Patella dislocations and patellofemoral instability: a current concepts review

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Abstract

Lateral patellar dislocation affects young, active patients with an incidence rate of 5.8 per 100 000. The management of first episode dislocations is non-surgical in the majority of cases, unless associated pathology dictates surgical intervention. Approximately 40% of cases that are treated non-surgically will develop recurrent patellofemoral instability. Evidence supports surgical intervention in these cases; however, the best approach is debatable. Most research and consensus statements agree that medial patellofemoral ligament reconstruction (MPFLR) should be performed in most cases. Additional procedures can be used ‘à la carte’ according to certain conditions or pathology. A tibial tubercle osteotomy (TTO) is usually indicated in patients with maltracking and/or patella alta, but the direction and degree of correction must be carefully considered. Trochleoplasty is technically demanding and should be reserved for a select few patients with severe trochlear dysplasia. It should be performed by an experienced knee surgeon due to the high risk of inadvertent complications.

Level of evidence: Level 5

Keywords: patellofemoral instability, patellar dislocation

Introduction

Patellofemoral instability is defined as symptomatic deficiency of the soft tissue, muscular and bony constraints maintaining the patella within the trochlear groove, such that the patella may escape either partially or completely from its asymptomatic position as the knee flexes. Patellar dislocation is a relatively common problem, with an incidence of 5.8 per 100 000 affecting young, active patients with an increased risk in adolescent females. It is best described by direction of instability with degree of flexion. As such, lateral instability in early flexion <45°, lateral instability in late flexion >45°, medial instability and multidirectional instability can be differentiated. This article will focus on lateral instability in early flexion. The aetiology of instability and dislocation can be attributed to an initial traumatic event or to underlying bone and soft tissue abnormalities (Table I).

The recurrence rate after nonoperative management may be higher than 40%, and literature suggests that up to 55% of patients with first-time dislocations do not return to sport after an initial dislocation. Management is aimed at preventing recurrent dislocations. However, despite substantial evidence on the topic, the ideal strategy for first-time lateral patellar dislocation remains controversial. Following conservative treatment for a first-episode dislocation, one-third of patients have good outcomes, one-third will have recurrent instability and require surgical intervention, and one-third of patients will not have recurrence – but will have persistent symptoms of pain and instability. Since the landmark work in 1994 by Dejour et al., which identified four anatomical risk factors (trochlear dysplasia, patella alta [Caton-Deschamps index ≥1.2], patellar tilt ≥20° and tibial tuberosity–trochlear groove [TT-TG] distance ≥20 mm), two schools of thought have emerged in the management of these patients. The first approach is to deal with each of the underlying anatomical abnormalities on an ‘à la carte’ basis, as compared to a standardised surgical approach, which involves performing an isolated MPFL reconstruction. Despite low-level evidence supporting either strategy, a combination approach has evolved, which involves performing an MPFL reconstruction along with correcting additional major risk factors. The difference between this method and the initial ‘a
la carte’ approach, is the addition of an MPFL reconstruction along with selective correction of major associated anatomical problems. An isolated MPFL reconstruction has been shown to be sufficient for low magnitude and low number of risk factors. However, the point at which this isolated procedure will fail and correction of additional factors is required is not fully understood. 12 In skeletally immature patients there are additional considerations due to open physes. Regardless of the treatment strategy, the initial assessment remains critically important and involves a thorough history, clinical examination as well as imaging to quantify the problem and guide decision-making.

Pathoanatomy

The biomechanics of the patellofemoral joint (PFJ) rely on the interplay between bony congruence and associated soft tissue static and dynamic constraints, to achieve joint stability throughout the range of motion. The mechanism of traumatic lateral patellar dislocation usually occurs with the knee in slight flexion with an associated valgus force, or by direct medial force to the patella. 13 The PFJ is most unstable in full extension, and stability improves as the patellar engages the femoral trochlea during flexion under normal circumstances. During the first 30° of flexion the MPFL has been shown to be important in preventing lateral translation. A recent anatomical study has shown the potential importance of associated medial structures, namely the medial patellotibial ligament (MPTL), and medial patellomeniscal ligament (MPML). The mean failure load for the MPFL, MPTL and MPML was 178 N, 147 N and 105 N, respectively. No significant difference was found between the MPFL and MPTL or between the MPTL and MPML. However, a significant difference was found between the MPFL and MPML. Interestingly the vast majority of failures occurred mid-substance. Both the semitendinosus and gracilis tendons would be appropriate graft options as their load failures exceed that which is described above (1 216 N and 838 N respectively). 14 The effects of the MPFL on PFJ stability has been widely investigated and is thought to be mostly isometric during the flexion arc of the knee joint. Work by Amis et al. showed that the MPFL is tightest when in terminal extension and early flexion. 15 Its origin is on the medial femur, approximately 4 mm distal and 2 mm anterior to the adductor tubercle, and inserts onto the proximal half of medial patella. 16 Lateral tightness can also contribute to instability and is usually as a result of a tight iliotibial band and/or capsule. Beyond 30° of flexion, the congruence between the patella and trochlea becomes the primary restraint. For this reason, patella alta (high-riding patella) can lead to lateral instability by increasing the distance travelled before engaging the trochlea. 4 Trochlear dysplasia and its variants may result in loss of the guiding effect on the patella beyond 30° of flexion causing lateral instability. 4 The aetiology of trochlear dysplasia is largely unknown; however, it is postulated to have both genetic and developmental origins. 18,19 Dejour et al. found that 96% of patients with a history of a true patellar dislocation had evidence of trochlear dysplasia. 4 The position of the tubial tubercle determines the force vector of the patellar tendon on the patella; therefore, a laterally based tubercle can cause lateral pull resulting in instability. The alignment and rotational profile of the lower limb may have a contributing effect on PFJ stability. External tibial torsion and/or internal femoral torsion will result in an increased lateral force vector, especially during terminal extension, which is accentuated by the screw-home mechanism of the knee. 4 Valgus coronal plane deformity will also contribute to this effect. The vastus medialis oblique (VMO) is often the first quadriceps muscle to weaken during functional impairment and can result in muscular imbalance causing lateral instability. 20

Clinical evaluation

A detailed history should include the age, sex, skeletal maturity, level of sport and expectation to return to competitive activity. The mechanism of injury and position of limb during dislocation should be noted as this may identify underlying pathology in subtle cases. Subsequent episodes need to be recorded and the presence of pain, deformity and disability needs to be identified. There is often an overlap of pain and instability symptoms which need to be evaluated independently.

A thorough gait and alignment examination may reveal valgus knees with potential thrusting. Rotational profile must be carefully checked to exclude femoral and/or tibial torsional problems. A particular combination of deformities was described by James et al. 21 as the ‘miserable malalignment syndrome’. These include valgus knees, increased femoral anteversion, pronation of the foot and external tibial torsion. The quadriceps should be evaluated for VMO wasting and the Q angle determined by measuring the angle between the line connecting the anterior superior iliac spine and the patella with the line connecting the patella and tibial tuberosity in extension. 22 Overall, the reliability of the Q-angle measurement has been questioned and evidence suggests that it should not be used. 23-26

Examine the knee for possible haemarthrosis. Patellar dislocation is the most common cause of traumatic haemarthrosis in children, and the second most common in adolescents after anterior cruciate ligament injuries. 27 Tenderness (Bassett sign) over the medial femoral condyle should be elicited. Anterior knee pain and/or positive patellofemoral grind (Clarke’s test) may indicate underlying osteochondral damage. Patellar tracking should be noted along with a possible J-sign (lateral subluxation of the patella when actively moving knee from flexion into extension). 28 Lateral glide (Sage sign) of the patella should not exceed two quadrants (compare to contralateral side). 29 The most sensitive (100%) and specific test (88.4%) for patellar instability is the moving patellar apprehension test as described by Ahmad et al. (a two-part test performed by taking the knee from full extension into flexion with a laterally directed force on the patella, resulting in apprehension and involuntary quadriceps activation to prevent further knee flexion. The second component again involves taking the knee from extension to flexion, this time with a medially directed force on the patella. A positive test shows no apprehension in this phase and the patient allows the knee to be fully flexed). Features of connective tissue disorders such as Ehlers–Danlos and Marfan syndromes should be sought, along with a general ligamentous laxity Beighton score if indicated. 31

Radiographic evaluation

Basic evaluation begins with four standard X-ray views, including an anteroposterior (AP), lateral, Rosenberg weight-bearing

| Table I: Factors associated with patellofemoral instability |
|---------------------------------------------------------|
| **Soft tissue** | **Bony** | **Malalignment** |
| Medial laxity (e.g. incompetent medial patellofemoral ligament, vastus medialis obliquus weakness) | Trochlea dysplasia | Lateralised tibial tubercle |
| Lateral tightness (e.g. iliotibial band) | Patella alta | Increased Q-angle |
| Global laxity (e.g. Marfan syndrome, Ehlers-Danlos syndrome) | | Increased femoral anteversion |
| | | Increased tibial torsion |

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bent-knee posteroanterior (PA) and a sunrise (bent-knee axial) as per the seminal paper by Dejour et al. Should there be any concern about coronal alignment, long-leg standing views of the legs should be performed. A lateral view of the knee in 30° flexion allows evaluation of the trochlea, as well as the patellar height. Three lines are evaluated on the lateral view, and include the two most anterior lines which represent the superimposed femoral condyles, followed by the third line which represents the trough of the trochlea groove. In a normal knee, the line representing the trochlea groove does not intersect the lines representing the femoral condyles. Evidence of trochlear dysplasia is thus demonstrated by the third line crossing the femoral condyles, the so-called crossing sign22 (Figure 1). Evidence of a trochlear bump/spur is evaluated with a line drawn along the anterior cortex of the femur, where the trochlea groove may either be anterior, posterior or neutral to this line. A trochlear groove line >3 mm anterior to this line represents a pathological spur/bump which may act like a ramp pushing the patella laterally33,34 (Figure 2). The double contour sign is represented by a line below the trochlear groove line on lateral view, representing a hypoplastic medial condyle. These findings form the basis of the Dejour classification of trochlear dysplasia, which is divided into four types (Figure 3).33,35 The Dejour classification system helps to guide management, and patients with types B and D may benefit from trochleoplasty.33,36 Recently a new MRI classification system, the Oswestry-Bristol classification, has emerged and appears to have improved inter- and intra-observer reliability as compared to the Dejour classification. This classification grades trochlea dysplasia as normal, mild, moderate and severe, with severe cases requiring trochleoplasty according to the suggested algorithm27 (Figure 4).

Axial views of the knee are also very useful in identifying trochlear dysplasia, patellar tilt and subluxation. On the sunrise view, patellar tilt (Laurin’s angle) and subluxation (Merchant’s congruence angle) can be quantified. The Merchant congruence angle view requires knee flexion of 45° with the X-ray beam angled at 30° caudally, and is usually 6–11° medial. The sulcus angle can be calculated by measuring the angle between the intercondylar trough and the femoral condyles. An angle greater than 145° is diagnostic of trochlear dysplasia. A patellar tilt angle less than 5° is normal. Patellar alta can be assessed on lateral radiographs using various ratios between the patella and the tibia/fibular tibial tubercle. These include the Blackburne-Peel ratio,39 Insall-Salvati ratio,40 Koshino ratio41 and the Caton-Deschamps ratio42,43 (Figure 5). Most surgeons prefer to use the Caton-Deschamps ratio as it is less reliant on the flexion position of the knee and better reflects the articulating portion of the patellofemoral joint. A Caton-Deschamps ratio greater than 1.2 indicates patella alta. Advanced imaging in the form of computed tomography (CT) and/or magnetic resonance imaging (MRI) is recommended for assessment of the underlying pathology prior to any surgical intervention and to exclude associated injuries in acute patella dislocations. High-resolution, cross-sectional imaging using CT

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**Figure 1.** Radiographic features of patellofemoral dysplasia a) Normal; b) Crossign sign; c) Double contour sign

(Adapted from Zaffagnini et al. The patellofemoral joint: dysplasia to dislocation. EFORT Open Rev. 2017;2(5):204-14. Use permitted under Creative Commons licence CC-BY-NC 4.0)

**Figure 2.** Trochlear bump: yellow line represents anterior femoral cortex; blue line represents the floor of the trochlea

(Adapted from Batailler C, Neyret P. Trochlea dysplasia: imaging and treatment options. EFORT Open Rev. 2018;3(5):240-47. Used with permission from corresponding author Philippe Neyret)

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**Figure 3.** Dejour classification. Type A: Crossing sign on the lateral view, shallow trochlea, sulcus angle >145° on the axial view (shallow trochlea). Type B: Crossing sign, supratrochlear spur/bump on lateral radiographs (flat or convex trochlea). Type C: Crossing sign, double contour sign (asymmetry of trochlear facets with a hypoplastic medial condyle). Type D: Crossing sign, supratrochlear spur/bump, double contour sign (asymmetry of trochlear facets plus vertical join and cliff pattern)

(Reproduced with permission from David Dejour. Original article: Dejour D, Reynaud P, Lecoultre B. Douleurs et Instabilité Rotulienne. Essai de classification. Med Hyg. 1998;56:1466-71)
accurately demonstrates trochlear dysplasia and rotational abnormalities of the tibia and femur. Furthermore CT imaging is used to calculate the tibial tubercle–trochlear groove (TT-TG) distance, and when more than 20 mm is associated with patellar instability.\(^4,5\) (Figure 6). It is important to note that knee flexion influences the measurement significantly, with the TT-TG distance shortening by 1 mm for every 5° of flexion, as described by Tanaka et al.\(^6\)

If there are any clinical suspicions of associated soft tissue and cartilage injuries, or concerns over radiation exposure, an MRI may be better indicated. MRI demonstrated 85% sensitivity and 70% specificity in identifying associated MPFL injuries.\(^7\) Cartilage injuries can be expected in 70–90% of acute and recurrent dislocations.\(^8,9\) Patellar height can also be assessed using the MRI-derived patella–trochlear index which measures the ratio of trochlea cartilage to patellar cartilage on a mid-sagittal view. The TT-TG distance can also be measured using MRI imaging; however, it has been shown to underestimate the distance by 3.8 mm when compared to CT.\(^10\) Furthermore, some clinicians believe that the position of the tibial tubercle is affected by knee rotation and therefore a more accurate measurement should reference from tibial structures alone. Thus the tibial tubercle–posterior cruciate ligament distance has been developed to assess lateralisation of the tibial tubercle which is independent of knee flexion.\(^11,12\) Other MRI-based measurements include the sagittal patellofemoral engagement index which acts as a supplementary assessment of patellar height, and the axial engagement index which indicates lateral patellar displacement.\(^13,14\) MRI has also been used to accurately measure trochlea depth, sulcus angle and facet asymmetry.\(^15\) MRI may be more accurate in grading trochlear dysplasia when compared to the X-ray-based Dejour classification.\(^16\)

Quantifying risk of dislocation

In order to predict the risk of recurrence and guide management, attempts have been made to quantify the cumulative effect of risk factors. According to Lewallen et al., the risk of recurrence in young patients (<25 years) is 27%, whereas if the patient has trochlear dysplasia the risk is 23%. On an individual basis, one might not consider surgery for either of the above situations after a primary dislocation; however, if these individual risk factors are combined, the exponential cumulative risk is 60% and the threshold for surgery is lower.\(^17\) Steensen et al.\(^18\) showed that 60% of recurrent dislocations had two or more associated risk factors and this was validated by a finite element model by Fitzpatrick et al.\(^19\) which used a prediction algorithm based on variable weighting of risk factors showing a 90% sensitivity and 87.5% specificity respectively. Hiemstra et al. grouped their patients into either WARPS (weak, atraumatic, risky anatomy, pain and subluxation) or STAID (strong, traumatic, anatomy normal, instability and dislocation) categories which allows a relatively simple approach to prognostication and management.\(^20\) Balcarek et al. introduced the patellar instability severity score (ISS), which identifies six risk factors: age (<16 years), bilateral instability and four anatomic risk factors measured on MRI (trochlear dysplasia, patellar height, TT-TG distance and patellar tilt). An ISS of more than 4 has a five times higher odds ratio of recurrence.\(^21\) There is a good correlation between the WARPS/STAID system and the ISS.\(^22\)

Management guidelines

The correct treatment of primary and recurrent lateral patellar dislocation may be a dilemma and should be determined on an individual basis. There are many potential surgical procedures, used in various combinations, which make direct comparisons in the literature difficult.

![Normal, Mild trochlear dysplasia, Moderate trochlear dysplasia, Severe trochlear dysplasia](Image)

**Figure 4.** Author’s diagrammatic representation of the Oswestry-Bristol Classification (Adapted from Sharma et al. The Oswestry-Bristol Classification: a new classification system for trochlear dysplasia. Bone Jt J. 2020;102(1):102-107)

![TT-TG distance measurement: Axial image of the deepest portion of the trochlear groove is marked and superimposed onto an axial image where the tibial tubercle can be marked. The distance between these two points is then measured.](Image)

**Figure 6.** TT-TG distance measurement: Axial image of the deepest portion of the trochlear groove is marked and superimposed onto an axial image where the tibial tubercle can be marked. The distance between these two points is then measured. (Adapted from Zaffagnini et al. The patellofemoral joint: from dysplasia to dislocation. EFORT Open Rev 2017;2(5):204-14. Use permitted under Creative Commons licence CC-BY-NC 4.0)
The initial aim is to decrease swelling which can hinder quadriceps muscle activity. Adequate assessment is required to confirm that the correct diagnosis is made (not cruciate or collateral ligament or meniscus injury); to exclude associated injuries (osteochondral fracture of the lateral femoral condyle or patella) which may require MRI and early surgery; to assess risk factors for recurrence with appropriate imaging modalities (young age, sports-related injury, patella alta, skeletal immaturity and trochlear dysplasia) and to counsel appropriately.

Nonoperative management

Conservative treatment is supported in most cases of first-time acute lateral patellar dislocations without associated osteochondral fractures. Reported recurrence rates vary between 15% and 44%, and 50–60% of patients report residual limitations to activity after conservative treatment. There is also growing evidence showing that the rate of re-dislocation is significantly lower following early operative reconstruction.2,5,6,62-72 Indications for surgery after a first episode dislocation may be influenced by using predictive tools as described above. This may result in cases being treated operatively which otherwise may have been treated nonoperatively.

Immobilisation and bracing

Most commonly, a period of three to six weeks of immobilisation is followed by progressive increase in mobility over time. Longer periods of immobilisation in a cast or posterior splint can cause stiffness, weakness and loss of proprioception.73-78 A position of 20° of knee flexion places the least amount of strain on the injured MPFL.15 Knee braces (hinged or lateral stabilisation) may decrease patients’ subjective feeling of patellar instability and improve patella tracking while allowing earlier free range of motion.79-83

Physical therapy

Physiotherapy is recommended for regaining early range of motion, quadriceps/gluteal strengthening and vastus medialis oblique (VMO) conditioning, specifically following closed-chain exercises and core stability exercises.82 Gait re-education and landing technique in sports may be important.76,77,79,82 There is little difference between non-, partial and full weight-bearing status. McConnell taping may help to control excessive patella motion during therapy and increase quadriceps muscle torque and activate VMO earlier than vastus lateralis during stair ascent and descent. It allows earlier functional rehabilitation, is easy to apply and is cheap.78,84-86 Return-to-sports guidelines follow the same principles of recovery as most knee injuries and occur in a stepwise manner as described by Ménétrey et al. and Respizzi and Cavallin.87,88

Surgical management

Patella stabilisation is indicated for those with recurrent instability that are symptomatic with continued apprehension despite conservative treatment.77,89 Early stabilisation may also be considered for those with significant anatomic abnormalities. Many authors recommend that the correct procedure is performed in a specialised unit with a multidisciplinary team and governance systems in place to review practice. Lateral patellar instability in early flexion (0–30°) is the most common problem warranting early surgery, and the restoration of a medial constraint (MPFL) is considered to be the most important surgical factor.1,90-92

The principle of surgical management with recurrent instability is to address the primary abnormal anatomical factor or interacting factors contributing to the instability, without resulting in excessive abnormal loads on the articular cartilage. However, addressing each risk factor, often with potential complications and unproven long-term side effects on the articular cartilage, is not currently supported by definitive evidence in the literature. It is not always straightforward, and many different operations have been described and various combinations used to address the abnormal anatomical factors. An MPFL or medial stabilisation procedure is typically performed in conjunction with the other bony procedures (Table II). This makes evaluation and comparisons of the literature difficult. An algorithmic approach is commonly recommended (Figures 7–9).

Surgical options include medial repair or reefing, lateral release, MPFL reconstruction, tibial tubercle osteotomy (with medialisation or distalisation), trochleoplasty and derotational osteotomies.

Lateral release

An isolated lateral retinacular release is no longer recommended and has shown to be ineffective in the treatment of patellar instability. It may be indicated in combination when there is pathologic retinacular tightness, i.e. when manual correction to neutral is not possible on physical examination (and not only evidenced by excessive patella tilt on imaging).2,93-96 Excessive lateral release may be complicated by medial instability.95

| Pathoanatomy | Surgical options |
|--------------|------------------|
| Instability without malalignment | MPFL reconstruction |
| Instability with malalignment | Tibial tuberosity medialisation + MPFLR |
| Instability with patella alta | Tibial tuberosity distalisation + MPFLR |
| Trochlear dysplasia | Trochleoplasty + MPFLR |
| Rotational problems | Derotation osteotomy |

Table II: The principles of surgical intervention based on the pathoanatomy of PFJI
Medial repair and imbrication

Repair may be considered in certain rare cases without evidence of dysplasia, malalignment and hypermobility, and with a clearly identifiable femoral avulsion injury. There is a high reported rate of recurrent instability due to the difficulty in visualising the exact location of the MPFL injury. In the paediatric and adolescent populations, medial imbrication has evolved from Insall’s extensive technique to a multitude of newer less invasive techniques involving medial reefing with or without arthroscopic lateral release, reporting good/excellent results. These techniques avoid injury to the physis and do not need soft tissue grafts.

MPFL reconstruction

The MPFL is the most important restraint to lateral patella displacement from 0–30° of flexion. It dramatically reduces subjective instability and frank dislocations. It is indicated as an isolated procedure when recurrent instability is present without associated major anatomical abnormalities, i.e. TT-TG distance <20 mm, normal/mild trochlear dysplasia (Dejour type A), absence of patella alta (Caton-Deschamps index <1.2), and a patella tilt <20°. Various autografts and allografts have been used, e.g. Gracilis tendon. Different patella attachment techniques have been described, e.g. bone tunnels, suture anchors and interference screws. All of these methods approach or exceed the load-to-failure of the native MPFL.

In a meta-analysis of 1 065 MPFL reconstructions in 31 studies, it was found that autograft was better, and double-limbed reconstructions had better outcomes. The most important aspect is determining the correct anatomic location using anatomic landmarks as well as radiographic parameters ensuring correct graft isometry and reproduction of normal tension during knee range of motion. Radiographic parameters which can be used intraoperatively include distal femoral percentage measurements as described by Stephen et al. More commonly, Schottle point is utilised which is 1.3 mm anterior to the tangent of the posterior femoral cortex, 2.5 mm distal to the perpendicular of the superior border of the femoral condyle, and immediately proximal to a perpendicular line from the supero-posterior aspect of Blumensaat line (Figure 10). This reproducibly locates the femoral tunnel within a 5 mm isometric point for fixation. Overtensioning can lead to increased patellofemoral contact pressures. Other complications are patella fracture, loss of motion and arthrofibrosis. The optimal amount of knee flexion to fix the graft has not been definitively determined, but fixation in >60° will exacerbate any malpositioned femoral fixation. Thaunat and Erasmus introduced the concept of favourable anisometry, or graft isometry from 0–30° flexion. Graft tension can be measured intraoperatively but should be compared to the contralateral knee. Stephen et al. reported that only 2 N of graft tension accurately restored contact pressure and patellar tracking. Koh and Stewart suggested that there should be

Figure 8. Suggested management algorithm for recurrent patellofemoral instability in skeletally mature patients

Figure 9. Suggested management algorithm for recurrent patellofemoral instability in skeletally immature patients
patient satisfaction has been rated to be good or excellent for excellent clinical outcomes.\textsuperscript{119,122-128} This is a technically demanding procedure with complication rates as high as 26%, up to 15.8% reoperation rate.\textsuperscript{118,129}

**Distal realignment procedures/tibial tubercle transfer**

Osteotomies for patellofemoral instability fall into three groups:\textsuperscript{130,131} 1. Fulkerson anteromedialisation (AMZ) of the tibial tubercle 2. Medial tibial tubercle transfer as described by Emslie-Trillat et al. 3. Distalisation using a step-cut or feathered distal cut

The Fulkerson AMZ, which was originally described for patella chondrosis, is most commonly used as it can unload the distal and lateral articular cartilage and improve patella maltracking. The oblique osteotomy allows customising the individual deformity. A long, hinged osteotomy fixed with a minimum of two screws with flat headed low-profile screws is preferred.\textsuperscript{132} The preferred magnitude of medialisation varies; however, most researchers agree that the postoperative TT-TG goal should be 9–15 mm.\textsuperscript{33,133-135} When assessing the role of patella alta in the instability, various indices can be used as discussed previously. No absolute cut-off value for increased TT-TG has been defined and the measurements are less than ideally reproducible.\textsuperscript{128} Indications for distal realignment include a TT-TG >15–20 mm\textsuperscript{22} and a Eaton-Deschamps >1.2–1.4.\textsuperscript{24,136-138} An elevated TT-PCL or a patellotrochlear index (PTI) <15–20% (<0.32) or sagittal patellofemoral engagement (SPE) <0.45 can also assist decision-making.\textsuperscript{24,54} Distalisation of roughly 6–7 mm using a feathered shingle can be used if CDI >1.2, and if CDI >1.4, a step-cut TTO is performed.\textsuperscript{24,54,132} Distalisation is indicated for patellar instability in the setting of patella alta. This may be combined with an AMZ in selected cases. Isolated anteriorisation as described by Maquet is not indicated for patellofemoral instability.\textsuperscript{139}

Isolating clinical outcomes is difficult because most studies have cohorts of patients with multiple contributory factors and have required concomitant procedures, but distal realignment procedures have been shown to result in low redislocation rates\textsuperscript{62,135,140-142} and patient satisfaction has been rated to be good or excellent for 63–90%.\textsuperscript{62,142-144} The overall risk of complications has been found to be between 4.6% and 7.4%, although removal of hardware is required in 36–50% of cases.\textsuperscript{134,145} In a recent systematic review of outcomes after concomitant MPFL and tibial tubercle transfer (TTT), these procedures were found to be effective in the setting of malalignment.\textsuperscript{146} Consensus groups are hesitant to universally recommend the use of medialisation or patellar instability.\textsuperscript{5,147-149}

**Trochleoplasty**

The aim is to create a recentralised groove, correcting the trochlear depth abnormality and thus stabilising the patella by an improved entrance into the trochlear groove.\textsuperscript{150} Several types of trochleoplasty have been described including a lateral facet-elevating Albee-type;\textsuperscript{151} a sulcus-deepening trochleoplasty described by Masse and Later modified by Jeanneret\textsuperscript{152} and Bereiter\textsuperscript{153}; and a proximal recession wedge trochleoplasty described by Goutallier.\textsuperscript{155} According to Dejour, trochleoplasty is indicated for severe trochlear dysplasia (Dejour types B and D).\textsuperscript{36} and according to the Oswestry-Bristol classification, indications are severe dysplasia as indicated by a convex/domed trochlea on MRI.\textsuperscript{37} Contraindications include an open physeal and patellofemoral arthritis. Most cases will also need an MPFL reconstruction, but the need for a TTT should be decided on a case-by-case basis.\textsuperscript{149,154} It is a technically challenging procedure and should be limited to surgeons experienced and trained in its use.

Trochleoplasty is often not performed, despite good basic science and clinical data, as there are concerns regarding the long-term effects on articular cartilage, arthrofibrosis (2–46%) and arthritis.\textsuperscript{1,151,155,156} The failure rates with recurrent instability are varied (0.8–10.5%) and the reoperation rates are high (14–25%).\textsuperscript{157-160} In a systematic review by Longo et al., 40% of patients who had a trochleoplasty had complications, including increased pain in 11% of cases; 6.7% reduction in range of motion; and 12% developed OA.\textsuperscript{157} Clinical outcome reviews describe a reduction in patella apprehension of 80%, and improved Kujala scores postoperatively, with up to 92% patient satisfaction.\textsuperscript{157,158,161}

**Skeletally immature patients**

In the skeletally immature population there is an especially high incidence in females aged between 10 and 17 years.\textsuperscript{5,162,163} The child typically presents with vague symptoms, and a high index of suspicion should be maintained. Management is usually nonoperative except in cases of large displaced osteochondral fragments; however, recent trends suggest acute surgical intervention may be warranted in certain situations with high risk factors for recurrence.\textsuperscript{164} Hinton and Sharma classified adolescent primary dislocators into two groups to guide decision-making (Table III). There is a shift from non-anatomic procedures to techniques that restore normal anatomy, and special attention is focused on avoiding physisal injury. No evidence of growth

| LAACS | TONES |
|-------|-------|
| Laxity and younger | Traumatic/sports-related |
| Atraumatic and chronic | Older age |
| Abnormal patellofemoral architecture | Normal alignment and architecture |
| Contralateral side | Equal sex distribution |
| Conservative management | MRI and consider early stabilisation |

(Adapted from Hinton KY, Sharma KM. Patellar instability in childhood and adolescence. In: Insall JN, Scott WN, editors. Surgery of the knee. 4th ed. London: Churchill Livingstone; 2006)
disturbance was found when using physeal-sealing techniques.\textsuperscript{165} An important consideration is that the femoral origin of the MPFL is located 5–6 mm distal to the open physis in the young patient.\textsuperscript{166,167} Anatomic fixation of the epiphyseal femoral origin is important to avoid proximalisation of the MPFL insertion and thus tightening of the ligament during growth.\textsuperscript{168}

Patellar stabilisation procedures are grouped into two main categories: proximal realignment and distal realignment procedures. Distal soft-tissue procedures or proximal-only procedures should be used when the tibial physis is open. Medial imbrication has evolved from Insall’s extensive technique to a multitude of newer, less-invasive techniques involving medial reefing with or without arthroscopic lateral release, reporting good/excellent results.\textsuperscript{190} An MPFL reconstruction as performed in adults has become the treatment of choice in most active adolescent patients.\textsuperscript{169}

Many other MPFLRs have been described using different graft options such as:

1. Semitendinosus around an MCL pulley\textsuperscript{170}
2. Autologous quadriceps tendon\textsuperscript{171}
3. Adductor magnus tendon\textsuperscript{172}
4. Semitendinosus around an adductor sling\textsuperscript{173}

Combined proximal and distal procedures like the modified Galleazi, Grammont and Roux-Goldthwait have also been described, the details of which are beyond the scope of this article.\textsuperscript{169,174-177}

In summary, when performing an MPFLR in skeletally immature patients, Ries and Bollier recommends wrapping the free ends of the graft around the adductor tendon in younger patients, and using fluoroscopy while creating the femoral epiphyseal tunnel in older adolescents. Distal realignment can be achieved with soft tissue procedures but TTT should only be considered in skeletally mature patients.\textsuperscript{190}

Conclusion
Patellofemoral dislocation occurs in young, active patients and can lead to recurrent instability unless it is appropriately managed. Nonoperative management is still the mainstay of treatment for most first-episode dislocations, unless there is associated osteochondral pathology requiring surgical intervention. Using this approach approximately 40% of patients will experience recurrent instability and require surgical intervention. Despite abundant evidence on the topic, there is no consensus on which surgical approach is most appropriate for recurrent dislocation. A reasonable approach, supported by evidence, includes performing an MPFL reconstruction in most cases of recurrent instability, with additional procedures (e.g. TTO/trochleoplasty) tailored to the individual as indicated. This serves to maximise the benefit to the patient, while limiting the risk of complications.

Ethics statement
The authors declare that this submission is in accordance with the principles laid down by the Responsible Research Publication Position Statements as developed at the 2nd World Conference on research integrity in Singapore, 2010. Ethical approval for this study was not obtained – review article.

Declaration
The authors declare authorship of this article and that they have followed sound scientific research practice. This research is original and does not transgress plagiarism policies.

Author contributions
Both authors contributed to the conception and design of the work, literature review, analysis, drafting of the work, and final approval of the version to be published.

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