Patellar Instability

Allison K. Perry, MD

Bhargavi Maheshwer, MD

Steven F. DeFroda, MD, MEng

Mario Hevesi, MD, PhD

Safa Gursoy, MD, PhD

Jorge Chahla, MD, PhD

Adam Yanke, MD, PhD

Investigation performed at the Midwest Orthopaedics at Rush University, Chicago, Illinois

Abstract

» Certain anatomic factors, such as patella alta, increased tibial tubercle-trochlear groove distance, rotational deformity, and trochlear dysplasia, are associated with an increased risk of recurrent patellar instability.

» The presence of a preoperative J-sign is predictive of recurrent instability after operative management.

» Isolated medial patellofemoral ligament reconstruction may be considered on an individualized basis, considering whether the patient has anatomic abnormalities such as valgus malalignment, trochlear dysplasia, or patella alta in addition to the patient activity level.

» More complex operative management (bony or cartilaginous procedures) should be considered in patients with recurrent instability, malalignment, and certain anatomic factors.

Patellar instability (PI) is a potentially devastating diagnosis considering the high recurrence rate (up to 71%)[1] and relatively modest rate of return to preinjury level of sport (67%) without surgery[2]. A thorough understanding of risk factors and how to properly evaluate and treat PI is crucial for successful management. Anatomic factors (patella alta, increased tibial tubercle-trochlear groove (TT-TG) and tibial tubercle-posterior cruciate ligament (TT-PCL) distance, rotational deformity, trochlear dysplasia, and connective tissue disorders) increase the risk of instability[3-7]. After the index instability episode, patients with a patellar dislocation history have nearly 7-fold increased odds of experiencing recurrence[8]. PI affects patients' abilities to perform activities of daily living. As such, clinicians must be able to diagnose and treat this condition using the most recently published literature. The purpose of this article was to review physical examination and imaging tests that aid in diagnosis of instability, outline risk factors of recurrence, and provide an algorithmic approach to current treatment modalities through a systematic literature.

Physical Examination

After an instability episode, lower limb alignment, hypermobility, and gait should be assessed. The Q-angle is measured by drawing 2 lines: the first from the anterior superior iliac spine to the center of the patella and the second from the center of the patella to the tibial tubercle. Angles between these lines >20° (females) and >15° (males) may indicate a greater lateral force on the extensor mechanisms, resulting in a greater risk of patellar dislocation[9]. Hypermobility is assessed with the Beighton score, a 9-point scale indicating ligamentous laxity if >4 of the following are fulfilled (1 point/extremity): passive pinky finger dorsiflexion >90°, passive thumb opposition to the flexor aspect of the wrist, elbow hyperextension >10°, knee hyperextension >10°, and the ability to flatten both palms on the floor with flexed hips and extended knees[10]. With PI, compensatory gait alterations may occur to decrease subjective instability or may be a predisposing factor to injury. Patients tend to have decreased knee and hip joint movement and a more valgus knee position during walking, likely because of an impaired hip

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSREV/A881).

abductor and external rotator and diminished knee extensor strength[11]. Hip rotation should be assessed in the prone and supine positions given that patients with PI tend to have increased femoral anteversion and associated pathologic increases in hip internal rotation[12,13]. Tibial torsion is most readily assessed in the supine position evaluating the thigh-foot angle at 90° of hip and knee flexion. Patients may require operative correction if they have external tibial torsion >30° or internal tibial torsion >15°[14]. Standing alignment should be evaluated with the skin exposed from the thighs to the ankles, allowing for the evaluation of both coronal alignment and any rotational deformities.

Dynamic evaluation of the patella allows for assessment of a J-sign, which is observed as the patella moving laterally as the knee is actively extended from a flexed position. The J-sign indicates that the patella moves lateral to the trochlear groove in extension with subsequent medial displacement in flexion as it engages with the trochlea[15]. It may be hard/jumping (snaps) or soft (glides), with the former being related to severe dysplasia vs. the later originating from malalignment resulting from a divergence of the line of pull of the extensor mechanism, its path across the trochlear groove, and a subsequent anchor point at the tibial tubercle. A thorough examination when the patient is supine and the knee is extended should be performed to determine medial and lateral patellar mobility, although acute swelling may affect interpretation of findings. If the patella can be displaced medially or laterally ≥3 quadrants, the lateral or medial patellar stabilizers may be injured, respectively[9]. The degree of knee flexion when patellar laxity is observed can allow for identification of the instability culprit. During patellar engagement within the trochlea (full extension to 30° flexion), the main patellar stabilizer is the medial patellofemoral ligament (MPFL). Beyond 30°, the main restraint is trochlear bony anatomy, although the medial patellotibial ligament and medial patellomeniscal ligament serve as secondary stabilizers beyond 45° of flexion[16]. For patients with loss of bony restraint, this primarily results from patella alta (the patella does not [yet] engage in the groove) or underlying trochlear dysplasia (the groove is shallow or convex). When assessing patellar apprehension, Ahmad et al. found that if a patient experiences apprehension when a lateral force is applied to the patella in full extension, through 90° flexion, and back to full extension but experiences relief with application of a medial force through these movements, PI can be diagnosed with excellent sensitivity (100%) and accuracy (94%)[17]. Zimmerman et al. described a technique combining the classic and moving apprehension tests: The knee is flexed to 120° and is then extended while applying a lateral force to the patella[18]. Apprehension at higher degrees of flexion is associated with anatomic abnormalities such as trochlear dysplasia or valgus deformity[18].

Imaging

Radiographs are used to assess patellar morphology and location (Fig. 1). Measurement of patellar height on radiographs was first described by Blumensaat et al. in 1938 and has since been described by multiple authors using both direct (relative to the femur) and indirect (relative to the tibia) methods[19-21]. A commonly used method, the Caton-Deschamps index (CDI), has good reliability[22,23]. The CDI is determined by comparing the distance between the inferior margin of the patellar articular surface and the anterosuperior angle of the tibial plateau to the length of the patellar articular

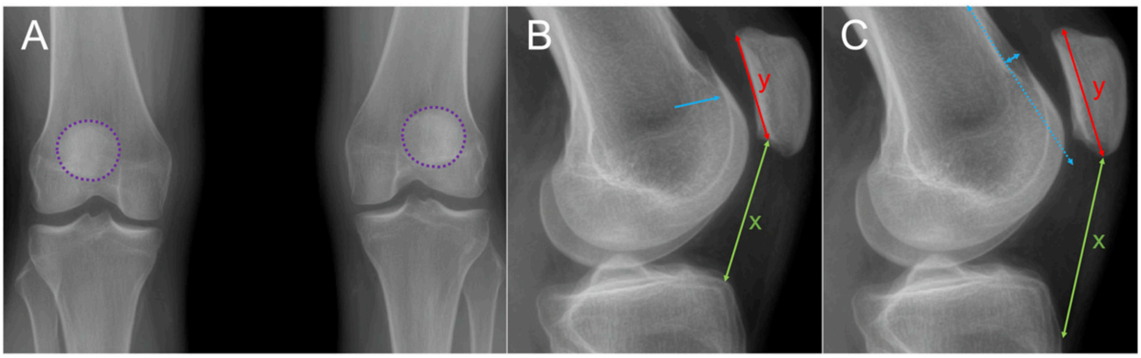


Fig. 1

Posteroanterior (PA) and lateral radiographs. PA radiographs (**Fig. 1-A**) can aid in comparison of the position of the patella (purple outline) between knees. Lateral radiographs (**Fig. 1-B**) can be used for the measurement of the Caton-Deschamps index (CDI), in which the distance between the inferior margin of the articular surface of the patella and the anterosuperior angle of the tibial plateau (x) is compared with the length of the patellar articular cartilage (y), with values greater than 1.3 indicating patella alta. Lateral radiographs can also be used to evaluate for the presence of the crossing sign (blue arrow). The Insall-Salvati ratio may also be measured on lateral radiographs (**Fig. 1-C**), which compares the length of the patellar tendon (x) to total patella length (y), with values >1.2 indicating patella alta. The size of trochlear bumps may be measured by drawing a line extending from the anterior femoral cortex (dotted blue line, **Fig. 1-C**) and measuring the distance from that line perpendicular to the most anterior aspect of the trochlear floor (solid blue line), with values >3 mm being abnormal.

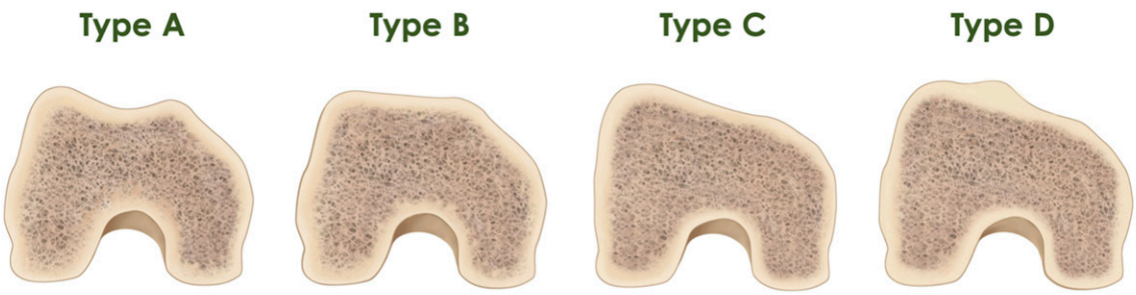


Fig. 2

Dejour classification. The shape of the trochlea can be described as shown above. **Fig. 2-A** Shallow trochlear groove. **Fig. 2-B** Flat trochlear groove. **Fig. 2-C** Medial femoral condyle hypoplasia. **Fig. 2-D** Flat trochlea with medial femoral condylar hypoplasia, representing a "cliff" sign.

cartilage on a lateral radiograph with the knee flexed to 30° (Fig. 1). CDI values >1.3 indicate patella alta[24]. The Insall-Salvati ratio may also be used, which is the length of the patellar tendon compared with total patella length (Fig. 1). Values >1.2 indicate patella alta. Importantly, a meta-analysis found that many studies using patellar height measurements have demonstrated poor control of the degree of knee flexion and whether the quadriceps was contracted during imaging, which may affect the patellar tilt angle and location and resultant measurements[25].

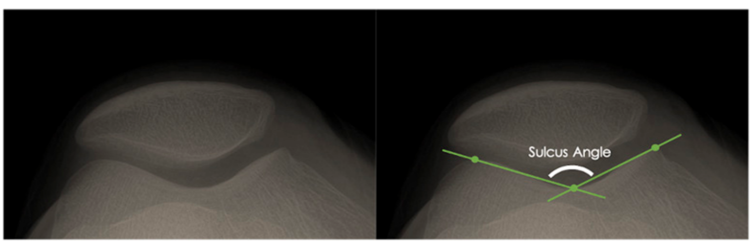
The Dejour classification describes the shape of the trochlear groove (Fig. 2). The degree of trochlear dysplasia is commonly assessed on lateral radiographs through identification of the "crossing sign" or the point at which the line of the trochlear floor crosses the anterior contour of the lateral femoral condyle (Fig. 1). As the crossing sign moves inferiorly and the condyles become more asymmetrical, the severity of trochlear dysplasia increases[5]. Lateral radiographs may be used to evaluate the presence of trochlear bumps by drawing a straight line extending from the anterior femoral cortex and measuring the distance from that line perpendicular to the most anterior aspect of the trochlear floor. Values >3 mm are abnormal[26] (Fig. 1). The true lateral radiograph aids in identification of a supratrochlear spur, which is a global prominence of the trochlea that results in patellar maltracking off the lateral facet in flexion and is indicative of high-grade trochlear dysplasia[26]. The sulcus angle (Fig. 3) and trochlear depth may also be evaluated on Merchant and lateral radiographs, respectively, with sulcus angles >145° and trochlear depths ≤4 mm indicating trochlear dysplasia[5]. Higher sulcus angles have a risk of osteochondral pathologies, including acute fracture[27]. The congruence angle can also be demonstrated on the Merchant view by measuring the angle between a line bisecting the sulcus angle and a line from the deepest point of the sulcus to the median ridge of the patella. Values >16° indicate patellar subluxation[28]. The Merchant view (superior-inferior, used for the evaluation of patellar subluxation) should be used over the Laurin view (inferior-superior, used for the evaluation of patellar tilt) when assessing PI[29].

Computed tomography (CT) has good intraobserver reliability in measurement of the TT-TG distance, which is measured by first identifying the deepest point of the trochlear groove in the axial view and drawing a line across the posterior condylar axis[25] (Fig. 4). A second line bisecting the trochlear groove is drawn perpendicular to the first. The axial view is adjusted until the most anterior portion of the tibial tubercle is identified, and a line parallel to that bisecting the trochlear groove is drawn. The TT-TG distance is measured between the 2 parallel lines[30]. Values >20 mm represent patella malalignment[5]. When normalizing the TT-TG values to other anatomic values, Heidenreich et al. found that adjusting the TT-TG distance to patellar length (PL) was the most predictive of recurrent instability[31].

When evaluating PI, magnetic resonance imaging (MRI) is useful in the assessment of associated bony, cartilaginous, and ligamentous lesions[32]. Previous studies have described the use of MRI for the measurement of TT-TG distances, but Anley et al. cautioned against this because they found that within the same cohort of patients, mean MRI TT-TG values were 4.16 mm less than CT measurements[33]. Nevertheless, TT-PCL distance can be measured on MRI with excellent interobserver and intraobserver reliability[34]. The TT-PCL

Fig. 3

Sulcus angle. The sulcus angle can be measured on Merchant view radiographs, with angles greater than 145° being indicative of trochlear dysplasia.



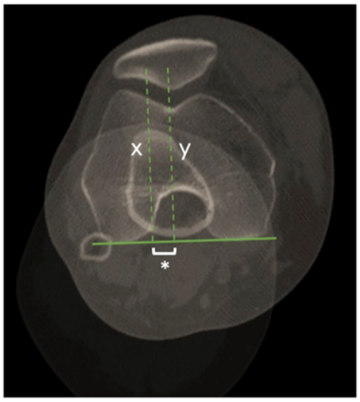


Fig. 4

Tibial tubercle-trochlear groove (TT-TG) distance. The TT-TG distance can be measured (*) from the most anterior portion of the tibial tubercle (x) and the deepest point of the trochlear groove (y) on axial view computed tomography images, with values >20 mm being considered abnormal.

distance is measured by first drawing a line connecting the medial and lateral dorsal condyles on the axial slice just below the tibial articular cartilage. Then, 2 parallel lines are drawn perpendicular to the first: one bisecting the midpoint of the inferior patellar tendon insertion and a second bisecting the most medial and lateral points of the PCL. The distance between the parallel lines is measured, with values >24 mm being abnormal[33,34]. Although both TT-TG and TT-PCL can be used to assess patellar alignment, an increased TT-PCL value represents true tibial tubercle lateralization[33]. In addition to dynamic CT[35], dynamic MRI may be used to assess patellar maltracking. A recent study found that in patients with maltracking, a greater degree of mediolateral translation (12.4 ± 6.9 mm vs. −0.1 ± 2.3 mm) and a more lateral position of the patella were present compared with controls. The authors also found that increased TT-TG distances, CDI values, and sulcus angles were associated with dynamic patellar translation and tilt[36]. Further studies assessing dynamic MRI accuracy may provide more insight into its clinical utility in diagnosing PI.

Risk Factors of Recurrent Instability

Recurrent PI has been reported to occur in up to 71% of cases managed conservatively and is typically multifactorial[1,37-40]. Primary and recurrent instability occurs most commonly in pediatric and teenage populations[41,42] and in those with physically high-demanding professions[43]. Previous studies have suggested that patella alta, increased TT-TG or TT-PCL distance, and trochlear dysplasia may be contributory[42,44]. In a review of imaging factors in 60 patients with recurrent instability and 120 patients without a history of patellar dislocation, Steensen et al. found that patients with recurrent patellar dislocations had higher rates of patella alta (60% vs. 21%), rotational deformity (27% vs. 3%), and trochlear dysplasia (68% vs. 6%) in addition to increased TT-TG distances (42% vs. 3%)[40]. In addition, patients with recurrent instability were more likely to have multiple abnormal anatomic factors compared with controls[40]. Of note, groups have recently advocated for normalizing TT-TG to patient-specific anatomy such as PL to provide increased sensitivity of such radiographic measures[31].

Multiple models using combined imaging and demographic-related factors have been proposed to predict recurrent instability[45-48]. Key factors for evaluating models for clinical use are applicability to a general population, appropriate follow-up, and ease of implementation in the clinical setting. A study by Christensen et al. with 584 patients and a 12-year mean follow-up demonstrated that the average time to recurrent instability was 3.7 years[42]. Therefore, predictive models limited to short-term follow-up should be used with caution because they may underestimate recurrence. Hevesi et al. presented a multivariable in-clinic model based on 81 patients followed for a mean of 10 years for predicting recurrent instability using age, skeletal immaturity, presence of dysplasia, and TT-TG/PL[46]. The authors provided free access to their calculator online for graphical implementation in pediatric and adult populations[49]. Similarly, Ling et al. used multicenter data from 291 patients with PI followed for 2 years and created a model that identified the following recurrence risk factors: younger age, previous contralateral patellar dislocation, skeletal immaturity, lateral patellar tilt, increased TT-TG distance, Insall-Salvati ratio, and trochlear dysplasia[45]. For clinicians interested in pediatric-specific scoring systems, Jaquith et al. provided a model using 266 knees followed for a mean of 1.3 years and reported that dysplasia, skeletal immaturity, patella alta, and a history of contralateral patellar dislocation were recurrence risk factors[47]. Although the prognostication of recurrent instability continues to be studied, it is clear that a multifactorial patient-centered approach is needed to properly evaluate and treat this condition.

Patellar dislocation recurrence may occur after surgical stabilization. In an analysis of 237 patients who underwent unilateral isolated MPFL reconstruction, Zhao et al. aimed to identify factors associated with recurrent lateral PI[50]. Although all included patients demonstrated clinical improvements in Kujala and International Knee Documentation Committee scores, 20 patients (8.4%) experienced some type of failure (redislocation or subjective instability) up to 5 years postoperatively. Although failure risk was not associated with radiographic features (patellar height, trochlear dysplasia, TT-TG distance, patellar tilt), the presence of a preoperative J-sign was associated with a 3-fold increased risk of postoperative instability. The authors also found a significant association between a J-sign and both a CDI value of ≥1.2 and trochlear dysplasia[50]. Similarly, Sappey-Marinier et al. reported that the presence of a preoperative J-sign or CDI ≥1.3 was predictive of failure, although no correlation was found between these 2 predictors[51].

Management

Nonoperative Management and Timing

Conservative management may be attempted for first-time dislocators without associated chondral lesions, osteochondral fractures, or loose bodies. A primary treatment goal in nonoperative management is to decrease swelling because it can inhibit quadriceps muscle activity[52]. Institutional nonoperative protocols often begin with immobilization and the use of crutches to weight-bear as tolerated. Immobilization can be achieved through simple bracing with the knee extended, patellar stabilization braces, and taping[53]. Firm taping to shorten the MPFL and medial retinacular tissue is also an immobilization option that allows for improved gait mechanics through stabilization of the disrupted tissue[54]. However, the outcomes of this method have not been extensively studied. After a brief period of immobilization, patients may begin to progressively increase mobility and strength with full return to activity by 8 weeks[55].

A systematic review of meta-analyses comparing nonoperative and operative management of acute patellar dislocations found that operative treatment may result in a lower rate of recurrent dislocations but does not improve functional outcome scores[56]. Even more recently, a randomized control trial demonstrated that MPFL reconstruction (MPFLR) was superior at protecting against additional patellar dislocations, with a 6.7% instability rate noted for MPFLR compared with 41.9% for nonoperative, active rehabilitation controls at 12 months of follow-up. Sanders et al. demonstrated that at the12-year mean follow-up, patients with recurrent dislocations had a 4.5-fold increase in odds of patellofemoral arthritis after index dislocation, suggesting potential utility of early management aimed at preventing subsequent instability[57]. Nevertheless, there remains a lack of consensus in the literature for the treatment of first-time dislocators. Although initial nonoperative management can be attempted in young, healthy patients with first-time patellar dislocations without underlying chondral injury or loose body formation, operative intervention may be considered if risk factors of recurrence are present.

Surgery

Although initial nonoperative management of first-time dislocators is commonplace, many studies have investigated the efficacy of operative intervention[58-61]. A study looking at 33 adolescents treated surgically after traumatic patellar dislocation reported good long-term functional outcomes[61] while another investigation comparing nonoperative and operative treatment in 126 patients found no difference between redislocation rates, functional and subjective outcomes, and activity levels at an 8-year follow-up[58]. MPFLR has become increasingly popular in PI management and is typically indicated after ≥2m dislocation episodes[62]. Other indications for isolated MPFLR include PI without concerning anatomic abnormalities on imaging, positive physical examination findings, or sports participation[62-64]. Ideal surgical candidates should fall within these criteria: (1) TT-TG distance <20 mm at 0° flexion, (2) CDI <1.4, (3) normal or type A dysplastic trochlea, and (4) patellar tilt <20° on axial imaging[62,65]. Patients with other underlying causes of recurrent instability (patella alta, patellofemoral arthritis, general ligamentous laxity, trochlear dysplasia) or those with excessive femoral anteversion, excessive tibial torsion, or valgus malalignment are typically not candidates for isolated MPFLR[66].

Surgical techniques for MPFLR can be characterized as proximal soft tissue, distal realignment, or combined procedures[62,67-72]. Various autograft and allograft sources have been described (gracilis, semitendinosis, patellar, quadriceps) in addition to artificial options[71,73]. Although some debate exists over whether to use an allograft or autograft, a recent systematic review reported no clear benefit of one over the other[74]. Despite disagreement in the surgical technique, the importance of restoration of native anatomy is agreed upon. The femoral MPFL insertion has been well-described, with many studies reporting the insertion to be in the curvature or "saddle" between the adductor tubercle and the medial epicondyle[75-80] (Fig. 5). LaPrade et al.[78] defined the insertion point in relation to the medial epicondyle (10.6 mm proximal, 8.8 mm posterior) and the adductor tubercle (1.9 mm anterior, 3.8 mm distal). When considering the MPFL's insertion on the patella, some authors prefer the term medial patellofemoral complex because some of the MPFL fibers insert on the quadriceps tendon in addition to the patella[75]. Although these fibers should be recognized during patellar fixation of an MPFL graft, debate exists on where patellar fixation should occur, as both single and double-bundle techniques have been described[66,81,82].

Complications after MPFLR may include patellar fracture, postoperative instability, flexion loss, and pain[83]. Although the use of trans-patellar bone tunnels in MPFLR allows for greater stability than suture repair, bone tunnels have been shown to increase the risk of iatrogenic fractures and lead to overall higher complication rates[62,83-85]. In addition, malpositioning of bone tunnels can cause medial patellofemoral overload and subsequent patellofemoral pain, arthrosis, or medial subluxation[55,86].

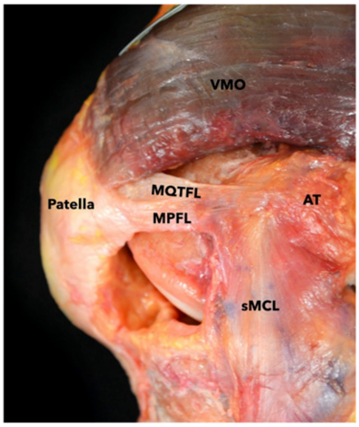


Fig. 5

MPFL insertion on the femur. When performing MPFL reconstruction, care should be taken to restore native anatomy by attaching the MPFL graft to the native MPFL insertion point. AT = adductor tubercle, MPFL = medial patellofemoral ligament, MQTFL = medial quadriceps tendon femoral ligament, sMCL = superficial medial collateral ligament, and VMO = vastus medialis oblique.

As reported by a recent meta-analysis including 25 articles and 629 knees, the mean overall complication rate for MPFLR is 26%[83]. However, the authors found great variability in reported complication rates, ranging from 0% to 85% and concluded that there is a lack of high-level evidence available on risks associated with MPFLR.

When Isolated MPFLR Is Not Enough

When anatomic abnormalities are present, isolated MPFLR may not be sufficient to address instability. Bony malalignment, defined by an increased Q angle or TT-TG distance, may require concomitant procedures. However, cutoffs for isolated MPFLR ineligibility vary in the literature. Increased Q-angle values have been defined as >20°[87,88] or within the range of 15 to 25°[62,63,89] while increased TT-TG distances have been defined as >20 mm[88], 22 mm[90], or 15 mm[91]. Similarly, although patellar or trochlear dysplasia has been reported as contraindications to isolated MPFLR, the specific amount of dysplasia considered to be unamenable to surgery is not yet established[62,64,92]. This lack of consensus highlights the importance of using information from a variety of sources, such as history, physical examination, and imaging, when making surgical decisions. Regarding patella alta, various values have been reported as cutoffs for isolated MPFLR (1.2-1.3 using Insall-Salvati index values[62,64,89,92] and 1.2-1.4 using CDI values[62,65,93,94]). When determining surgical management, these thresholds should be considered in the context of recent literature reporting good clinical outcomes of isolated MPFLR, regardless of bony abnormalities such as increased TT-TG distance, trochlear dysplasia, and increased CDI[95,96].

When to Add Tibial Tubercle Osteotomy

Tibial tubercle osteotomy (TTO) with MPFLR is typically considered with elevated TT-TG (>20 mm) or TT-PCL (>24 mm) distances[55]. In cases with TT-TG distances of 17 to 20 mm and recurrent instability, MPFLR combined with anteromedialization TTO has been shown to result in superior functional outcome scores and patellar kinematics compared with isolated MPFLR[97]. Ideal surgical candidates for anteromedialization exhibit isolated chondrosis of the distal or lateral patella, excessive lateral patellar tilt, or subluxation associated with increased TT-TG distance[98,99].

The Elmslie-Trillat technique describes tibial tubercle transfer through elevating and medializing the tibial tubercle, followed by reattachment with a cannulated screw[100,101]. More popular is the Fulkerson procedure or the anteromedialization technique[102]. The ability to create simultaneous anteriorization and medialization is achieved through an oblique osteotomy of the tibial tubercle[98]. Other techniques include complete detachment of the tibial tubercle to achieve optimal medialization, distalization, or both[103-105]. These techniques are not without complications. The Elmslie-Trillat technique has been associated with increased patellofemoral joint pressure and arthritic changes[101] while the Fulkerson procedure may lead to persistent pain, stiffness, arthrofibrosis, progressive chondral deterioration, and symptomatic hardware[98]. Risk factors of poor functional outcomes after combined MPFLR and TTO include female sex and TTO medialization >10 mm[106]. A systematic review quantifying the risk of early postoperative complications after TTO with different surgical techniques found that the complication risk was higher when the tibial tubercle was completely detached (11%) compared with medialization (3%) and anteromedialization (4%) techniques. Regardless of the technique, the overall risk of major complications was 3% after TTO and MPFLR[103]. The location of patellar chondrosis may affect the outcome of TTO. Anteromedialization with TTO leads to better outcomes when patellar chondrosis is localized to the distal and lateral facet regions compared with medial, central, or diffuse regions[99].

Special Circumstances Requiring Further Procedures

Recurrent PI may require more extensive surgical intervention. With trochlear dysplasia, trochleoplasty is effective in providing patellar stabilization while minimizing maltracking through normalization of kinematics during patellofemoral articulation[107,108]. Sulcus-deepening procedures may be used in Dejour type B and D trochleas[109]. If malalignment is present, lateral retinacular release, medial retinaculum imbrication, or a combination may be used. Lateral retinaculum release alone has not been shown to restore normal kinematics in PI but can be an adjunct to patellofemoral alignment procedures addressing recurrent instability[110]. Lateral retinacular release was reported to be the most common (43.7%) adjunct procedure performed in a study investigating nationwide surgical trends in the management of PI[111]. Another soft-tissue procedure for PI is proximal patella realignment, which has been shown to have excellent results for patients with chondromalacia (up to 94%)[112] with no difference in outcomes when proximal patella realignment is performed with/without TTO[113]. Imbrication of the medial retinaculum is usually performed with a distal alignment procedure or distal femoral osteotomy[114]. If imbrication is performed, caution should be taken to avoid overtensioning of the MPFL. Combination procedures are becoming increasingly used to optimize postoperative stability. The modified Elmslie-Trillat procedure includes lateral retinacular release, medial capsular reefing, and medial transposition of the anterior tibial tubercle[101,115]. While the treatment of focal cartilage defects is beyond the scope of this review, patients undergoing patellofemoral cartilage restorative procedures have been shown to benefit from a combined anteromedialization procedure through an improved contact area and decreased patellofemoral forces that optimize the biochemical environment of the new cartilage implant[98,102]. Furthermore, in PI patients presenting with

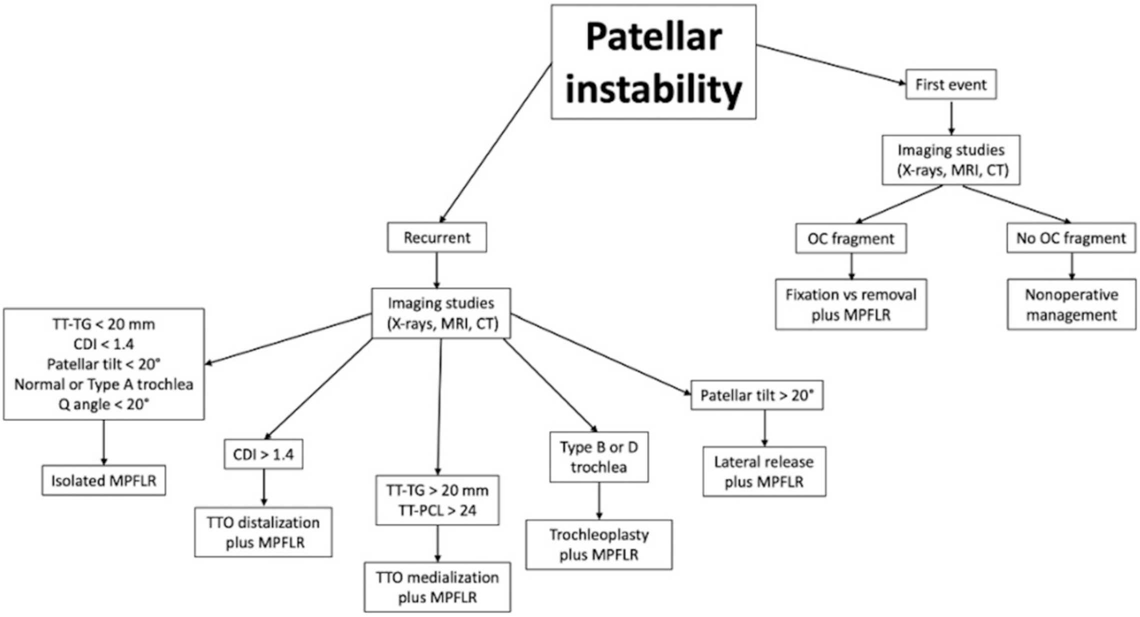


Fig. 6

Treatment algorithm for patellar instability. CDI = Caton-Deschamps index, CT = computed tomography, MPFLR = medial patellofemoral ligament reconstruction, MRI = magnetic resonance imaging, OC = osteochondral, TTO = tibial tubercle osteotomy, TT-PCL = tibial tubercle-posterior cruciate ligament, and TT-TG = tibial tubercle-trochlear groove.

an avulsion fracture of the medial facet, acute surgical repair has not been shown by Sillanpaa et al. to improve outcomes compared with nonsurgical management. However, surgery may be warranted in avulsion injuries involving the articular cartilage to restore cartilage integrity. Thus, a thorough review of imaging must be performed when determining the treatment of medial facet avulsion fractures in the setting of PI[116].

Future Directions

Owing to the complexity and variability in patient presentation, the ability to derive a gold standard management of patellofemoral instability has remained difficult. A survey study of the International Patellofemoral Study Group implementing the Delphi method found 8 consensus statements, including nonoperative management being the standard of care for first-time dislocators without osteochondral fragments or loose body excision and most surgeons favoring medial reconstruction for recurrent instability. However, there remained no consensus regarding the most appropriate type of bony procedure to perform in patients with underlying bony deformities[117]. To best address these uncertainties in optimal management, high-quality multicenter randomized controlled trials directly comparing specific surgical methods are needed. The senior author's preferred evidence-based treatment algorithm is shown in Figure 6.

Conclusion

Although PI is one of the most prevalent knee disorders orthopaedic surgeons encounter, management strategies continue to develop. Given the multiple contributing comorbidities that can present with PI, diagnosis and treatment will continue to vary based on individual patient presentation and pathology, surgical technique preference, and functional expectations.

Source of Funding

No funding was used in this investigation.

Allison K. Perry, MD[1],
Bhargavi Maheshwer, MD[2],
Steven F. DeFroda, MD, MEng[1],
Mario Hevesi, MD, PhD[1],
Safa Gursoy, MD, PhD[1],
Jorge Chahla, MD, PhD[1],
Adam Yanke, MD, PhD[1]

[1]Division of Sports Medicine, Midwest Orthopaedics at Rush University, Chicago, Illinois

[2]University of Cincinnati College of Medicine, Cincinnati, Ohio

Email address for corresponding author: akperry13@gmail.com

References

1. Palmu S, Kallio PE, Donell ST, Helenius I, Nietosvaara Y. Acute patellar dislocation in children and adolescents: a randomized clinical trial. J Bone Joint Surg Am. 2008;90(3):463-70.

2. Ménétrey J, Putman S, Gard S. Return to sport after patellar dislocation or following surgery for patellofemoral instability. Knee Surg Sports Traumatol Arthrosc. 2014;22(10):2320-6.

3. Waterman BR, Belmont PJ Jr, Owens BD. Patellar dislocation in the United States: role of sex, age, race, and athletic participation. J Knee Surg. 2012;25(1):51-7.

4. Atkin DM, Fithian DC, Marangi KS, Stone ML, Dobson BE, Mendelsohn C. Characteristics of patients with primary acute lateral patellar dislocation and their recovery within the first 6 months of injury. Am J Sports Med. 2000;28(4):472-9.

5. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc. 1994;2(1):19-26.

6. Franco B, Sadigursky D, Daltro GC. Patellar position in patients with patellofemoral syndrome as characterized by anatomoradiographic study. Rev Bras Ortop. 2018;53(4):410-4.

7. Arendt EA, England K, Agel J, Tompkins MA. An analysis of knee anatomic imaging factors associated with primary lateral patellar dislocations. Knee Surg Sports Traumatol Arthrosc. 2017;25(10):3099-107.

8. Fithian DC, Paxton EW, Stone ML, Silva P, Davis DK, Elias DA, White LM. Epidemiology and natural history of acute patellar dislocation. Am J Sports Med. 2004;32(5):1114-21.

9. Buchanan G, Torres L, Czarkowski B, Giangarra CE. Current concepts in the treatment of gross patellofemoral instability. Int J Sports Phys Ther. 2016;11(6):867-76.

10. Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. Ann Rheum Dis. 1973;32(5):413-8.

11. Lucas KCH, Jacobs C, Lattermann C, Noehren B. Gait deviations and muscle strength deficits in subjects with patellar instability. Knee. 2020;27(4):1285-90.

12. Nelitz M, Dreyhaupt J, Williams SR, Dornacher D. Combined supracondylar femoral derotation osteotomy and patellofemoral ligament reconstruction for recurrent patellar dislocation and severe femoral anteversion syndrome: surgical technique and clinical outcome. Int Orthop. 2015;39(12):2355-62.

13. Han H, Kubo A, Kurosawa K, Maruichi S, Maruyama H. Hip rotation range of motion in sitting and prone positions in healthy Japanese adults. J Phys Ther Sci. 2015;27(2):441-5.

14. Staheli LT. Torsion—treatment indications. Clin Orthop Relat Res. 1989(247):61-6.

15. Post WR. Clinical evaluation of patients with patellofemoral disorders. Arthroscopy. 1999;15(8):841-51.

16. Philippot R, Boyer B, Testa R, Farizon F, Moyen B. The role of the medial ligamentous structures on patellar tracking during knee flexion. Knee Surg Sports Traumatol Arthrosc. 2012;20(2):331-6.

17. Ahmad CS, McCarthy M, Gomez JA, Shubin Stein BE. The moving patellar apprehension test for lateral patellar instability. Am J Sports Med. 2009;37(4):791-6.

18. Zimmermann F, Liebensteiner MC, Balcarek P. The reversed dynamic patellar apprehension test mimics anatomical complexity in lateral patellar instability. Knee Surg Sports Traumatol Arthrosc. 2019;27(2):604-10.

19. Phillips CL, Silver DA, Schranz PJ, Mandalia V. The measurement of patellar height: a review of the methods of imaging. J Bone Joint Surg Br. 2010;92(8):1045-53.

20. Insall J, Salvati E. Patella position in the normal knee joint. Radiology. 1971;101(1):101-4.

21. Blackburne JS, Peel TE. A new method of measuring patellar height. J Bone Joint Surg Br. 1977;59(2):241-2.

22. Thévenin-Lemoine C, Ferrand M, Courvoisier A, Damsin JP, Ducou le Pointe H, Vialle R. Is the Caton-Deschamps index a valuable ratio to investigate patellar height in children? J Bone Joint Surg Am. 2011;93(8):e35.

23. Berg EE, Mason SL, Lucas MJ. Patellar height ratios. A comparison of four measurement methods. Am J Sports Med. 1996;24(2):218-21.

24. Caton J. Method of measuring the height of the patella [in French]. Acta Orthop Belg. 1989;55(3):385-6.

25. Smith TO, Davies L, Toms AP, Hing CB, Donell ST. The reliability and validity of radiological assessment for patellar instability. A systematic review and meta-analysis. Skeletal Radiol. 2011;40(4):399-414.

26. Batailler C, Neyret P. Trochlear dysplasia: imaging and treatment options. EFORT Open Rev. 2018;3(5):240-7.

27. Fones L, Jimenez AE, Cheng C, Chevalier N, Brimacombe MB, Cohen A, Pace JL. Trochlear dysplasia as shown by increased sulcus angle is associated with osteochondral damage in patients with patellar instability. Arthroscopy. 2021;37(12):3469-76.

28. Endo Y, Shubin Stein BE, Potter HG. Radiologic assessment of patellofemoral pain in the athlete. Sports Health. 2011;3(2):195-210.

29. Beaconsfield T, Pintore E, Maffulli N, Petri GJ. Radiological measurements in patellofemoral disorders. A review. Clin Orthop Relat Res. 1994(308):18-28.

30. Song EK, Seon JK, Kim MC, Seol YJ, Lee SH. Radiologic measurement of tibial tuberosity-trochlear groove (TT-TG) distance by lower extremity rotational profile computed tomography in Koreans. Clin Orthop Surg. 2016;8(1):45-8.

31. Heidenreich MJ, Sanders TL, Hevesi M, Johnson NR, Wu IT, Camp CL, Dahm DL, Krych AJ. Individualizing the tibial tubercle to trochlear groove distance to patient specific anatomy improves sensitivity for recurrent instability. Knee Surg Sports Traumatol Arthrosc. 2018;26(9):2858-64.

32. Adhikari K, Kumar Gupta M, Devkota K, Baral P, Koirala S. Magnetic resonance imaging evaluation of patellofemoral joint. J Nepal Health Res Counc. 2021;19(1):122-6.

33. Anley CM, Morris GV, Saithna A, James SL, Snow M. Defining the role of the tibial tubercle-trochlear groove and tibial tubercle-posterior cruciate ligament distances in the work-up of patients with patellofemoral disorders. Am J Sports Med. 2015;43(6):1348-53.

34. Seitlinger G, Scheurecker G, Högler R, Labey L, Innocenti B, Hofmann S. Tibial tubercle-posterior cruciate ligament distance: a new measurement to define the position of the tibial tubercle in patients with patellar dislocation. Am J Sports Med. 2012;40(5):1119-25.

35. Rosa SB, Ewen PM, Doma K, Ferrer JFL, Grant A. Dynamic evaluation of patellofemoral instability: a clinical reality or just a research field? A literature review. Orthop Surg. 2019;11(6):932-42.

36. Frings J, Dust T, Krause M, Ohlmeier M, Frosch KH, Adam G, Warncke M, Mass KJ, Henes FO. Objective assessment of patellar maltracking with 3 T dynamic magnetic resonance imaging: feasibility of a robust and reliable measuring technique. Sci Rep. 2020;10(1):16770.

37. Mäenpää H, Lehto MU. Patellar dislocation. The long-term results of nonoperative management in 100 patients. Am J Sports Med. 1997;25(2):213-7.

38. Mäenpää H, Huhtala H, Lehto MU. Recurrence after patellar dislocation. Redislocation in 37/75 patients followed for 6-24 years. Acta Orthop Scand. 1997;68(5):424-6.

39. Smith TO, Song F, Donell ST, Hing CB. Operative versus non-operative management of patellar dislocation. A meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2011;19(6):988-98.

40. Steensen RN, Bentley JC, Trinh TQ, Backes JR, Wiltfong RE. The prevalence and combined prevalences of anatomic factors associated with recurrent patellar dislocation: a magnetic resonance imaging study. Am J Sports Med. 2015;43(4):921-7.

41. Duthon VB. Acute traumatic patellar dislocation. Orthop Traumatol Surg Res. 2015;101(1 suppl):S59-67.

42. Christensen TC, Sanders TL, Pareek A, Mohan R, Dahm DL, Krych AJ. Risk factors and time to recurrent ipsilateral and contralateral patellar dislocations. Am J Sports Med. 2017;45(9):2105-10.

43. Hsiao M, Owens BD, Burks R, Sturdivant RX, Cameron KL. Incidence of acute traumatic patellar dislocation among active-duty United States military service members. Am J Sports Med. 2010;38(10):1997-2004.

44. Sanders TL, Pareek A, Hewett TE, Stuart MJ, Dahm DL, Krych AJ. High rate of recurrent patellar dislocation in skeletally immature patients: a long-term population-based study. Knee Surg Sports Traumatol Arthrosc. 2018;26(4):1037-43.

45. Ling DI, Brady JM, Arendt E, Tompkins M, Agel J, Askenberger M, Balcarek P, Parikh S, Shubin Stein BE. Development of a multivariable model based on individual risk factors for recurrent lateral patellar dislocation. J Bone Joint Surg Am. 2021;103(7):586-92.

46. Hevesi M, Heidenreich MJ, Camp CL, Hewett TE, Stuart MJ, Dahm DL, Krych AJ. The recurrent instability of the patella score: a statistically based model for prediction of long-term recurrence risk after first-time dislocation. Arthroscopy. 2019;35(2):537-43.

47. Jaquith BP, Parikh SN. Predictors of recurrent patellar instability in children and adolescents after first-time dislocation. J Pediatr Orthop. 2017;37(7):484-90.

48. Balcarek P, Oberthür S, Hopfensitz S, Frosch S, Walde TA, Wachowski MM, Schüttrumpf JP, Stürmer KM. Which patellae are likely to redislocate? Knee Surg Sports Traumatol Arthrosc. 2014;22(10):2308-14.

49. Hevesi M. Recurrent instability of the patella (RIP) score. MedCalc [Webpage]. 2021. Available at: https://www.mdcalc.com/recurrent-instability-patella-rip-score. Accessed August 8, 2021.

50. Zhao Z, Wang Y, Li J, Wang H, Bai X, Wang Q, Li Z. Clinical outcomes and prognostic factors in patients with recurrent patellar lateral dislocation treated with isolated medial patellofemoral ligament reconstruction: a retrospective single-center analysis. Orthop J Sports Med. 2021;9(4):2325967121995803.

51. Sappey-Marinier E, Sonnery-Cottet B, O'Loughlin P, Ouanezar H, Reina Fernandes L, Kouevidjin B, Thaunat M. Clinical outcomes and predictive factors for failure with isolated MPFL reconstruction for recurrent patellar instability: a series of 211 reconstructions with a minimum follow-up of 3 years. Am J Sports Med. 2019;47(6):1323-30.

52. Spencer JD, Hayes KC, Alexander IJ. Knee joint effusion and quadriceps reflex inhibition in man. Arch Phys Med Rehabil. 1984;65(4):171-7.

53. Stensdotter A-K, Hodges P, Mellor R, Sundelin G, Häger-Ross C. Quadriceps activation in closed and in open kinetic chain exercise. Med Sci Sports Exerc. 2003;35(12):2043-7.

54. McConnell J. Rehabilitation and nonoperative treatment of patellar instability. Sports Med Arthrosc Rev. 2007;15(2).

55. Duerr RA, Chauhan A, Frank DA, DeMeo PJ, Akhavan S. An algorithm for diagnosing and treating primary and recurrent patellar instability. JBJS Rev. 2016;4(9):e2.

56. Erickson BJ, Mascarenhas R, Sayegh ET, Saltzman B, Verma NN, Bush-Joseph CA, Cole BJ, Bach BR Jr. Does operative treatment of first-time patellar dislocations lead to increased patellofemoral stability? A systematic review of overlapping meta-analyses. Arthroscopy. 2015; 31(6):1207-15.

57. Sanders TL, Pareek A, Johnson NR, Stuart MJ, Dahm DL, Krych AJ. Patellofemoral arthritis after lateral patellar dislocation: a matched population-based analysis. Am J Sports Med. 2017;45(5):1012-7.

58. Buchner M, Baudendistel B, Sabo D, Schmitt H. Acute traumatic primary patellar dislocation: long-term results comparing conservative and surgical treatment. Clin J Sport Med. 2005;15(2):62-6.

59. Nikku R, Nietosvaara Y, Aalto K, Kallio PE. Operative treatment of primary patellar dislocation does not improve medium-term outcome: a 7-year follow-up report and risk analysis of 127 randomized patients. Acta Orthop. 2005;76(5):699-704.

60. Bitar AC, Demange MK, D'Elia CO, Camanho GL. Traumatic patellar dislocation: nonoperative treatment compared with MPFL reconstruction using patellar tendon. Am J Sports Med. 2012;40(1):114-22.

61. Hartmann F, Dietz S-O, Rommens PM, Gercek E. Long-term outcome after operative treatment of traumatic patellar dislocation in adolescents. J Orthop Trauma. 2014;28(3): 173-80.

62. Dall'Oca C, Elena N, Lunardelli E, Ulgelmo M, Magnan B. MPFL reconstruction: indications and results. Acta Biomed. 2020;91(4-S):128-35.

63. Mehta VM, Inoue M, Nomura E, Fithian DC. An algorithm guiding the evaluation and treatment of acute primary patellar dislocations. Sports Med Arthrosc Rev. 2007; 15(2):78-81.

64. Ronga M, Oliva F, Giuseppe Longo U, Testa V, Capasso G, Maffulli N. Isolated medial patellofemoral ligament reconstruction for recurrent patellar dislocation. Am J Sports Med. 2009;37(9):1735-42.

65. Bartsch A, Lubberts B, Mumme M, Egloff C, Pagenstert G. Does patella alta lead to worse clinical outcome in patients who undergo isolated medial patellofemoral ligament reconstruction? A systematic review. Arch Orthop Trauma Surg. 2018;138(11):1563-73.

66. Wang C-h, Ma L-f, Zhou J-w, Ji G, Wang H-y, Wang F, Wang J. Double-bundle anatomical versus single-bundle isometric medial patellofemoral ligament reconstruction for patellar dislocation. Int Orthop. 2013;37(4): 617-24.

67. Ahmad CS, Brown GD, Stein BS. The docking technique for medial patellofemoral ligament reconstruction: surgical technique and clinical outcome. Am J Sports Med. 20092009;37(10): 2021-7.

68. Cossey AJ, Paterson R. A new technique for reconstructing the medial patellofemoral ligament. Knee. 2005;12(2):93-8.

69. Deie M, Ochi M, Sumen Y, Adachi N, Kobayashi K, Yasumoto M. A long-term follow-up study after medial patellofemoral ligament reconstruction using the transferred semitendinosus tendon for patellar dislocation. Knee Surg Sports Traumatol Arthrosc. 2005;13(7): 522-8.

70. Nomura E, Inoue M. Surgical technique and rationale for medial patellofemoral ligament reconstruction for recurrent patellar dislocation. Arthroscopy. 2003;19(5):1-9.

71. Schöttle PB, Fucentese SF, Romero J. Clinical and radiological outcome of medial patellofemoral ligament reconstruction with a semitendinosus autograft for patella instability. Knee Surg Sports Traumatol Arthrosc. 2005; 13(7):516-21.

72. Steensen RN, Dopirak RM, Maurus PB. A simple technique for reconstruction of the medial patellofemoral ligament using a quadriceps tendon graft. Arthroscopy. 2005; 21(3):365-70.

73. Enderlein D, Nielsen T, Christiansen SE, Faunø P, Lind M. Clinical outcome after reconstruction of the medial patellofemoral ligament in patients with recurrent patella instability. Knee Surg Sports Traumatol Arthrosc. 2014;22(10):2458-64.

74. McNeilan RJ, Everhart JS, Mescher PK, Abouljoud M, Magnussen RA, Flanigan DC. Graft choice in isolated medial patellofemoral ligament reconstruction: a systematic review with meta-analysis of rates of recurrent instability and patient-reported outcomes for autograft, allograft, and synthetic options. Arthroscopy. 2018;34(4):1340-54.

75. Tanaka MJ, Chahla J, Farr J II, LaPrade RF, Arendt EA, Sanchis-Alfonso V, Post WR, Fulkerson JP. Recognition of evolving medial patellofemoral anatomy provides insight for reconstruction. Knee Surg Sports Traumatol Arthrosc. 2019;27(8):2537-50.

76. Baldwin JL. The anatomy of the medial patellofemoral ligament. Am J Sports Med. 2009;37(12):2355-61.

77. LaPrade MD, Kallenbach SL, Aman ZS, Moatshe G, Storaci HW, Turnbull TL, Arendt EA, Chahla J, LaPrade RF. Biomechanical evaluation of the medial stabilizers of the patella. Am J Sports Med. 2018;46(7):1575-82.

78. LaPrade RF, Engebretsen AH, Ly TV, Johansen S, Wentorf FA, Engebretsen L. The anatomy of the medial part of the knee. J Bone Joint Surg Am. 2007;89(9):2000-10.

79. Philippot R, Chouteau J, Wegrzyn J, Testa R, Fessy MH, Moyen B. Medial patellofemoral ligament anatomy: implications for its surgical reconstruction. Knee Surg Sports Traumatol Arthrosc. 2009;17(5):475-9.

80. Placella G, Tei MM, Sebastiani E, Criscenti G, Speziali A, Mazzola C, Georgoulis A, Cerulli G. Shape and size of the medial patellofemoral ligament for the best surgical reconstruction: a human cadaveric study. Knee Surg Sports Traumatol Arthrosc. 2014;22(10):2327-33.

81. Placella G, Speziali A, Sebastiani E, Morello S, Tei MM, Cerulli G. Biomechanical evaluation of medial patello-femoral ligament reconstruction: comparison between a double-bundle converging tunnels technique versus a single-bundle technique. Musculoskelet Surg. 2016; 100(2):103-7.

82. Kang H, Zheng R, Dai Y, Lu J, Wang F. Single- and double-bundle medial patellofemoral ligament reconstruction procedures result in similar recurrent dislocation rates and improvements in knee function: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2019;27(3): 827-36.

83. Shah JN, Howard JS, Flanigan DC, Brophy RH, Carey JL, Lattermann C. A systematic review of complications and failures associated with medial patellofemoral ligament reconstruction for recurrent patellar dislocation. Am J Sports Med. 2012;40(8):1916-23.

84. Hendawi T, Godshaw B, Flowers C, Stephens I, Haber L, Waldron S. Autograft vs allograft comparison in pediatric medial patellofemoral ligament reconstruction. Ochsner J. 2019;19(2): 96-101.

85. Mayer P, Schuster P, Schlumberger M, Eichinger M, Pfaff M, Immendörfer M, Richter J. Midterm results after implant-free patellar fixation technique for medial patellofemoral ligament reconstruction. J Knee Surg. 2020;33(11): 1140-6.

86. Stupay KL, Swart E, Stein BES. Widespread implementation of medial patellofemoral ligament reconstruction for recurrent patellar instability maintains functional outcomes at midterm to long-term follow-up while decreasing complication rates: a systematic review. Arthroscopy. 2015;31(7):1372-80.

87. Hvid I, Andersen LI, Schmidt H. Chondromalacia patellae: the relation to abnormal patellofemoral joint mechanics. Acta Orthop Scand. 1981;52(6):661-6.

88. Zhou J-W, Wang C-H, Ji G, Ma L-F, Wang J, Zhang F, Dong JT, Wang F. A minimally invasive medial patellofemoral ligament arthroscopic reconstruction. Eur J Orthop Surg Traumatol. 2014;24(2):225-30.

89. Hiemstra LA, Kerslake S, Kupfer N, Lafave M. Patellofemoral stabilization: postoperative redislocation and risk factors following surgery. Orthop J Sports Med. 2019;7(6): 2325967119852627.

90. Lippacher S, Dreyhaupt J, Williams SRM, Reichel H, Nelitz M. Reconstruction of the medial patellofemoral ligament: clinical outcomes and return to sports. Am J Sports Med. 20142014;42(7):1661-8.

91. Ma L-F, Wang F, Chen B-C, Wang C-H, Zhou J-W, Wang H-Y. Medial retinaculum plasty versus medial patellofemoral ligament reconstruction for recurrent patellar instability in adults: a randomized controlled trial. Arthroscopy. 2013;29(5):891-7.

92. Panni AS, Alam M, Cerciello S, Vasso M, Maffulli N. Medial patellofemoral ligament reconstruction with a divergent patellar transverse 2-tunnel technique. Am J Sports Med. 2011;39(12):2647-55.

93. Arendt EA, Dahm DL, Dejour D, Fithian DC. Patellofemoral joint: from instability to arthritis. Instruct Course Lect. 2014;63:355-68.

94. Mishra CB. Reconstruction of medial patellofemoral ligament for chronic patellar instability. Indian J Orthop. 2012;46:447-54.

95. Erickson BJ, Nguyen J, Gasik K, Gruber S, Brady J, Shubin Stein BE. Isolated medial patellofemoral ligament reconstruction for patellar instability regardless of tibial tubercle-trochlear groove distance and patellar height: outcomes at 1 and 2 years. Am J Sports Med. 2019;47(6):1331-7.

96. Liu JN, Brady JM, Kalbian IL, Strickland SM, Ryan CB, Nguyen JT, Shubin Stein BE. Clinical outcomes after isolated medial patellofemoral ligament reconstruction for patellar instability among patients with trochlear dysplasia. Am J Sports Med. 2018;46(4):883-9.

97. Franciozi CE, Ambra LF, Albertoni LJB, Debieux P, Granata GSdM, Kubota MS, Carneiro M, Abdalla RJ, Luzo MVM, Cohen M. Anteromedial tibial tubercle osteotomy improves results of medial patellofemoral ligament reconstruction for recurrent patellar instability in patients with tibial tuberosity–trochlear groove distance of 17 to 20 mm. Arthroscopy. 2019;35(2):566-74.

98. Farr J, Cole BJ, Kercher J, Batty L, Bajaj S. Anteromedial tibial tubercle osteotomy (Fulkerson osteotomy). In: Anterior Knee Pain and Patellar Instability. New York, NY: Springer; 2011:455-62.

99. Pidoriano AJ, Weinstein RN, Buuck DA, Fulkerson JP. Correlation of patellar articular lesions with results from anteromedial tibial tubercle transfer. Am J Sports Med. 1997;25(4):533-7.

100. DeFroda SF, Gil JA, Boulos A, Cruz AI Jr. Diagnosis and management of traumatic patellar instability in the pediatric patient. Orthopedics. 2017;40(5):e749-57.

101. Barber FA, McGarry JE. Elmslie–Trillat procedure for the treatment of recurrent patellar instability. Arthroscopy. 2008;24(1):77-81.

102. Fulkerson JP, Becker GJ, Meaney JA, Miranda M, Folcik MA. Anteromedial tibial tubercle transfer without bone graft. Am J Sports Med. 1990;18(5):490-7.

103. Payne J, Rimmke N, Schmitt LC, Flanigan DC, Magnussen RA. The incidence of complications of tibial tubercle osteotomy: a systematic review. Arthroscopy. 2015;31(9):1819-25.

104. Koeter S, Diks MJF, Anderson PG, Wymenga AB. A modified tibial tubercle osteotomy for patellar maltracking: results at two years. J Bone Joint Surg Br. 2007;89(2):180-5.

105. Mayer C, Magnussen RA, Servien E, Demey G, Jacobi M, Neyret P, Lustig S. Patellar tendon tenodesis in association with tibial tubercle distalization for the treatment of episodic patellar dislocation with patella alta. Am J Sports Med. 2012;40(2):346-51.

106. Allen MM, Krych AJ, Johnson NR, Mohan R, Stuart MJ, Dahm DL. Combined tibial tubercle osteotomy and medial patellofemoral ligament reconstruction for recurrent lateral patellar instability in patients with multiple anatomic risk factors. Arthroscopy. 2018;34(8):2420-6.e3.

107. Amis AA, Oguz C, Bull AMJ, Senavongse W, Dejour D. The effect of trochleoplasty on patellar stability and kinematics: a biomechanical study in vitro. J Bone Joint Surg Br. 2008;90(7):864-9.

108. Laidlaw MS, Feeley SM, Ruland JR, Diduch DR. Sulcus-deepening trochleoplasty and medial patellofemoral ligament reconstruction for recurrent patellar instability. Arthrosc Tech. 2018;7(2):e113-23.

109. Van Haver A, De Roo K, De Beule M, Labey L, De Baets P, Dejour D, Claessens T, Verdonk P. The effect of trochlear dysplasia on patellofemoral biomechanics: a cadaveric study with simulated trochlear deformities. Am J Sports Med. 2015;43(6):1354-61.

110. Lattermann C, Toth J, Bach BR Jr. The role of lateral retinacular release in the treatment of patellar instability. Sports Med Arthrosc Rev. 2007;15(2).

111. Arshi A, Cohen JR, Wang JC, Hame SL, McAllister DR, Jones KJ. Operative management of patellar instability in the United States: an evaluation of national practice patterns, surgical trends, and complications. Orthop J Sports Med. 2016;4(8):2325967116662873.

112. Insall J, Bullough PG, Burstein AH. Proximal "tube" realignment of the patella for chondromalacia patellae. Clin Orthop Relat Res. 1979(144):63-9.

113. Waaler PAS, Jellestad T, Hysing-Dahl T, Elvehøy E, Inderhaug E. Insall proximal realignment with/without tibial tubercle osteotomy for recurrent patellar instability yields acceptable medium- to long-term results but risk of osteoarthritis progression is considerable. J Exp Orthop. 2022;9(1):64.

114. Duchman KR, Bollier MJ. The role of medial patellofemoral ligament repair and imbrication. Am J Orthop. 2017;46(2):87-91.

115. Cox JS. An evaluation of the Elmslie-Trillat procedure for management of patellar dislocations and subluxations: a preliminary report. Am J Sports Med. 1976;4(2):72-7.

116. Sillanpää PJ, Salonen E, Pihlajamäki H, Mäenpää HM. Medial patellofemoral ligament avulsion injury at the patella: classification and clinical outcome. Knee Surg Sports Traumatol Arthrosc. 2014;22(10):2414-8.

117. Liu JN, Steinhaus ME, Kalbian IL, Post WR, Green DW, Strickland SM, Shubin Stein BE. Patellar instability management: a survey of the International Patellofemoral Study Group. Am J Sports Med. 2018;46(13):3299-306.