

The MPFL arises on the medial femur approximately 4 mm distal and 2 mm anterior to the adductor tubercle in a sulcus between the tubercle and the medial femoral epicondyle.<sup>13</sup> It attaches to the proximal half of the patella in a variable linear footprint insertion pattern and, in some patients, to the quadriceps tendon as well. The MPFL provides restraint against lateral translation of the patella from 0° to 30° of knee flexion.<sup>9</sup> At 30 degrees, the patella fully engages the trochlear groove, and the role of the MPFL is diminished as the groove becomes the most important restraint.<sup>13</sup> Fifty to sixty percent of the resistance to the patella's lateral translation comes from the MPFL.<sup>6</sup> A laceration, avulsion, or traumatic disruption of the MPFL will result in patellar instability. The key focus in treatment when doing an MPFL reconstruction is the location and optimal femoral position to restore normal anatomic knee biomechanics.<sup>8</sup> Radiography can be used to identify the Schottle point, which is a reliable and precise location for the femoral attachment of the MPFL.<sup>6</sup> Schottle point is 1.3mm anterior to the posterior femoral diaphyseal cortex, 2.5mm distal to the posterior origin of the medial femoral condyle, and proximal to the level of the posterior point of Blumensaat's line.<sup>10</sup>

The patellofemoral joint consists of the posterior surface of the patella and the trochlear surface of the distal anterior femur. The patella acts as a fulcrum to increase the mechanical advantage of the quadriceps. To withstand the immense compressive forces generated during weight-bearing flexion, the articulating surface of the patella is covered with a thick layer of articular cartilage.<sup>6</sup> The bony structures of the patellofemoral joint provide inherent stability to the patella, and any defect in the bony surface will result in instability.<sup>6</sup> Patellar-femoral bony structures account for stability in deeper knee flexion. With the knee in complete extension, the patella lies above and beyond the femoral sulcus. It enters the trochlea when the knee is in 10–30° flexion, depending on patellar tendon length. The shape of the femoral condyles and the orientation of the trochlear groove are critical for containing the patella. A dysplastic, flattened lateral femoral condyle or a shallow, misoriented trochlear groove fails to provide an adequate bony buttress. This architectural defect directly contributes to abnormal lateral patellar tilt and an increased congruence angle, severely compromising stability.<sup>11,14</sup> Sex-based differences in trochlear morphology and Q-angle also partly explain why patellar instability is more prevalent in female athletes.<sup>15</sup>

## Definitions and Classifications

Patellar instability refers to abnormal and symptomatic motion of the patella within the trochlear groove, which may manifest as apprehension, pain, recurrent subluxation, or frank dislocation.<sup>16</sup> A validated classification system is essential to properly diagnose and guide management strategies. Broadly, the literature distinguishes between acute traumatic, chronic patholaxity, and habitual instability.<sup>17,18</sup> Acute traumatic dislocations usually follow a direct blow or twisting injury and occur equally in males and females.<sup>6</sup> Chronic patholaxity, on the other hand, involves recurrent subluxations or dislocations associated with bony malalignment and is more common in females. Habitual patellar instability typically develops painlessly and is triggered during each flexion cycle of the knee.<sup>19</sup> Beyond this clinical framework, additional classification systems have been introduced to better stratify patients. The Lyonaise school classification, now widely recognized, divides patellofemoral disorders into three groups:<sup>5,14</sup> (1) Objective patellar instability, describing patients

with a documented history of at least one dislocation or subluxation plus identifiable anatomic risk factors. Additionally, this group encompasses patients suffering from significant patellar instability characterized by recurrent or persistent dislocations.<sup>20</sup> (2) Potential instability, characterized by anterior knee pain with anatomic risk factors but without prior dislocation; and (3) Isolated patellofemoral pain, where symptoms are present without identifiable instability risk factors.<sup>5,6,14</sup>

More recently, risk-based scoring systems have been developed. In particular, Balcarek et al (2010) proposed the Patellar Instability Severity Score (PISS), which integrates demographic and radiographic features to estimate the likelihood of recurrent instability.<sup>21</sup> This tool has been validated as a reliable predictor of redislocation risk and has enhanced decision-making regarding surgical stabilization.<sup>21</sup>

Overall, the combination of clinical pattern recognition (acute, chronic, habitual), structured classifications such as the Lyonnaise system, and risk stratification tools like PISS reflects the multifactorial nature of patellar instability. Modern classification not only improves diagnostic precision but also provides a framework for individualized treatment planning.<sup>22</sup>

## Presentation

### Clinical Presentation

Although anterior knee discomfort is occasionally experienced by patients with patellar instability, episodes of knee collapse or shifting are more common.<sup>20</sup> The sensation of the knee “going out” or “giving way” is a common indicator. This must be carefully differentiated from the “giving way” associated with anterior cruciate ligament (ACL) tears; patellofemoral instability typically occurs during simple flexion-extension cycles or minor weight shifts, whereas ACL tears are usually associated with high-energy pivoting or deceleration. It’s important to find out if the symptoms started after a sudden traumatic event.<sup>1,17,20</sup> Most dislocations occur with the knee in slight flexion, with the tibia externally rotated.<sup>23</sup> In case of acute trauma, there is frequently a significant hemarthrosis typically indicating an MPFL tear and potentially suggesting an osteochondral shear lesion of the lateral trochlear ridge or medial patellar facet.<sup>23</sup> Physical exam can be limited due to pain. While acute patellar dislocations often resolve via spontaneous reduction, the 20% of patients with persistent dislocation present with severe pain, visible deformity, and an apparent inability to fully extend the knee—a “pseudo-contracture” primarily driven by pain and joint effusion rather than fixed tissue shortening.<sup>7,23</sup> A thorough ligamentous examination is necessary to rule out concomitant cruciate or collateral ligament tears. In a subacute or chronic setting, after swelling and hemarthrosis have resolved, examination of patellar instability consists of the J sign, the moving patellar apprehension test, and lateral patellar translation.<sup>7,23</sup> The “J-sign” observed clinically is a direct manifestation of this pathomechanics: as the laterally subluxated patella in extension abruptly engages the trochlear groove during early flexion, it shifts medially, tracing an inverted “J” pattern.<sup>15</sup> Excessive lateral translation in extension, which “pops” into the groove as the patella engages the trochlea early in flexion, is considered positive.<sup>7,15</sup> The patellar apprehension test is considered positive when passive lateral translation results in guarding and a sense of apprehension. In addition to these examinations, following the resolution of acute symptoms, a systematic physical examination is mandatory and should begin with a general neuromuscular assessment, including the Beighton score to screen for generalized hyperlaxity and an evaluation for “miserable malalignment syndrome”; the triad of increased femoral anteversion, genu valgum, and external tibial torsion. The clinician must also assess the extensor mechanism for quadriceps tone, vastus medialis obliquus (VMO) wasting, and an increased Q-angle. In addition to instability episodes, up to 40% of first-time patellar dislocations are associated with concomitant osteochondral fractures, most commonly involving the medial patellar facet or lateral femoral condyle.<sup>22</sup> These injuries should be identified early, as they often warrant surgical fixation or removal. Entire clinical workup should be complemented by validated patient-reported outcome measures like the Kujala score or KOOS-PF to provide a standardized baseline for function and quality of life.<sup>24</sup>

### Imaging

Accurate imaging is essential in the assessment of patellofemoral instability, as it allows for the evaluation of anatomical risk factors, identification of associated injuries, and preoperative planning. Conventional radiographs remain the first-

line imaging modality, complemented by advanced CT and MRI techniques that provide detailed characterization of both bony and soft tissue structures.

Plain radiographs provide important clues about any pathology of the patellofemoral joint.<sup>7</sup> An anteroposterior view, weight-bearing in extension, is used to rule out overall lower extremity malalignment and version. An osteochondral fracture of the medial patellar edge or loose bodies can also be seen.<sup>20</sup> The true lateral radiograph, in 30 degrees of flexion, is critical for identifying trochlear dysplasia through the crossing sign, double-contour sign, or a supratrochlear spur and to evaluate patellar height.<sup>7,23</sup> To assess patellar tracking and morphology, a skyline or Merchant view is required to measure the sulcus angle, which evaluates the depth of the trochlear groove (abnormal if  $>142^\circ$ ), and the congruence angle, which quantifies the lateral subluxation of the patellar apex relative to the groove (abnormal if  $>+16^\circ$ ).<sup>2,6</sup> Additionally, the patellofemoral angle can be assessed on the Merchant view. It is formed by a line drawn along the lateral facet of the patella and a line connecting the anterior margins of the medial and lateral femoral condyles on an axial radiograph.<sup>25</sup> In 97% of normal knees, this angle expands laterally. In 60% of cases of patellar subluxation, the lines are parallel, and in the other 40%, the angle opened medially.<sup>15,25</sup>

Computed Tomography is highly helpful in characterizing several pathological values of the patellofemoral joint, such as the patellar tilt, TT-TG value, and the femoral and tibial torsion angles.<sup>25</sup>

MRI is an effective means to evaluate the painful patellofemoral joint. MPFL rupture can be diagnosed both on the sagittal and axial T2-weighted images.<sup>26</sup> A sequence with fat suppression is important to identify bone marrow edema and fluid collection, which is present in the case of acute patellar subluxation in a patient with chronic instability.<sup>26</sup> Extracapsular soft tissue edema is typically localized at the anterior margin of the knee.<sup>27</sup> Osteochondral fracture, which is an indication for early surgical intervention, can be detected on MRI.<sup>27</sup> Newer diagnostic tools, such as weight-bearing CT and motion analysis, can further characterize maltracking patterns and rotational abnormalities that may be missed on static imaging.<sup>27</sup>

## Predisposing Factors

Dejour et al suggested reference values for imaging analysis of four principal predisposing risk factors for patellar instability: Trochlear dysplasia, elevated TT-TG, patella alta, and patellar Tilt. Additional secondary predisposing factors include elevated Q-angle, elevated femoral anteversion, VMO hypoplasia, hyperlaxity, and genu recurvatum and patellar dysplasia.<sup>2,17,20,23</sup>

## Primary Predisposing Factors

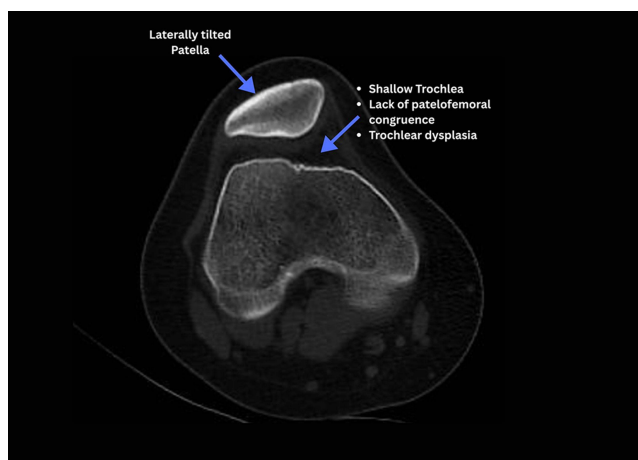
### Trochlear Dysplasia

Trochlear dysplasia is one of the main risk factors for lateral patellar dislocation. It is considered a developmental abnormality.<sup>2</sup> It is characterized by a reduced depth, a flat or even convex trochlear surface with an incongruent patellofemoral joint as seen in [Figure 1](#)

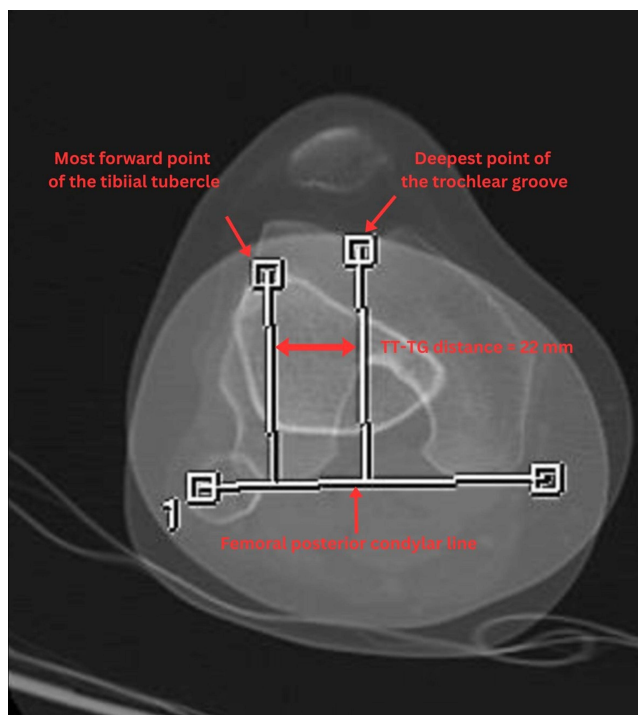
The crossing sign, the supratrochlear spur, and the double-contour sign seen on true lateral conventional radiographs and axial conventional radiographs can be used to diagnose and classify trochlear dysplasia based on the four types of Dejour classification.<sup>14</sup> Dejour's classification system categorizes trochlear dysplasia into four distinct types (A, B, C, and D) based on specific morphological abnormalities observed on lateral radiographs and axial imaging. Type A is characterized by a shallow trochlea, while Type B presents a flat or convex surface with a supratrochlear spur; Types C and D are defined by facet asymmetry and a "cliff" or "dual-base" appearance, respectively.<sup>14,28</sup>

### Tibial Tubercle-Trochlear Groove (TT-TG) Distance

The tibial tubercle might be lateralized relative to the trochlear groove.<sup>2</sup> An increased lateralization of the tibial tubercle shifts the extensor mechanism's force vector in the knee, predisposing for lateral patellar subluxation.<sup>20,25</sup> This lateral displacement can be measured using the tibial tubercle-trochlear groove (TT-TG) distance on a axial CT scan as seen in [Figure 2](#). It is the distance in mm between the tibial tuberosity and the deepest point of the trochlear groove.<sup>1,20,25</sup>



**Figure 1** Axial computed tomography (CT) image at the level of the patellofemoral joint demonstrating lateral patellar tilt and lateral translation with lack of patellofemoral congruence due to poor engagement of the medial patellar facet within a shallow trochlear groove, consistent with trochlear dysplasia and patellofemoral maltracking.



**Figure 2** Axial CT cut demonstrating the TT–TG distance. A vertical line is drawn from the deepest point of the trochlear groove, and a second vertical line is drawn from the center of the tibial tubercle. The horizontal distance between these two points represents the TT–TG value, which in this case measures 22 mm, indicating a lateralized tibial tubercle consistent with pathological malalignment.

A distance of 15 to 20 mm is considered significant malalignment.<sup>2,25</sup> Originally, TT-TG distance measurements were taken from plain radiographs, but today they are commonly assessed using CT and MRI scans.<sup>2</sup> This condition can be surgically treated through an osteotomy, followed by the medial repositioning of the tibial tubercle.

### Patellar Tilt

Patellar tilt is assessed on a CT scan acquired with the knee fully extended. The patellar tilt angle can be measured between a reference line through the transverse axis of the patella and a line tangential along the femoral condyles posteriorly.<sup>2,25</sup> Values that exceed 20 degrees are considered abnormal and an indication of MPFL insufficiency.<sup>2,16</sup>

## Patellar Height

Patella alta, or high-riding patella, is a major risk factor for recurrent lateral patellar dislocations.<sup>2,20,29</sup> The trochlear groove serves as the primary bony stabilizer of the patellofemoral joint.<sup>2,6</sup> Typically, the patella engages in the trochlear groove at around 20 degrees of knee flexion.<sup>29</sup> However, with patella alta, higher flexion angles are required for the patella to enter the groove, leading to a wider range of motion without the bony stabilization provided by the trochlear groove.<sup>30</sup> Patella alta is measured on a lateral radiograph. The four most widely used methods for measuring patellar height are the Insall-Salvati, Grelsamer-Meadows, Caton-Deschamps, and Blackburne-Peel indexes. The most preferred ratio by many clinicians is the Caton-Deschamps.<sup>30</sup>

Additional secondary predisposing factors contribute to patellar instability. This includes elevated Q-angle, elevated femoral anteversion, VMO hypoplasia, hyperlaxity, and genu recurvatum and patellar dysplasia.<sup>4</sup> The secondary factors can be categorized clinically at first, and then further identified by certain imaging or radiological tests.

In addition to classical parameters, newer indices have been introduced. The tibial tubercle–posterior cruciate ligament (TT–PCL) distance has been suggested as a reliable alternative to TT–TG that avoids variability due to trochlear morphology.<sup>31</sup> Other MRI-based parameters, including lateral trochlear inclination angle and the patellotrochlear index, improve diagnostic accuracy for trochlear dysplasia.<sup>32</sup> Genetic connective tissue disorders such as Ehlers-Danlos and Marfan syndrome also predispose to recurrent instability due to generalized ligamentous laxity, and their presence should be considered in high-risk patients. Finally, pediatric patients represent a unique subgroup, as surgical planning must account for open physes and growth potential.<sup>33</sup>

## Secondary Predisposing Factors

Multiple minor factors have been identified, such as increased Q angle ( $> 15^\circ$ ), genu valgum ( $> 15^\circ$ ), external tibial torsion ( $> 30\text{--}40^\circ$ ), femoral anteversion ( $> 30^\circ$ ), generalized ligamentous laxity, vastus medialis weakness or hypoplasia, and subtalar joint pronation/pes planus.<sup>34–37</sup>

## Non-Operative Management

Most patients with a first-time dislocation are treated nonoperatively, but many experience ongoing instability, with around 44% experiencing recurrent dislocations, and nearly half will face recurrent instability or pain.<sup>38</sup> However, patellar dislocation tended to decrease in frequency with age, and despite multiple recurrences, there was little evidence of osteoarthritis after long-term follow-up.<sup>39</sup>

The specific modalities of rehabilitation have been minimally studied, but there is consensus that the patients should initially be immobilized for 2–3 weeks to manage pain. Knee braces can be applied to stabilize the patella once the pain permits. Weight-bearing is permitted soon, based on the patient's pain level.<sup>23</sup> Quadriceps exercises begin early and progress as tolerated. Patients should avoid activities that mimic the injury during recovery. As strength improves, patients progress out of the brace to single-plane walking, running, cutting, and eventually to sport-specific activities. Early exercise and motion help maintain quadriceps function and support articular cartilage health.<sup>17</sup>

In a systematic review,<sup>18</sup> after reviewing 70 articles, the authors recommend that conservative management is appropriate for the majority of primary patellar dislocations. However, they emphasized that surgical treatment is warranted when specific risk factors or associated injuries are present; namely chondral or osteochondral fractures, significant disruption of the medial patellar stabilizers confirmed clinically and radiologically (CT or MRI), a laterally subluxated patella despite normal alignment in the contralateral knee, recurrent dislocation, or failure to improve with structured rehabilitation.

## Operative Management and the “À La Carte” Approach

When conservative treatment fails or when structural “red flags” are present in an inaugural dislocator, surgical intervention is required. The modern philosophy follows an “à la carte” approach, where each patient's specific anatomical risk factors are addressed through tailored procedures to restore joint stability and preserve the patellofemoral cartilage.<sup>40,41</sup>

## Medial Patellofemoral Ligament Reconstruction

Medial patellofemoral ligament (MPFL) reconstruction has become the gold-standard procedure for restoring patellofemoral stability, particularly when the medial restraint has been compromised by recurrent instability or acute bony avulsions.<sup>42</sup> MPFL bone avulsions at the patella typically require surgical fixation due to their low healing rate and potential for poor functional outcomes.<sup>43,44</sup> Ideal candidates for isolated MPFL reconstruction typically present with relatively preserved bony anatomy, characterized by normal trochlear morphology or type A dysplasia, a tibial tuberosity–trochlear groove distance less than 20 mm, normal patellar height ratios (Caton-Deschamps index <1.2), and minimal patellar tilt (<20°). It should be avoided in cases of significant bony malalignment, such as excessive femoral anteversion, increased knee valgus angle, elevated Q-angle, excessive tibial torsion, patellofemoral arthritis, abnormal hind foot position, or abnormal pelvic geometry.<sup>42,45–49</sup>

The graft, most commonly a doubled hamstring or quadriceps tendon, is fixed at the superomedial patella and the femoral attachment localized to Schottle's point. Technical precision is the most critical determinant of success because femoral tunnel malposition, specifically the failure to accurately localize Schottle's point 1.3 mm anterior to the posterior femoral cortex and 2.5 mm distal to the posterior origin of the medial femoral condyle, remains the leading cause of surgical failure.<sup>50</sup> Proper graft tensioning is equally vital; the graft should be secured with the knee in 30° of flexion to ensure it engages as the patella enters the trochlea, while avoiding over-tensioning that could increase medial patellofemoral contact pressures and accelerate medial facet chondral wear.<sup>1,6,42</sup> These complications remain relatively uncommon but lead to stiffness or medial overload, rare patellar fractures from tunnel placement, hardware irritation, arthrofibrosis, and residual instability if concomitant malalignment is uncorrected.<sup>4,43,44,48</sup> Compared with trochleoplasty or tibial tubercle osteotomy, MPFL reconstruction has lower failure and complication rates (reported 0–33% vs. up to 31–40% for bony procedures), but it is not interchangeable, each procedure addresses specific pathology.<sup>14</sup> Thus, MPFL reconstruction is sufficient as an isolated technique when osseous parameters are within normal limits, while combined, “à la carte” approaches are warranted when previously mentioned risk factors exist, underscoring the importance of individualized, anatomy-driven surgical planning.<sup>13,40</sup>

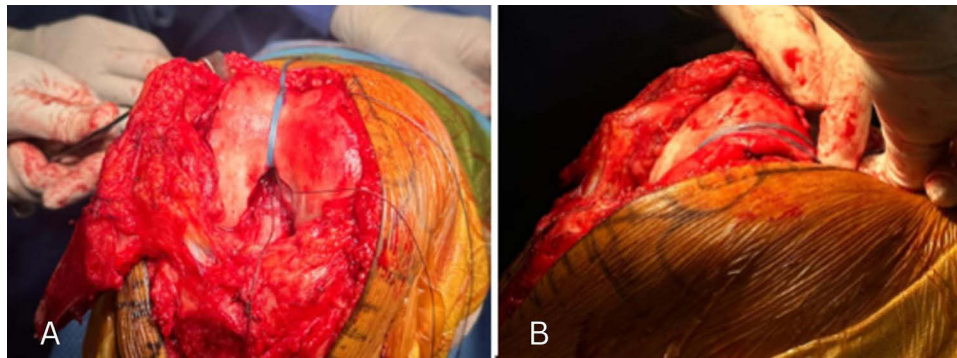
## Trochlear Dysplasia: Trochleoplasty

Trochlear dysplasia is recognized as a significant contributor to patellar instability and has been reported to exist in 85–96% of patients with a history of patellar dislocation.<sup>14</sup> Although trochleoplasty has been introduced as a surgical option to address this condition, it is rarely a first-line intervention, and its precise role and indications in the management of patellar instability remain uncertain.<sup>51</sup> First developed by Dejour and Walch in 1987, the procedure is technically demanding and generally reserved for specific, complex cases. Its primary indication is recurrent patellar dislocation, especially when trochlear protrusion exceeds 6 mm or in patients with grade B or D dysplasia.<sup>23,52</sup>

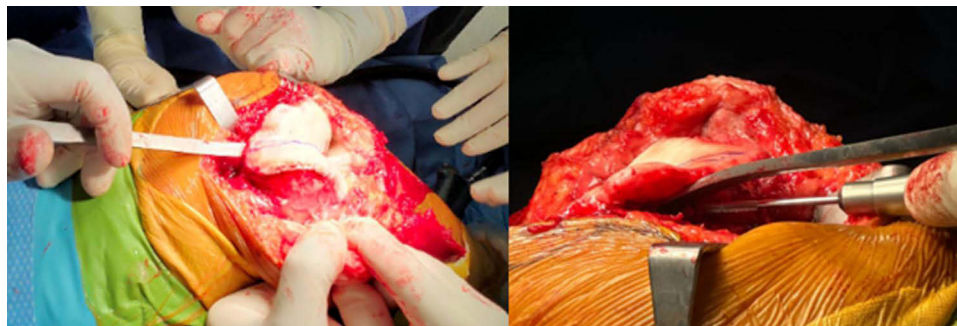
The procedure is strictly contraindicated in patients with open physes or advanced patellofemoral osteoarthritis (Outerbridge grade III–IV) due to the risk of growth disturbance and the lack of viable cartilage for reshaping.<sup>53,54</sup> In indicated cases, it has shown superior results in pain relief, patient satisfaction, return to sport, and improved Kujala scores.

Several variations of trochleoplasty exist, including lateral facet elevation (Albee trochleoplasty), recession trochleoplasty, and sulcus-deepening trochleoplasty (Berieter and Dejour techniques).<sup>55</sup> The lateral facet elevation technique (also known as Albee trochleoplasty) was one of the earliest approaches and involves elevating the lateral femoral condyle to improve patellar engagement, but it is now less frequently utilized due that it increases trochlear prominence which unnaturally alters patellar loading and can induce secondary arthritis.<sup>56</sup> Recession wedge trochleoplasty targets the prominent supratrochlear spur, particularly in Dejour type B dysplasia, by excising a bone wedge to recess the anterior aspect of the trochlea, thereby facilitating more normal patellar tracking.<sup>57</sup> The Dejour technique, initially standardized in 1990 and refined in 2010, is the most widely used for correcting both trochlear anatomy and alignment. This approach involves elevating an osteochondral flap and deepening the trochlear groove, then fixing the flap in the new position.<sup>14</sup>

Recent evidence from a three-dimensional modeling study suggests that a recession wedge trochleoplasty, which specifically targets the trochlear spur, may offer optimal results for patients with Dejour type B dysplasia. In contrast, cases of Dejour type C and D dysplasia appear to benefit more from deepening trochleoplasty procedures, which more effectively address the complex anatomical abnormalities characteristic of these higher-grade dysplasia types.<sup>58</sup> While



**Figure 3** Trochleoplasty Procedure: (A) Coronal intra-operative view showing re-shaping of the trochlear groove. (B) Sagittal view demonstrating the deepening of the trochlea during the procedure.



**Figure 4** Intra-operative view of thin osteochondral flap in thin flap trochleoplasty.

effective, trochleoplasty has a prolonged recovery period and carries the risk of patellofemoral osteoarthritis.<sup>53</sup> Additionally, patellar dysplasia must be assessed and treated as it can exacerbate joint incongruence or lead to abnormal patellar kinematics following trochleoplasty.<sup>28</sup> Rehabilitation following trochleoplasty is gradual and typically spans several months, with full recovery and return to sport taking up to eight months. Most patients undergoing this procedure are not high-level athletes and have experienced long-term knee dysfunction, so rehabilitation must be tailored to their unique needs and deficits.<sup>28</sup>

Thin-flap (cartilage-preserving) sulcus-deepening trochleoplasty is a technique other than Dejour, where it is performed by elevating a thin (~3–5 mm) osteochondral flap from the trochlea and resecting the underlying subchondral bone to fashion a new, deeper groove.<sup>59</sup> Figures 3 and 4 represent intraoperative images of this technique.

Compared to Dejour’s original “thick-flap” osteotomy, the thin-flap (Bereiter) technique preserves cartilage but removes less bone; the thick-flap variant leaves  $\geq 5$  mm of subchondral bone and is considered less aggressive to cartilage (making it preferable in older patients or those with thinner cartilage).<sup>60</sup> Clinical results after thin-flap sulcus-deepening are excellent: for example, Frings et al reported high functional scores, ~93% patient satisfaction, and very low re-dislocation (1.8%) and overall complication (5.3%) rates following combined thin-flap trochleoplasty with MPFL reconstruction.<sup>61</sup> Notably, both imaging and histologic studies show that the articular cartilage remains viable and does not deteriorate over the short term after a thin-flap trochleoplasty.<sup>56,59</sup> These findings suggest that thin-flap sulcus-deepening trochleoplasty is a safe, joint-preserving solution for severe trochlear dysplasia in well-selected patients.

## Patella Alta → Tibial Tuberosity Distalization (TTD)

TTD is a surgical procedure designed to address patella alta by lowering the tibial tubercle, thereby repositioning the patella to a more anatomical height. Patella alta with Caton–Deschamps index  $>1.2$  is corrected by lowering

the tubercle until the index lies between 0.8 and 1.0.<sup>62</sup> This improves patellofemoral congruence and promotes earlier engagement of the patella in the trochlear groove, which enhances stability throughout the range of motion.<sup>63</sup> Notably, when the patellar tendon exceeds 52 mm in length, instability can persist even after correcting the bone structure, due to a “windscreen-wiper” effect that encourages lateral patellar movements.<sup>64</sup> Surgically, the tuberosity is released through a V-shaped or oblique osteotomy and carefully repositioned distally. The osteotomy cuts must be deep enough to include cancellous bone for better union. The bone fragment is mobilized with its periosteal attachment intact, provisionally pinned, and then secured with compression screws (typically 4.5 mm cortical) that should be 2 mm larger to ensure adequate fixation and should not be tightened excessively to avoid posterior positioning of the tuberosity or fracture. The periosteum is meticulously repaired to support healing and reduce risks such as nonunion or fracture. If the patellar tendon remains longer than 52 mm after this transfer, a tenodesis procedure is added: the tendon is anchored to the repositioned tuberosity fragment using sutures or anchors, shortening it by around 10%, which restores normal tendon length and enhances patellofemoral mechanics while paying attention not to cause patella baja.<sup>65</sup> Following tibial tubercle distalization, ambulation is permitted in a locked extension splint until radiographic union, while the knee should rest at ~30° flexion to prevent patella infera.<sup>62</sup> Early rehabilitation emphasizes isometric quadriceps activation and gentle patellar mobilization, with gradual progression to passive flexion (limited to 90°) during initial healing. Once the union is confirmed (generally at 6–8 weeks), patients resume unrestricted walking and daily activities but should avoid high-flexion tasks and kneeling for at least six months to minimize complications and optimize functional recovery.<sup>65</sup>

### Elevated TT-TG Distance → Medialization of Tibial Tuberosity

Medializing the tibial tuberosity is indicated in patients with a lateralized tubercle, typically identified by a TT–TG distance greater than 15 to 20 mm, with the goal of restoring this measurement to a physiological range of 10 to 15 mm.

This procedure is most appropriate in individuals who present with patellar maltracking, lateral chondral overload, or recurrent instability, provided that patella alta is not the primary underlying abnormality.<sup>66</sup> The classic Elmslie-Trillat procedure describes elevating and medializing the tibial tubercle, while the Fulkerson anteromedialization technique uses an oblique osteotomy to achieve both medial and anterior translation, thus offloading the distal/lateral patellar facet.<sup>52</sup> Other techniques mention complete detachment of the osteotomy for ideal medialization, and when distalization is also recommended.<sup>67</sup> The Elmslie-Trillat technique is associated with increased patellofemoral joint pressure and a higher risk of developing arthritic changes, whereas the Fulkerson (anteromedialization) procedure may result in complications such as persistent pain, stiffness, arthrofibrosis, progressive cartilage deterioration, and symptomatic hardware.<sup>68,69</sup>

Risk factors for low functional outcomes after combined MPFLR and TTO (Tibial Tubercle Osteotomy) include female sex and TTO medialization of more than 10 mm.<sup>52</sup> Clinical outcomes following medialized tibial tubercle osteotomy are favorable. A systematic review involving more than 1,000 knees found that 67–74% of patients achieved good to excellent results, with the procedure consistently leading to reduced pain and improved stability.<sup>70</sup> Complication rates vary; complete detachment osteotomies carry ~10.7% risk of fracture or nonunion, underscoring the importance of preserving a hinge and ensuring robust fixation. Overall major complication rate for TTO with MPFL reconstruction is ~3%; revisions often result from hardware irritation or stiffness.

### Surgical Considerations in the Skeletally Immature Patient

Patellar instability in skeletally immature patients presents unique challenges due to concerns about physeal injury and high recurrence rates. Clinical manifestations include first-time dislocations, habitual dislocations, and permanent instability. Effective management relies on precise classification systems such as those by Chotel et al, Parikh et al, and Dejour’s anatomical predisposition model. Identifying anatomical risk factors, trochlear dysplasia, patella alta, increased tibial tubercle-trochlear groove (TT-TG) distance, ligamentous laxity, and genu valgum, is essential for individualized treatment strategies.<sup>71</sup>

Initial episodes of patellar dislocation without osteochondral fractures are primarily managed conservatively through activity modification, bracing, quadriceps strengthening, and neuromuscular retraining.<sup>72</sup> However, due to high recurrence rates (approximately 60%), surgical intervention often becomes necessary in younger patients.<sup>4</sup> Physseal-sparing medial patellofemoral ligament (MPFL) reconstruction has emerged as the gold-standard surgical treatment, demonstrating excellent outcomes (success rates >95%) while safeguarding physseal integrity.<sup>73</sup> Techniques involving distal femoral fixation via epiphyseal tunnels or utilizing soft-tissue grafts such as adductor magnus and quadriceps tendon grafts have proven effective.<sup>74</sup>

The 4-in-1 procedure was traditionally utilized as a comprehensive soft-tissue realignment for children, combining a lateral release, medial capsular plication, VMO advancement, and a Roux-Goldthwait distal realignment. Historically, this approach addressed the multi-factorial nature of pediatric instability without the need for bony osteotomies that would risk iatrogenic physseal arrest. However, modern surgical philosophy has largely shifted from this non-anatomical “realignment” toward anatomical MPFL reconstruction. Current evidence suggests that restoring the specific medial restraint provides superior joint kinematics and a lower risk of postoperative stiffness compared to the more extensive 4-in 1 approach.<sup>12,75</sup>

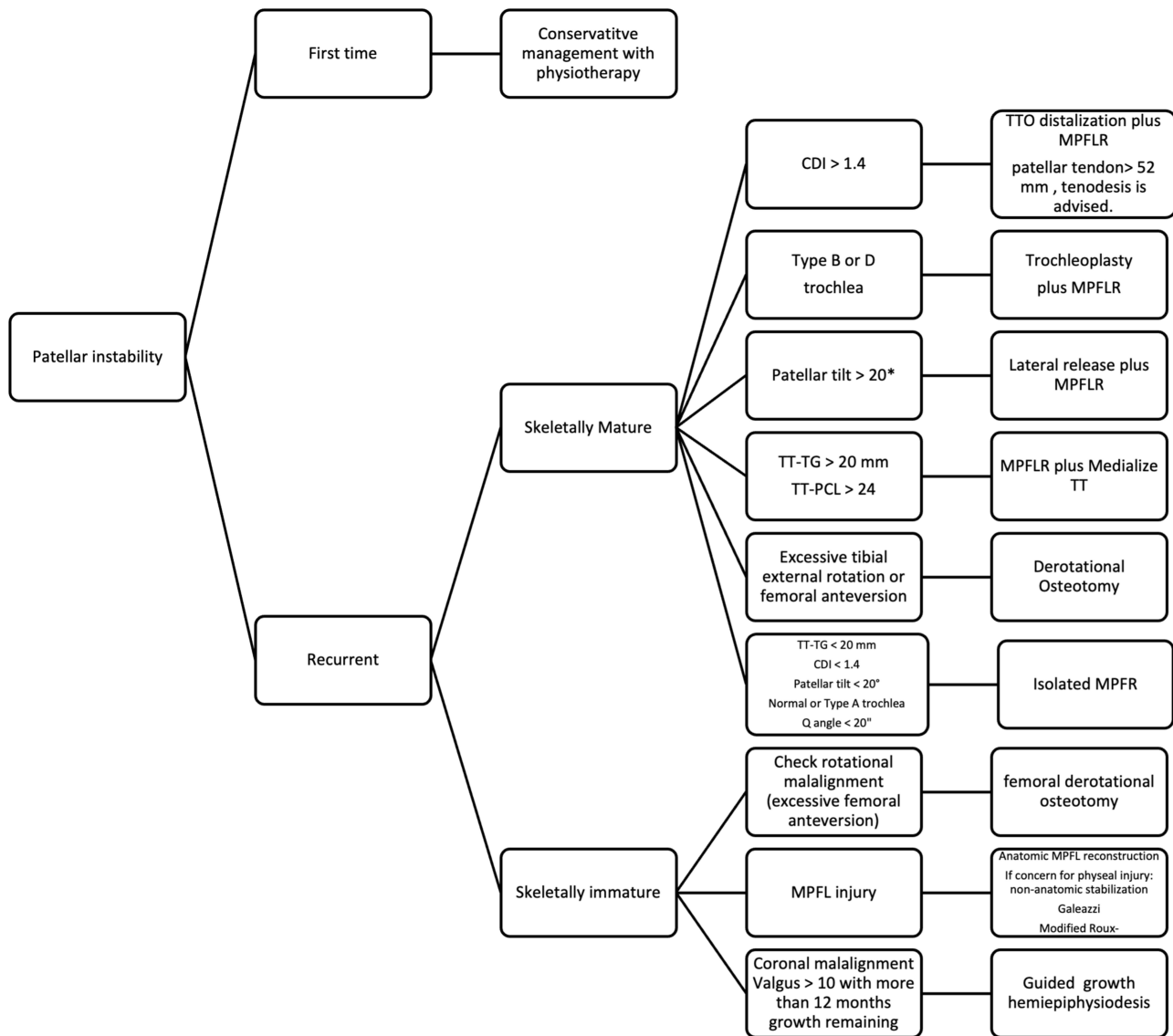


Figure 5 Treatment algorithm for patellar instability.

Genu valgum is a modifiable factor often managed simultaneously through guided growth techniques. The insertion of tension-band plates across distal femoral or proximal tibial physes can correct valgus deformities progressively at approximately 0.6–0.7° per month.<sup>76</sup> Combined with MPFL reconstruction, this approach significantly enhances stability, reducing the necessity for invasive corrective osteotomies.<sup>77</sup>

Surgical interventions like tibial tubercle osteotomy and trochleoplasty are contraindicated until skeletal maturity due to risks associated with physeal injury.

In summary, management of patellar instability in skeletally immature patients should integrate detailed classification, conservative treatment for first-time dislocations, physeal-sparing MPFL reconstruction for recurrent cases, and timely correction of genu valgum through guided growth to ensure optimal stability and preserve skeletal development.

## “À La Carte” Algorithm and Case Applications

The “à la carte” management algorithm in Figure 5 presented in this narrative review advocates for an anatomy-driven approach where surgical interventions are tailored to a patient’s specific risk factors. Under this protocol, isolated MPFL reconstruction is reserved for those with near-normal bony parameters, while patients with complex deformities undergo combined procedures. For example, a 22-year-old female with Dejour Type B dysplasia, a TT-TG of 24 mm, and a Caton–Deschamps index of 1.5 would undergo a “triple procedure” consisting of sulcus-deepening trochleoplasty, TTO medialization/distalization, and MPFL reconstruction. In contrast, for a 12-year-old with genu valgum and open physes, the algorithm directs treatment toward guided growth with tension-band plates and physeal-sparing MPFL reconstruction. This strategy systematically addresses the “full house” of deformities while strictly respecting skeletal maturity, thereby minimizing the high recurrence rates historically associated with non-individualized surgical planning.

## Conclusion

Patellar instability is a multifactorial orthopedic challenge that necessitates a shift from historical realignment methods to a highly individualized, anatomy-driven surgical strategy. While conservative management remains the primary choice for first-time dislocations without osteochondral injury, the high recurrence rates in patients with anatomical “red flags”, specifically high-grade trochlear dysplasia, a Caton Deschamps index exceeding 1.2, and a TT-TG distance over 20 mm, require proactive, algorithmic intervention. This narrative review emphasizes that MPFL reconstruction is most effective as an isolated procedure only when the underlying bony architecture is within physiological limits. For patients with complex malalignment, the “à la carte” approach, utilizing combined procedures such as sulcus deepening trochleoplasty and tibial tubercle osteotomy, is essential to prevent graft failure and minimize long term patellofemoral arthritis. Furthermore, in the skeletally immature population, the transition from non-anatomical procedures to physeal-sparing MPFL reconstruction and guided growth represents the modern gold standard for preserving skeletal development while ensuring stability. Ultimately, optimal clinical outcomes hinge on a comprehensive preoperative workup that integrates precise radiographic measurements into a tailored surgical plan, ensuring that each intervention addresses the specific mechanical drivers unique to the patient.

## Abbreviations

MPFL, Medial patellofemoral ligament; VMO, Vastus medialis obliquus; 3D, Three-dimensional; CT, Computed tomography; MRI, Magnetic resonance imaging; TT-TG, Tibial tubercle–trochlear groove distance; TTD, Tibial tuberosity distalization; TTO, Tibial tubercle osteotomy; KOOS-PF, Knee injury and Osteoarthritis Outcome Score – Patellofemoral subscale; PISS, Patellar Instability Severity Score; MPFLR, Medial patellofemoral ligament reconstruction.

## Ethical Approval

Not applicable. This article is a narrative review and does not involve human participants or identifiable data.

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

## Funding

The authors received no funding for this work.

## Disclosure

The authors declare no conflicts of interest related to this work.

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