Diagnosis and Treatment of Patellofemoral Instability

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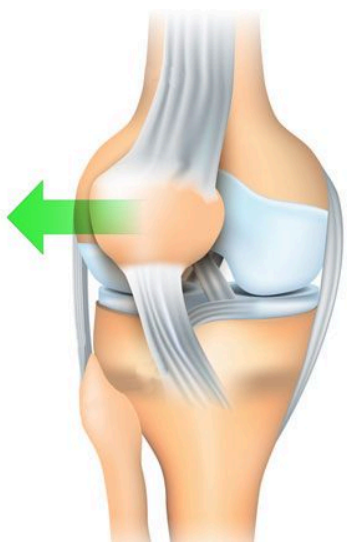

INTRODUCTION

FIGURE 1. LEFT; An anterior view radiograph of the left knee. The patella is dislocated laterally out of the femoral groove. The red arrow points to the patella. This is an example of patellar dislocation. RIGHT; A merchant view radiograph of the left knee showing lateral subluxation of the patella. In both cases the patella has moved in the lateral direction, towards the outside of the knee joint.

The patellofemoral joint (PFJ) is commonly injured in acute traumatic knee injuries. Patellar subluxation/dislocation often produces patellofemoral instability (PFI), which describes the abnormal tracking of the patella in the femoral groove during flexion and extension. Dislocation/subluxation of the patella in the medial or lateral plane accounts for about 3-4% of all traumatic knee injuries and accounts for up to 13% of knee hemarthrosis due to traumatic knee injury. Anterior Cuciate Liagament (ACL) injuries account for up to 70% of knee hemarthrosis, making patellar dislocation the second most common cause of hemarthrosis in knee injuries.[1,2,3,38,41,62]

Anatomy

The patella-femoral joint relies on dynamic and static stabilizers to maintain proper function. Understanding the basic anatomy of the knee is vital to comprehending its biomechanical function and the etiology of PFI.

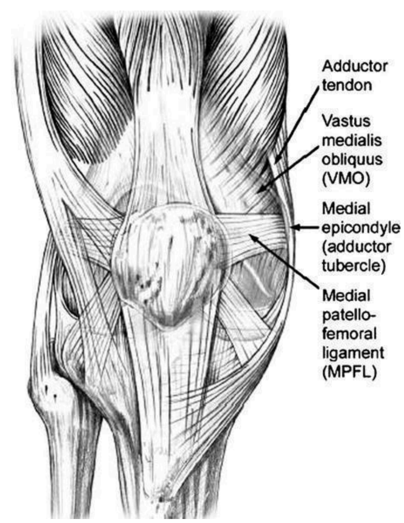

FIGURE 2. Anatomical diagram of the right knee with emphasis on the medial structures.

Dynamic stabilizers are structures capable of contraction and relaxation. Dynamic stabilization of the patella occurs through the vastus medialis obliquus (VMO). The VMO is one of the main contributors to medial stabilization of the patella-femoral joint.

Static stabilizers are structures that are stationary or fixed. Static stabilization occurs through the quadriceps tendon, the patellar tendon, and medial and lateral stabilizers. Medial static stabilizers are composed of the medial patellofemoral ligament (MPFL), the medial patellomeniscal ligament (MPML), the medial retinaculum, and the medial patellotibial ligament (MPTL). Lateral stabilizers are composed of the lateral patellofemoral ligament (LPFL), the joint capsule, the iliotibial band (ITB), and the lateral retinaculum. The quadriceps and patellar tendon insert into the apex and base of the patella, respectively, and support patellar stability in the vertical plane. Medial and lateral stabilizers support patellar stability in the horizontal plane. The femoral condyle, the tibial plateau, and the posterior patella are covered with hyaline articular cartilage, which provides cushioning and reduces friction during flexion and extension. Additionally, the medial and lateral menisci, which are two small crescent-shaped pads located at the medial and lateral tibial plateau, provide stability to the knee. The combination of these structures within the knee allow it to efficiently and safely move and carry out regular functions. The MPFL and VMO contribute significantly to the medial stability of the knee joint. The MPFL alone provides approximately 50-80% of the counteracting mechanism to patellar glide, or movement of the patella within the knee.[8] The MPFL connects the superomedial edge of the patella to the femur between the medial femoral epicondyle and the adductor tubercle (Fig. 2).

Etiology

Approximately 6.6 million knee injuries have been presented in the United States Emergency Departments from 1999 to 2008, with an estimated 260,000 cases of patellar subluxation or dislocation.[2] Most occurrences are sustained during physical or sports activity. Two-thirds of the cases include patients under 20 years of age.[3] Patellar subluxations and dislocations are most common in the 15-24 age group and decrease with age.[2] Among the general population, the average annual incidence among first occurrences is about 5.8 per 100,000. The incidence increases to about 29 per 100,000 cases with younger individuals in the 10-17 age group, possibly due to increased activity levels and participation in sports.[4] Sports with a high incidence of patellofemoral injuries would be those involving planting and twisting motions, such as volleyball, soccer, basketball, and football. In this group aged 10-17 years old, females have been found to be at the highest risk.[1,4,6,66] Females between the ages of 10-17 have been reported to have a 36.8% chance for recurrent dislocation at a10 10-year follow-up after their initial patellar dislocation event.[66]

The mechanism of these injuries often involves injury to supporting patellar structures such as the medial patellofemoral ligaments (PFL), the patellomeniscal ligaments (PML), or patellotibial ligaments (PTL), or the medial or lateral retinaculum (Fig. 2). Non-contact active knee injuries in flexion and valgus is the leading mechanism in lateral patellar dislocation, accounting for as many as 93% of all cases.[3] The medial patellofemoral ligament (MPFL) is the most commonly disrupted ligament in patellar subluxation and dislocation events.[9–15] Other less common mechanisms may include external rotation of the tibia with the foot firmly fixed or planted on the ground, in a very similar fashion, which may result in increased stress on medial stabilizers.[3] The exact etiology of medial subluxation and dislocation events is not well understood. It is thought to arise iatrogenically following surgical intervention in a lateral subluxation or dislocation event such as lateral retinaculum release, detachment of the vastus lateralis from the patella, prior medial tibial tubercle transfer, and an overly tight and/or malpositioned MPFL graft.[16]

Injury to the articular cartilage that incorporates the undersurface of the posterior aspect of the patella is also common with subluxation and dislocation. Oftentimes, osteochondral fractures may result from subluxation and dislocation events. Osteochondral fractures are most common on the inferomedial patellar surface as compared to the femoral or tibial surfaces.[17–20] This is most likely the result of the impact of the inferomedial patella against the lateral femoral condyle during lateral dislocation.[19]

Repetitive patellar subluxation or dislocation events often result in an increased risk of recurrence or occur in the setting of pre-existing PFI, which will often warrant surgical management due to the heightened risk of recurrence. Fithian et al. have found the dislocation/subluxation rate to be 6.6 times more likely in patients with a history of prior dislocation/subluxation.[4] Gravesen et al. performed a Danish nationwide epidemiological study and reported the risk of a recurrent dislocation in the affected as being 22.7% and in the contralateral knee as 5.8%.[66] Zhang et al. described the rate of lateral patellar dislocation as being 35.5% (59 of 166 patients) in patients with a prior patellofemoral injury.[62] Some of the anatomical factors contributing to PFI include patella alta, large sulcus and congruence angles affecting the bony constraints on the patella, large Quadriceps angles, lateralized tibial tuberosity, subtalar ankle joint pronation (which create valgus knee positioning), ligament hyperlaxity, and weakness of the vastus medialis obliquus (VMO). Zhang et al. have found through their prospective study that there were anatomical defects as noted above in 95% of patients who suffered a first-time lateral patellar dislocation and in 100% of patients who suffered a second-time lateral patellar dislocation after being treated conservatively.[62] Huntington LS et al. described the recurrence after a first-time dislocation event as being 33.6%, upon reviewing 17 studies.[92] Thus, management of these conditions often involves a mix of physical therapy and multifaceted surgical approaches due to anatomical variants.

Injury to one or more of the supporting structures at the patellofemoral joint may lead to PFI. PFI may result in patellar subluxation or dislocation, of which three types have been described: primary, recurrent, and habitual. Primary refers to the first occurrence, whereas recurrent refers to subsequent occurrences following a primary event, and habitual refers to ongoing recurrent occurrences that are not directly resulting from iatrogenic or traumatic injury.[5] Primary events are commonly traumatic in nature. Recurrent and ongoing events are usually the culmination of several abnormal anatomical factors. Patellar translation most often occurs in the lateral direction and, unless specified, usually refers to a lateral patellar translation event, which is due to medial stabilizer lesions following traumatic lateral knee injury. Medial translation is less common, usually iatrogenic in nature, and is more common in the case of recurrent patellar subluxation or dislocation.[2] Intra-articular translation, which involves movement of the patella vertically within the patellofemoral joint, is even less common as compared to medial ligament disruptive events.[8]

MECHANISM OF INJURY

Subluxation and Dislocation

The specific mechanism of injury can vary widely. A non-contact knee sprain in flexion and valgus is the leading mechanism in lateral patellar dislocation, accounting for as many as 93% of all cases.[3] When the knee is flexed and in valgus (which is deviation to the outside, lateral), there is additional stress on medial stabilizers, and direct trauma to the knee can lead to the disruption of these medial stabilizers.[3] The MPFL is a significant contributor to medial patellar stability, and as such, a tear or sprain of this ligament will likely lead to lateral patellar translation. The MPFL is the most commonly disrupted ligament in patellar subluxation and dislocation events.[9–15] Other less common mechanisms may include external rotation of the tibia with the foot firmly fixed or planted on the ground, in a very similar fashion, which may result in increased stress on medial stabilizers.[3] The exact etiology of medial subluxation and dislocation events is not well understood, though it is thought to arise iatrogenically following surgical intervention for a lateral subluxation or dislocation event; lateral release, detachment of the vastus lateralis from the patella, prior medial tibial tubercle transfer, or an overly tight and/or malpositioned MPFL graft.[16]

Patellar Osteochondral Fractures

Injury to the articular cartilage that surrounds the posterior aspect of the patella is also very common with subluxation and dislocation. Oftentimes, osteochondral fractures may result from subluxation and dislocation events. Osteochondral fractures are most common on the inferomedial patellar surface as compared to the femoral or tibial surfaces.[17–20] This is most likely the result of the impact of the inferomedial patella against the lateral femoral condyle during lateral dislocation.[19]

RISK FACTORS

Several risk factors have been described in the occurrence and recurrence of PFI. They are often anatomical in nature, but certain lifestyle factors are also commonly implicated. Primary and recurrent PFI have been associated with risk factors such as: patella alta, abnormal sulcus and congruence angle and trochlear dysplasia, quadriceps-angle, lateralized tibial tuberosity, genu valgum, external tibial torsion, increased femoral anteversion, associated VMO hypoplasia, ligament hyperlaxity, subtalar joint pronation, height and weight, and abnormal patellar tracking.[1,3–6,8,12,21–29] Demographic and lifestyle factors also play a role in the occurrence of PFI. Those age 20 and younger, women, and athletes who participate in basketball, soccer, and football are more prone to instances of PFI.[30] Additionally, those with a prior history of dislocations or have family with a history of patellar dislocations will be at a higher risk of future dislocations.[1,4,39,60]

Patellar Height

Patellar height has been correlated with various clinical conditions that affect PFJ function (Fig. 3). The patella is commonly referred to as patella alta when it sits higher in the patellofemoral joint and, upon flexion, does not engage as fully within the femoral groove. This is more common in women and has been associated with a higher risk of patellofemoral instability and chondromalacia.[4,31,32] A decrease in patellar height, such that the patellar sits lower in the femoral groove, is referred as patella baja. Patella baja is associated with a higher risk of patellofemoral osteoarthritis, Osgood-Schlatter disease, and a limited range of motion of the knee due to increased reactive forces on the knee, i.e. compressive forces.[4,31,32]

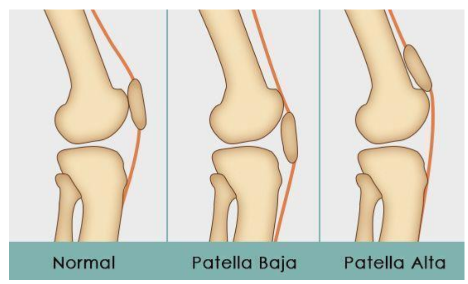

FIGURE 3. Anatomical side view of normal, low, and high patellar height.

Sulcus and Congruence Angle

The sulcus angle is a measure of the concavity of the femoral condyle in the knee joint and is often used to diagnose trochlear dysplasia. It is measured by drawing a line from the lateral and medial condyles to the intercondylar sulcus on a merchant view axial radiograph. Larger angles are associated with more severe trochlear dysplasia, which is characterized by a shallow trochlear groove, which can lead to disengagement of the patella.[3,4,6,33] Congruence angle is a test of patellar alignment within the femoral condyle and is measured by taking the angle between the patellar articular ridge to the intercondylar sulcus on a merchant view radiograph (Fig. 4). Congruence angles larger than 16 degrees lateral subluxation are abnormal among the general population, and angles larger than 12 degrees lateral subluxation have been previously associated with a higher risk of first time or recurrent PFI.[4,33]

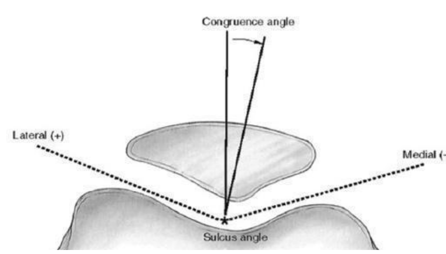

FIGURE 4. Anatomical merchant view drawing of the left knee depicting measurements of congruence and sulcus angle.

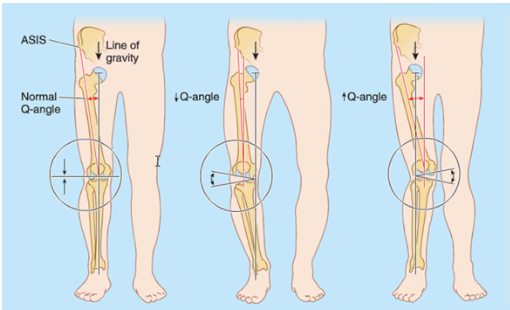

FIGURE 5. An anterior view of the measurement of Q-angle. A line is drawn from the anterior superior iliac spine through the patella and forms an angle with a line through the center of the patella and the tibial tuberosity. Increase of Q-angle is associated with genu valgum (knock-knees), decreased Q-angle is associated with genu varum (bow-legged).

Quadriceps-angle and Lateralization of the Tibial Tuberosity

Quadriceps-angle, or Q-angle, is the angle formed by the intersection of lines drawn from the anterior superior iliac spine to the center of the patella, and through the center of the patella to the tibial tuberosity (Fig. 5). Women commonly have larger Q-angles than men, 17 degrees and 12 degrees respectively, with larger angles being associated with excessive lateral pull on the patella.[3,4,6,34] Lateralization of the tibial tuberosity also pulls the patella laterally during flexion and has been associated with increases in Q-angle and lateral PFI (Fig. 6).[3,4,6,34] Genu valgum, or knock-knee, is commonly diagnosed through measuring Q-angle and is associated with higher Q-angles, external tibial torsion, and femoral anteversion.[2,5,25] External tibial torsion, or duck-footedness, is outward rotation of the tibia and fibula from the PFJ, while femoral anteversion is inward rotation of the femur about the PFJ. Increased Q-angle and femoral anteversion are more common in women.[6,30,34]

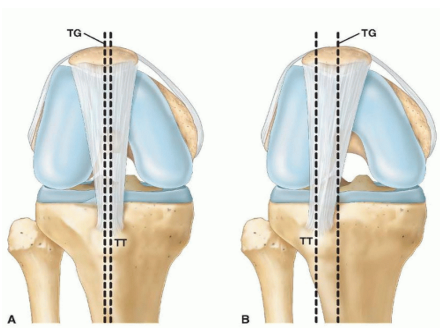

FIGURE 6. Normal tibial tuberosity versus lateralized tibial tuberosity on the right. Lateralized tibial tuberosity is associated with increased Q-angle and genu valgum.

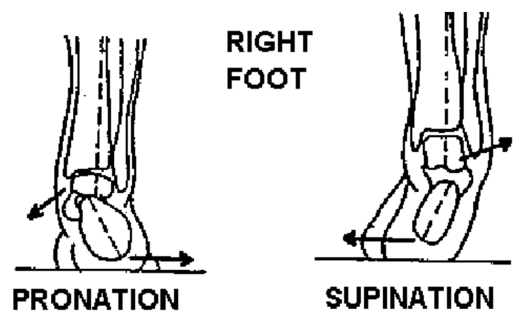

FIGURE 7. Normal tibial tuberosity versus lateralized tibial tuberosity on the right. Lateralized tibial tuberosity is associated with increased Q-angle and genu valgum.

VMO, Ligament Hyperlaxity, and Subtalar Joint Pronation

VMO hypoplasia has also been associated with lateral PFI, and recent literature has implicated VMO atrophy in the pathophysiology of PFI.[4,6,35] The VMO plays an important role in the stability of the PFJ, particularly in regard to patellar glide, patellar tilt, and force exerted laterally on the patella.[35] Ligament hyperlaxity is when a ligament is too loose or weak, and in the case of the PFJ, familial laxity has been closely associated with PFI.[4,8,25,36] Subtalar joint pronation, outward movement of the ankle relative to the foot, is associated with lateral PFI (Fig. 7).[3,4,6] Taller height and higher weight have also been associated with the occurrence of PFI among Finnish male conscripts.[3]

TREATMENT

A dislocated patella should be reduced by extending the knee and applying force opposite to the direction in which the patella is dislocated.[6,37,41] Treatment is determined in the initial evaluation of a patellofemoral injury by conducting a physical examination, assessing the history of patellar dislocation and hyperlaxity, and performing diagnostic studies.[1,37,38] Anatomical factors such as the Q-angle and patella alta should be assessed during a physical exam. The contralateral knee, in addition to the injured knee, should be evaluated to identify hyperlaxity or anatomical differences. Hyperlaxity in the contralateral knee is a helpful diagnostic tool as it is linked with a higher probability of articular lesions.[59] Palpation may also show signs of soft-tissue damage in the surroundings of the knee joint. Positive signs upon palpation may be used as early diagnostic tools when choosing between operative and nonoperative treatment, although diagnostic studies will always be necessary before choosing operative treatment.

X-rays and CT are always obtained in patients to assess for bony pathology.[6,69] X-ray is particularly useful for assessing osteochondral fractures and the degree of dislocation. CT is often most useful with reconstruction views, which help evaluate the patella-femoral position in the trochlear groove and present a three-dimensional model of the joint. Finally, an MRI is often obtained to assess the integrity of soft tissue stabilizers, particularly the MPFL, and to rule out other potential injuries.[1,4]

In patients with moderate-to-severe effusion, aspiration of the knee joint should be considered, as hemarthrosis is very common with patellar subluxation/dislocation injuries.[38] A larger hemarthrosis volume and fatty globules is associated with a major acute traumatic patellofemoral injury and an osteochondral fracture.[3,6,38,40] Additionally, patients may be given analgesic or anesthetic agents to conduct a physical exam and diagnostic studies without pain and discomfort and to improve image fidelity.[1]

Treatment for patellofemoral injury varies between surgical and non-surgical. Initial patellar dislocations are typically managed conservatively. The following indications which may warrant surgical intervention: (1) first time dislocation with osteochondral fracture or loose body, (2) first time dislocation in presence of anatomical risk factors which make re-dislocation likely, (3) subluxed patella on merchant view radiograph when compared to contralateral knee, (4) failure to improve with conservative measures, (5) recurrent dislocations, and (6) imaging demonstrating disrupted MPFL. Redislocation rates for conservative and surgical treatment vary between 20-60%.[4] A review study by Tsai CH et al. found redislocation rates to be 10-30% after surgical treatment and 13-53% after nonsurgical treatment.[37] Sillanpää et al. suggest early surgical stabilization due to reductions in re-dislocation, although in the absence of any clear subjective long-term benefit.[63]

Zhang et al. found that ultrasound imaging may provide accurate results in identifying a torn MPFL.[70,71] While this is not common practice as MRIs offer a more detailed image, it may be considered for patients that would struggle undergoing an MRI.

Conservative Treatment:

Conservative treatment for patellofemoral instability (PFI) includes closed reduction of any dislocation followed by immobilizing the knee joint. Immobilization typically utilizes a motion-restricting or a neoprene non-hinged knee brace for 3-4 weeks, with early weight bearing.[3,37-41] Early mobilization is important in maintaining joint cartilage blood flow; as such, the immobilization period should not be prolonged.[6,69] After allowing soft tissue structures time to heal, patients should begin strengthening the VMO, as it is a natural patella stabilizer.[39,40] Once patients feel they are capable, they will begin to strengthen the muscles in the quadriceps with single-plane exercises while avoiding any twisting motion or the mechanism of their injury to avoid hindering recovery.[69] Although there is relative agreement in VMO strengthening post-dislocation, there is evidence that post-injury physical therapy is mandatory and indicated to return to normal strength at the knee joint.

Once conservative treatment has been exhausted and the patient has experienced recurrent lateral PFI, medial patellofemoral ligament reconstruction is the preferred method, as lateral patellar dislocation is a common acute disorder leading to lateral PFI.[61] Other surgical indications include a displaced osteochondral fracture or the presence of a loose body after a dislocation event, recurrent dislocations, a disrupted or ununited MPFL shown through an MRI, etc.[37] With surgical intervention after recurrent patellar dislocation or a traumatic knee injury, the goal is to reconstruct static stabilizers and the dynamic stabilizers found at the knee such as the MPFL and the VMO, respectively.

Surgical Treatment:

Surgical treatment for patellofemoral instability includes several different techniques depending on the extent of injury to bony structures, fracture pattern, and whether soft tissue structures are injured. After reviewing the literature, there is not a "one-size-fits-all" surgical technique. Surgeons will choose between varying grafts, bundle techniques, patellar/femoral fixation, and tensioning techniques.[42-55,57] However, seeing as how the medial patellofemoral ligament is injured in almost all primary lateral patellar dislocation events, it is almost always addressed when treating unstable patellofemoral injuries operatively.[6,57] However, an MPFL tear is seldom the only issue needing to be addressed in these cases and often occurs concurrently with osteochondral fractures or in the presence of anatomical deficiencies.

There is rarely an immediate need for surgery following a patellar dislocation event. However, surgery is indicated after conservative treatment has already failed or when there are clear surgical indications present following the first dislocation event. Surgical indications are determined through X-rays, MRIs, and CT scans, where physicians will look for defects in the structure of the patella and surrounding ligaments, which may be affected during a traumatic injury of the knee.[6,41]

Tibial Tubercle Osteotomy:

Tibial tubercle osteotomies are performed to address the defects in the tibial-trochlear groove, such as patella alta or increased tibial tubercle-trochlear groove (TT-TG) distance. The following three studies performed tibial tuberosity osteotomies in conjunction with medial patellofemoral reconstruction when indicated.[6,40,42-44] Patella alta is found in knees where the patella is sitting superior to its anatomical position on the patellar groove. An increased TT-TG distance is found to cause lateralization of the patella, which may cause an increased risk of lateral patellofemoral injuries.[34]

A 2016 publication by Kang et al. compared the effectiveness of MPFL reconstruction with two different graft tensioning techniques, the self-balance (SB) technique and the arthroscopy-view (AV) technique.[42] In this study patients were excluded based on: 1) previous knee injuries, 2) trochlear femoral angle greater than 150 degrees, 3) patella alta, 4) an Outerbridge class III or IV used to measure damage to the patellofemoral chondral surfaces, and 5) meniscal or tibial-femoral ligament injury requiring repair or reconstruction. For all patients, a semitendinosus tendon autograft was harvested and two suture anchors were fixed at the superomedial corner and midpoint, medial patella, and fixed distally between the adductor tubercle and the medial epicondyle using an interference screw.

The arthroscopy-view graft tensioning technique allows for direct visualization of the graft. The surgeon tensions the graft by ensuring the patella remains centered during the first 30° of knee flexion. In the self-balance technique, the surgeon observes graft tension, patellar tracking, and femoral graft friction forces from full extension to 90 degrees of flexion, fixing the graft at 30 degrees of flexion.

The self-balance technique seems like a much more comprehensive technique than the arthroscopy-view technique, where the surgeon will fix the graft at 30 degrees of flexion without observing prior knee flexion and extension. This study found similar results in both groups of patients who had undergone MPFL reconstruction, while there were three patients who reported postoperative apprehension, and there were no incidents of re-dislocation reported in this study. We would also like to point out that although this study excluded many patients who displayed what are considered the typical surgical indications, they included patients with a tibial tuberosity to trochlear groove distance (TT-TG) equal to or greater than 20 mm. In these cases, patients underwent a tibial tuberosity medialization using Elmslie-Trillat's technique (a common technique used to medialize the tibial tubercle to help align the patellar tendon to an anatomically correct position as it relates to the tibia) prior to MPFL reconstruction.[76] Additionally, a lateral retinacular release was performed on patients demonstrating tightness of the lateral structures with a positive patellar tilt test under anesthesia.

A 2014 publication by Enderlein et al. reported less convincing results. To repair the MPFL, surgeons utilized a gracilis tendon autograft harvested from the PES anserinus passed through the medial and proximal patella with two bone tunnels, fixed at the anatomic Schöttle's point (radiographically identified at the medial femoral condyle) using an interference screw, and lightly tensioned at 30 degrees.[43,77] This study consisted of 224 patients, of which 51 underwent a tibial-tubercle osteotomy to address their increased tibial tuberosity trochlear groove. A limitation we found in this study was the lack of outcome measures. A possible explanation for the high rates of pain and redislocation in this study was the bone tunneling technique used to fix the tendon graft and the fact that 70% of patients demonstrated trochlear dysplasia preoperatively, respectively. Additionally, the patient population in this study differs from most other studies. We have observed other studies excluding patients with a history of prior surgery, while 33% of patients in this study had undergone a prior knee surgery.[42,44,46,47,52,53]

A 2014 publication by Berruto et al. performed distalization of the anterior tibial trochlear tuberosity when indicated. Berruto et al. selected patients where the Caton-Deschamps Index measured on sagittal X-ray views were > 1.2 (8 knees). Medialization of the anterior trochlear tuberosity was indicated in cases where the TT-TG was measured to be > 20 mm using CT (5 knees), and lateral retinacular release was indicated upon conducting the patellar tilt test (16 knees).[44] To repair the MPFL surgeons utilized a biosynthetic second-generation LARS R69400 graft fixed at the patella through bone tunnels, sutured at the lateral side and brought back through the patella and fixed with an interference screw in Schöttle's point at the femur, and tensioned "lightly" at 30 degrees of knee flexion.[44] While this was a smaller study, the follow-up at 40.6 months demonstrated a significant improvement in Kujala scores (a screening instrument utilized to measure patellofemoral pain, with a higher score indicating higher function and less pain) from 57 ± 8.4 pre-operative to 84.3 ± 10.2 post-operative and no redislocation.[75]

Table 1: A comparison between clinical studies conducting tibial tubercle osteotomies in conjunction with medial patellofemoral ligament reconstructions.

Article	Open vs Closed Surgery	Brief study description	Sample size at follow-up	Duration of follow-up	Post-op recurrence	Post-op apprehension	Patient reported outcome measures	Graft Type	Study conclusions
Kang et al. (2016)	Open	Elmslie-Trillat's technique performed to correct TT-TG > 20mm. Comparison between two graft tensioning techniques, the self-balance and the arthroscopy group.	23 in Self-balance 25 in Arthroscopic-view	24 months	SB: 0 AV: 0	SB: 2 AV: 1	N/A	Semitendinosus https://link.springer.com/article/10.1007/s40279-021-01494-tendon autograft	The author suggests the S.B. technique is a good alternative to the graft tensioning techniques
Enderlein et al. (2014)	Open	Distal realignment performed in patients with elevated TT-TG distance.	97%	41 months	4.6% redislocation 3.2% revision surgeries 39% had one or more episodes of instability No patellar fractures seen.	14%	N/A	Gracilis tendon autograft	The author suggests that MPFL reconstruction is a safe and effective procedure to address recurrent patellar instability. In their study, they compared isolated MPFL reconstruction to

									reconstruction + tibial tubercle osteotomy and reported similar outcomes.
Berruto, et al. (2014)	Open	Biosynthetic graft for MPFL repair in conjunction with the distalization or medialization of the anterior tibial tuberosity, and lateral retinacular release when indicated	18	40.6 months	0	0	88 patient satisfaction	LARS R69400 graft (synthetic)	The author suggests the LARS biosynthetic ligament is a viable graft option for MPFL repairs and associated MPFL repairs

Lateral Retinacular Release:

The use of the lateral retinacular release (LRR) in conjunction with MPFL reconstruction is widely observed in the literature. However, the role and efficacy of this technique remain unclear and are the subject of discussion.[40,58] Among the fifteen studies reviewed, there were four that performed an MPFL reconstruction combined with a lateral retinacular release.[45,46,47,51] In four of those studies, the LRR was the only combined intervention technique alongside the MPFL reconstruction.[45,46,47,51]

A 2018 publication conducted by Sim JA et al. tested using an adjustable length loop device to insert a semitendinosus autograft onto the patella and femur. Surgeons harvested a semitendinosus tendon autograft and double-bundled the tendon using the adjustable length loop device. It was then fixed at the proximal margin and center of the patella using suture anchors. A tunnel was made at Schöttle's point, and the button of the adjustable loop device was pulled through to the lateral femur. Once the button was fixed, the surgeon tensioned the graft by manual traction of the sutures while putting the knee joint through a full range of motion.[45] This surgical procedure yielded results comparable to other studies with small sample sizes. With a mean follow-up time of 28.8 months, they did not report any postoperative cases of patellar instability or signs of postoperative apprehension.

A 2019 publication by Malatray M et al. compared the outcome measures between an isolated MPFL reconstruction group and a lateral retinacular release + MPFL group. Patients in this study were selected if they had knee cases where anatomical defects were not identified; they were split among the experimental groups randomly. Surgeons in this study harvested a gracilis tendon autograft and shaped it into a “Y”. Both free ends of the Y-shaped graft were passed through one of two 4.5 mm bone tunnels on the medial border of the patella before suturing the ends of the graft onto itself. The bone tunnel in this study did not pass through the width of the patella. Instead, the graft exits through the anterior aspect of the patella. The other end of the graft is fixed onto Schöttle's point using an interference screw. The LRR in this study was performed prior to the MPFL reconstruction when the arthroscopic exploration took place. The release was performed along the entire length of the lateral retinaculum. This study concluded that outcomes were not statistically different in IKDC scores, a screening instrument utilized to measure patellofemoral pain, with a higher score indicating higher function and less pain and patellar tilt angle.[46, 91] This study, however, did not include many outcome measures other than the IKDC scores.

A 2016 publication by Khemka et al. sought to study the efficacy of the lateral retinacular release in combination with MPFLR utilizing LARS, Ligament, CORIN Ltd, Mersilene Tape MT, or AchilloCordPLUS Ligament, Neoligaments, which are artificial ligaments. All MPFL repairs were performed in conjunction with a lateral retinacular release. A double-bundle MPFL graft was attached to the patella using an endobutton and onto Schöttle's point using interference screws. A Through Tunnel Technique was performed by drilling through the patella and at the anatomical attachment of MPFL on the femur. The MPFL graft was passed through the lateral opening of the patella and through the medial opening of the femur, it was fixed onto the lateral patella with an endobutton and onto the lateral femur with a peel screw. The graft was tensioned under full extension.[47] During this study, surgeons opted out of utilizing the LARS biosynthetic graft as it was associated with a prominence over the medial condyle in two knees. Surgeons decided to utilize Mersilene Tape for the remaining knees. However, some complications were similar to those associated with the LARS biosynthetic graft, so they decided that AchilloCord^{PLUS} should be used subsequently. Results in this study are promising and support the use of an artificial ligament, although there were not many outcome measures utilized in this study.

A 2021 publication by Xu J.-c. et al. performed MPFL reconstruction using FiberTape in conjunction with lateral retinacular release on patients with primary patellar dislocations who failed nonoperative treatment. All procedures in this study were conducted with a lateral retinacular release prior to MPFL reconstruction. Surgeons utilized a FiberTape synthetic suture tape fixed at the patella through a bone tunnel and onto Schöttle's point on the femur with a 4.75-mm knotless anchor (SwiveLock; Arthrex). For tensioning, an adjustable loop was utilized on the femur side, which is convenient for adjusting the tension of the FiberTape when it is fixed onto the knee at 30 degrees of flexion. A curved hemostat was placed under the FiberTape before fixation to avoid over-tensioning. There was one dislocation event at follow-up and two patients showing positive apprehension signs. It should be noted that one patient suffered re-dislocation, one patient suffered loss of fixation 6 months post-operatively, four patients had a prominence of the ligament over the medial femoral condyle, and one patient experienced anterior knee pain post-operatively. This study is looking at a newer method of MPFL repair using synthetic material to reconstruct the medial patellofemoral ligament. The benefits of this method include its stiffness and resistance to elongation, the fact that tendon harvesting is unnecessary, and the risk of donor rejection. Conversely, disadvantages include the stiffness of the tape; it does not stretch over time like grafts, therefore it is necessary to be cautious of excessive tensioning.[51]

Table 2: A comparison between clinical studies conducting lateral retinacular release in conjunction with medial patellofemoral ligament reconstructions.

Article	Open vs Closed	Brief study description	Sample size at follow-up	Duration of follow-up	Post-op recurrence	Post-op apprehension	Patient reported outcome measures	Graft Type	Study conclusions
Sim et al. (2018)	Closed	Two-point insertion of the double-bundle graft alongside LRR when indicated	12	28.8 months	0	0	N/A	Semitendinosus autograft (double bundle)	The author suggests that fixating the double-bundle graft onto the patella and femur using an adjustable-length loop achieves proper graft fixation
Malatray et al. (2019)	Closed	Blind randomized trial to compare the outcomes in isolated MPFLR with and without LRR. Arthroscopy exploration prior to all surgical procedures. Y-shaped gracilis autograft fixed onto the femur. Both free ends of the Y-shaped graft were passed through one of the two tunnels in the patella before wrapping back around the patella and being secured onto itself.	LRR: 17 NO LRR: 16	24 months	0	0	N/A	Gracilis tendon autograft	In this study the author suggests there is no evidence supporting lateral retinacular release in association with MPFL reconstruction.
Khemka et al. (2016)	Closed	Arthroscopy performed prior to all surgeries to remove any loose bodies or intra-articular pathologies and release the lateral-retinaculum in all patients. This was followed with an MPFL reconstruction utilizing an artificial ligament.	31	43 months	1	4	N/A	LARS Ligament (synthetic)	The author suggests that utilizing an artificial graft for the MPFL reconstruction offers a minimally invasive procedure with acceptable results. Results included 1 knee suffering re-dislocation and 4 knees with low persistence of apprehension.

Xu, J.-c. et al. (2021)	Closed	Arthroscopy performed prior to all surgeries to visualize the knee and release the lateral retinaculum in all patients. This was followed with an MPFL reconstruction utilizing an artificial ligament.	17	Avgerage: 14 months	1 at 12-month follow-up	2	N/A	FiberTape (synthetic)	The author suggests that utilizing an artificial ligament as the graft for an MPFL reconstruction yields similar results to other methods and is minimally invasive.

Trochleoplasty:
We found two studies where variations of the Bereiter technique (a classic technique utilized to deepen the tibial trochlear groove to allow better patellofemoral tracking) for a sulcus deepening trochleoplasty to correct trochlear dysplasia were conducted along with an MPFL reconstruction.[59,60,78]

A 2014 publication by Banke et al. combined sulcus-deepening and lateralizing trochleoplasty with MPFLR to correct anatomical pathologies that are commonly observed in PFI. Surgeons harvested an autologous gracilis tendon graft. Utilizing the double-bundle technique they attached the graft to the patella using two bioresorbable interference screws and to the anatomic point on the femur using one bioresorbable interference screw.[59] The graft was tensioned at 30 degrees of knee flexion. This study demonstrated an overall improvement in 17 patients after 30.5 months +/- 5.9. Limitations in this study included small sample groups, a short follow-up, and no operative control group being observed. Conservative treatment noted to fail.

A 2017 publication by von Engelhardt et al. performed a modified Bereiter technique in combination with an MPFL reconstruction. Surgeons in this study performed an extensive procedure where the groove in which the patella sits in is deepened utilizing a chisel and a high-speed burr.[60] As opposed to the traditional Bereiter technique, the trochlear groove was approached medially to avoid the saphenous nerve. The MPFL is reconstructed once the patella has been given added bony-stabilization. Surgeons harvested a gracilis tendon graft and inserted it into a V-tunnel drilled into the medial patella and attached the other end of the graft onto Schöttle's point.[60] This surgery attempts to avoid over-tensioning the MPFL by not inserting any hardware into the bone or joint and by testing out the motion of the joint prior to permanently fixing the graft. It seems the success in this study was partly due to the modified Bereiter technique they employed, which is meant to deepen the groove in which the patella sits on. In this study, the graft was temporarily fixed at 30 degrees of flexion; after testing and balancing the graft, it was permanently fixed. This study yielded promising results: in 33 knees, there were no postoperative apprehension signs, subluxations, or dislocation at mean follow-up of 29 +/- 23 month,s and the majority of patients who were active prior to surgery returned to sports after the surgery.[60]

Table 3: A comparison between clinical studies conducting trochleoplasties in conjunction with medial patellofemoral ligament reconstructions.

Article	Open vs Closed	Brief study description	Sample size at follow-up	Duration of follow-up	Post-op recurrence	Post-op apprehension	Patient reported outcome measures	Graft Type	Study conclusions
Banke et al. (2014)	Open	Trocheoplasty performed in patients with recurring PFI demonstrating a flat/convex trochlea.	17 patients/ 18 knees	30.5 +/- 5.9 months	0	0	One patient reported being unsatisfied with this procedure	Gracilis tendon autograft	The author in this study suggests this procedure should be considered in patients with recurrent patellar dislocations caused by anatomical defects at the trochlear groove.
von Engelhardt et al. (2017)	Open	Deepening trochleoplasty performed in all patients, followed up with an MPFL reconstruction.	30 patients/ 33 knees	29 +/- 23 months	0	0	Two patients reported persistent avoidance behavior. Two patients reported dissatisfaction with the outcome. Four patients reported increased pain at follow-up. 26 of 33 cases returned to sports or regular physical activity, of the patients who did not return there was a mix between those demonstrating avoidance behavior and those who found their sports were too strenuous to return to play.	Gracilis tendon graft	The author in this study suggests that trochleoplasty procedures to address anatomical defects in the trochlear groove have better outcomes when performed with an associated MPFLR.

Isolated Medial Patellofemoral Reconstruction:

Four studies evaluated the efficacy of MPFL reconstruction without performing an additional procedure.[50,52,53,54] These studies were mainly:

A 2014 publication by Lippacher et al. chose to perform isolated MPFL reconstruction in patients demonstrating recurrent dislocation after being treated non-operatively. This study chose to exclude cases where anatomical deformities were found and surgically repaired. Surgeons harvested a gracilis tendon autograft which was inserted into the V-shaped tunnels drilled into the superomedial portion of the patella, allowing the graft to loop through the patella. A tunnel was drilled into the femur at Schöttle's point and the loose ends of the graft were inserted into the tunnel and fixed with a bioresorbable interference screw. This study analyzed the ability of patients to return to sports 2 years post MPFL repair utilizing a gracilis tendon graft. Of the 62 participants who played sports pre-injury, all were able to return to sports post-surgery. Of the participants who returned to sport, only 53% returned to the same level of intensity. It should be noted that this study was looking at a younger population (Average age 18.4). Persistent instability occurred in 7 of the 72 knees, and 24 out of 72 reported loss of knee flexion.[50]

A 2019 publication by Peter G. et al. performed isolated MPFL reconstruction in patients with recurrent patellar dislocation, an MRI-verified MPFL tear, and an anatomically normal knee. Surgeons harvested a quadriceps tendon autograft, which was left attached at the proximal pole of the patella. The quadriceps tendon autograft was flipped 90 degrees at the proximal pole of the patella and passed through the medial prepatellar periosteum, then between the joint capsule and the VMO to be inserted at the femur. The graft is inserted at Schöttle's point, which was identified under fluoroscopy and marked with a guide pin. The tendon was tensioned under 20 degrees of knee flexion, manual tension, then the knee was cycled through a full range of motion 5 times before final fixation. At a minimum of 24 months follow-up, there were no reports of postoperative signs of apprehension, subluxation, or dislocation. MPFL reconstruction using a quadriceps tendon autograft provides good outcomes as measured at 24 months. Changes in Kujala and Lysholm were small compared to other semitendinosus graft studies.[42,46] Quadriceps grafting seems less invasive and is anatomically more similar to the MPFL in structure. However, it poorly duplicates the patellar MPFL insertion site. It is unclear if this has any influence on patient outcomes. This is still a good alternative to hamstring tendon autografts because it doesn't place unnecessary stress on the patella through techniques that may lead to chondral stress or intraoperative or postoperative patellar fracture. We would like to point out that this study had patients complete a “Back-in-Action” (BIA) test battery at the final follow-up, where patients performed a series of stability, agility, and jumping tests. Only 50% of patients could attend the BIA test, but the results showed that 80% or more of patients’ operated legs returned to the functional level of their uninjured knees.[52] The BIA, introduced by Hildebrand et al., is a simple test designed to objectively measure knee function and progress.[67] In a clinical application study, Herbst et al. utilized the BIA test to determine whether patients were ready to return to sports 8 months post-ACL reconstruction; only one out 69 patients was found to meet the strict criteria for return to sports.[68] This study determined that in order to return to sports, patients must score at least “normal” in all categories of the BIA test, and if patients were to return to competitive high-risk sports, they needed to score at least “good” in all categories. Normative values for “very weak,” “weak,” “normal,” “good,” and “very good” were determined by having 434 healthy individuals complete the BIA test for comparison.[68]

A 2020 publication by Gao G. et al. reviewed the outcomes of isolated MPFL reconstruction in patients with recurrent dislocation. Additionally, to be included in the study, patients were required to have completed their follow-up at least 5 years after surgery. The surgeon conducting these procedures harvested a gracilis tendon autograft and sutured the ends of the tendon together for a double-bundle technique. Two bone tunnels were drilled into the superomedial aspect of the patella, exciting at the medial midline of the patella, and the graft was passed through the bone tunnels. The graft was then drawn through the 2nd and 3rd layers of the medial joint capsule, and attached at Schöttle's point in the femur using an interference screw. The tendon graft was tensioned with the knee flexed at 90°, and proper patellar tracking was confirmed through free knee flexion until 110° of flexion.[53] At a minimum of 5 years follow-up, there were two cases of dislocation and no postoperative signs of apprehension. The results of this study seemed to show that the tunnels they drilled into the patella for a modified double-bundle graft is a promising technique, which in other studies has been shown to be associated with a higher risk of patellar fractures or chondral damage.[53]

A 2014 publication by Fink et al. conducted an isolated MPFL reconstruction with a quadriceps tendon (QT) strap in patients with recurrent dislocations. A quadriceps tendon graft is harvested and left attached proximal to the patella. The QT graft is folded at 90 degrees medially and sutured to the medial patellar border. The graft is then passed through the vastus medialis obliquus and joint capsule to be inserted at the medial patellofemoral ligament's anatomical insertion site using a bioabsorbable screw. The knee was cycled 5 times with moderate tension placed on the graft, which was then fixed with the knee at 20 degrees to flexion.[54] Follow-up periods were at 6 months and at 12 months. There were no reports of dislocations or subluxations, but there were four cases with signs of postoperative apprehension at 6 months and one at 12 months. The limitations of this study include having a small sample size as well as a short follow-up time. Although the study shows promising short-term results, it does not seem to show many benefits over hamstring grafts.

Table 4: A comparison between clinical studies conducting isolated medial patellofemoral ligament reconstructions.

Article	Open vs Closed	Brief study description	Sample size at follow-up	Duration of follow-up	Post-op recurrence	Post-op apprehension	Patient reported outcome measures	Graft Type	Study conclusions
Lippacher et al. (2014)	Closed	This study performed isolated MPFL reconstruction with the purpose of having patients return to playing sports.	72	2 years	2 redislocations and 5 subluxations	5 with slight apprehension	23 very satisfied, 31 satisfied, 11 partially satisfied. 3 not satisfied, who reported pain postoperatively compared with no pain before surgery. 26 patients had undergone surgery	Gracilis tendon autograft	The author suggests that isolated MPFL reconstruction is a viable option for patients without anatomic defects. MPFLR patients may expect to return to sports about 2 years post-operatively.

							before MPFL reconstruction; 3 very satisfied, 16 satisfied, 6 partially satisfied, and 1 not satisfied post-operatively.		
Peter G. et al. (2019)	Closed	This study performed isolated MPFL reconstruction in a an athletic patient population of mean age 22.6 years	37	24 months	0	1	N/A	Quadriceps tendon autograft	The author suggests isolated MPFL reconstruction utilizing the quadriceps tendon is an effective method, while avoiding bone tunnels or implants in the patella.
Gao G. et al. (2020)	Closed	This was a retrospective study analyzing the results of isolated MPFL reconstruction.	80	66.1 months	2	0	"Excellent" by 86.4%, "good" by 12.1%, and "fair" by 1.5%	Gracilis tendon autograft	The author in this study suggests isolated MPFL reconstruction using a two tunnel insertion at the patella is a safe and effective technique.
Fink et al. (2014)	Closed	This study gave short-term results for isolated MPFL reconstruction in patients using the quadriceps tendon	17	6 month and 12 month	0	6 month - 4 12 month- 2	94.1% would undergo the procedure again and were satisfied with the cosmetic outcome.	Quadricep tendon graft	The author i in this study suggests that utilizing the quadriceps tendon as the graft for an MPFL reconstruction is a safe and effective technique that avoids risk associated with patellar tunnels.

Clinical Decision-Making:

To provide a structured approach to the diagnosis and treatment of PFI, we propose a clinical decision flowchart. This flowchart integrates our current literature findings, guiding clinicians through conservative and surgical treatment options based on risk factors, imaging, and recurrence. The decision-making process considers patient-specific anatomical factors, functional goals, and likelihood of redislocation (Fig. 8).

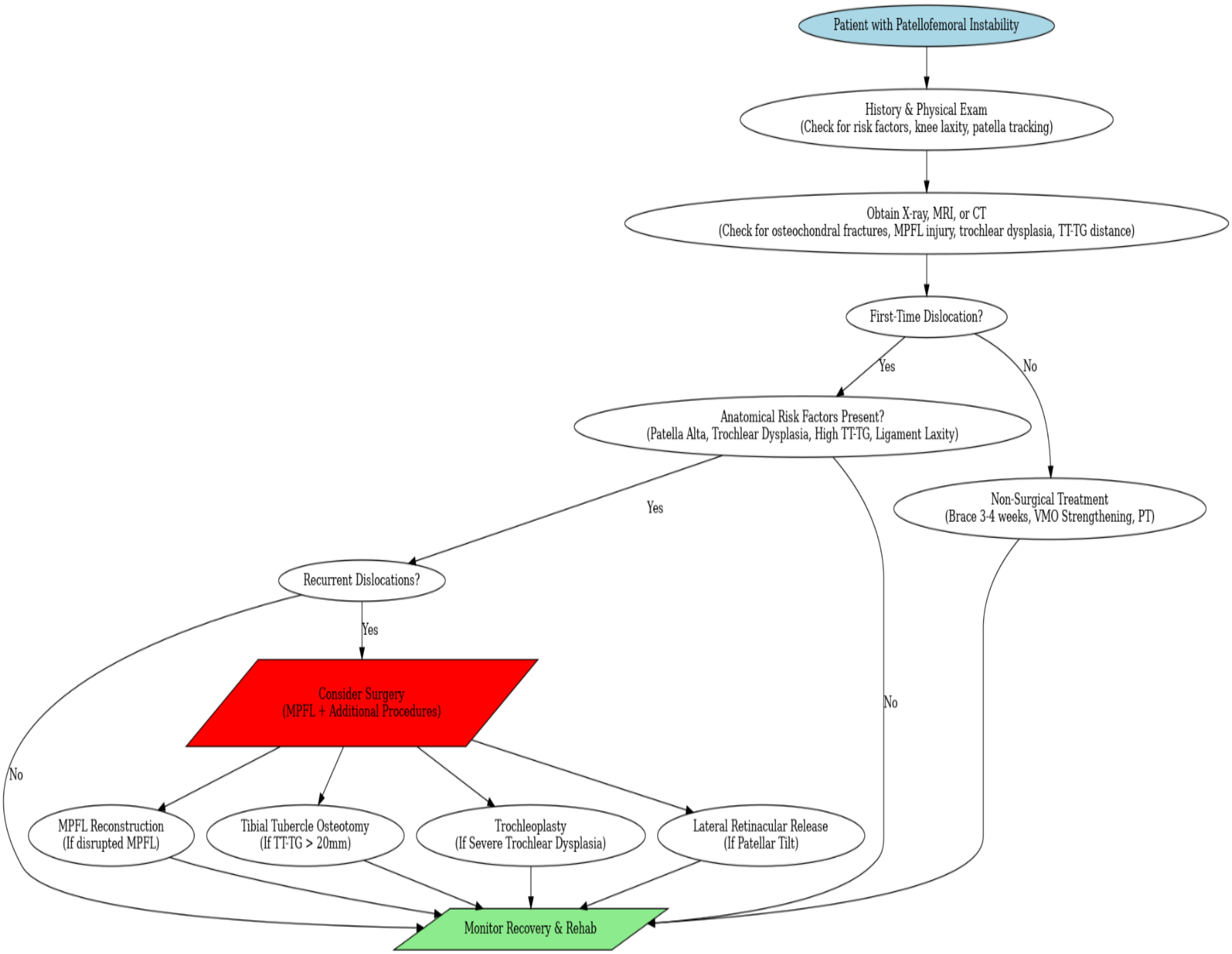

Figure 8. Clinical decision guidelines for managing patellofemoral instability, outlining diagnostic steps and treatment pathways.

Post-operative management:

Successful treatment of patellofemoral instability does not end with surgery or conservative management. Rehabilitation plays a critical role in preventing recurrence and ensuring a full return to function. Post-operative management should include immobilization of the knee joint using a knee brace for 2-4 weeks, depending on the study.[6] Some studies have employed the use of a continuous passive motion device to encourage healing in the knee after surgery.[73,74] Enderlein et al. had patients fully weight-bearing with free range of motion on the first day after surgery, while Kang et al. had patients walking on the second day after surgery but with limited range of motion for four weeks.[42.43] Patients should begin passive motion and quadriceps strengthening motion immediately after surgery.[44] Once the patient can maintain full extension and 90-degree flexion and regain full quadriceps control, they can begin physical therapy to strengthen the VMO and surrounding muscles to help avoid any future dislocation.[44] Patients who undergo secondary procedures to the MPFL reconstruction should take longer in each period of recovery, and there should be little to no weight bearing 2-4 weeks and full weight bearing 4-8 weeks postoperatively.[15,42,43]

Patients should undergo physical therapy to regain muscle strength and balance until a physical therapist has cleared them before returning to everyday activities and then to sports. Timelines for returning to exercising or sports vary between most studies. Patient recovery and rehabilitation will vary between individuals, so the timelines for returning to full activity should function as a general guideline. Patients should reach specific benchmarks to continue progressing and lifting restrictions during rehabilitation. Manske et al. have suggested that postoperative rehabilitation should be a four-phase progression for patients, where they must meet with clinical milestones before progressing to the next phase.[15] Similarly, Hildebrand et al. and Berbst et al. have suggested that patients should only be cleared for certain activities depending on the scores they achieve on a functional assessment that compares them to healthy individuals.[67,68]

A phase-based rehabilitation protocol ensures a progressive return to function while minimizing the risk of re-injury. The following timeline outlines functional goals and recommended exercises based on principles from Manske et al. and LaBella et al., with modifications to incorporate structured progressions and additional return-to-sport criteria (Table 5).

Table 5. Phase-based rehabilitation for PFI.

Phase	Timeline	Goals	Recommended Exercises
Phase 1: Protection and healing	Weeks 0-4	- Minimize pain and swelling - Achieve full knee extension - Initiate quadriceps activation	- Immobilization with brace (if needed) - Passive range of motion (0°-30° initially, progressing to 90°) - Quadriceps isometrics (straight leg raises) - Patellar mobilization techniques
Phase 2: Strength and mobility	Weeks 4-8	- Restore full range of motion - Improve weight-bearing ability - Develop baseline	- Stationary cycling & pool therapy - Bodyweight squats & step-ups - Closed-chain

		quadriceps strength	quadriceps exercises (e.g., leg press) - Balance & proprioception drills
Phase 3: Functional strength and control	Weeks 8-12	- Normal gait pattern restored - Improve single-leg stability - Strengthen hip and core stabilizers	- Lunges & single-leg squats - Lateral band walks (hip abductors) - Controlled plyometrics (mini-hops) - Progressive dynamic balance training
Phase 4: Return to sport and prevention	3-6 months	- Achieve full quadriceps strength - Demonstrate neuromuscular control in sport-specific tasks - Reduce risk of re-injury	- Sport-specific agility drills - Cutting and pivoting exercises - Single-leg hop test for function - Gradual return to high-impact activities

Tendon Healing and Rehabilitation Considerations:

Our review of the current literature on conservative and surgical treatment aligns well with the established science of ligament and tendon healing. After an acute injury, ligaments and tendons begin a rapid healing process. Within the first two days, an inflammatory response occurs, bringing clots and fibroblasts to the damaged areas. This early response is critical for initiating tissue repair. Following the inflammatory phase, fibroblasts proliferate within the extracellular matrix, promoting angiogenesis and depositing Type-III collagen.[81]

At this stage, collagen fibers are disorganized, and vascularity is increased. Additionally, the tendon has a higher water content, which has been theorized to serve as a marker for healing progression on MRI scans. However, the extent to which MRI findings correlate with functional recovery remains debated. Quantitative techniques being used nowadays, such as the signal/noise quotient (SNQ) and T2* relaxation time, are currently being researched for their utility in determining graft maturity. A higher SNQ intensity correlates with increased water content and graft vascularization. Based on our knowledge of tendon healing, a higher SNQ would indicate that the graft is still not mature. The T2* relaxation time is indicative of tissue property reflecting collagen organization, hydration, and the local magnetic environment.[94]

A study by Zhou T, Xu Y, Zhang A, et al. utilized quantitative MRI techniques to explore the relationship between athlete return-to-sport timeline and tendon graft healing as seen on MRIs. A hamstring autograft was used in the ACL reconstruction for this study; a bundle was formed by braiding a semitendinosus and gracilis autograft. The SNQ and the T2* representations of graft maturity, as seen through MRIs, were lower in athletes who did return to sports and higher in athletes who did not return to sports at 9 months post-surgery.[83] A study by Liu S, Xie Y, Chen Q, et al. also utilized MRI techniques to find whether there was a relationship between clinical outcomes post rotator cuff repairs and the SNQ. Once again, the signal intensity of the repair was observed to decrease gradually over time. Although they could not determine how long before signal intensity would return to normal, it was found that poor clinical outcomes within 1-3 months were correlated with higher signal intensities.[86] A review article by van Groningen B, Wolfstadt JI, Wasserstein D, et al. investigated tendon healing with a meta-analysis to review studies performing biopsies, MRI SNQs, and clinical outcomes of ACL reconstructions. Histological studies included in their analysis showed evidence of ongoing healing between 6 months and even 2 years after surgery.[84] This was irregular cell morphology, increased vascularity surrounding the tendon graft, and collagen orientation in the months and years following reconstruction. MRI techniques to determine an SNQ for maturing grafts demonstrated an increase of SNQ up to 6 months with a gradual decrease over time.[84]

Collagen plays an integral role in the extracellular matrix of connective tissue, contributing to both force transmission and structural integrity.[82] This is why patients must avoid weight-bearing too soon after surgery—allowing time for clot formation and fibroblast infiltration is essential for proper collagen remodeling. Approximately two weeks post-injury, Type-III collagen is gradually replaced by Type-I collagen, which has greater tensile strength due to increased cross-linking.[80] This remodeling process continues for months to years, affecting long-term tendon strength and function.

A key debate in rehabilitation is whether early mechanical loading or initial immobilization yields better outcomes. Tendons are mechano-responsive, which means they adapt to mechanical stimuli by reorganizing collagen fibers in response to directional load.[87,88] However, premature mechanical loading may overstress the healing tissue, increasing the risk of re-injury. Massoud EI et al. had patients return to normal weight-bearing 4 weeks after a patellar tendon reconstruction.[87] Conversely, Manske et al. proposed immediate weight-bearing following surgery and advised against knee joint immobilization to avoid stiffness.[15]

When considering whether patients should remain immobile, it is important to note that tendons respond to mechanical cues. Killian ML et al. reviewed the literature on rotator cuff repair, ACL reconstruction, and flexor tendon repair. They found evidence supporting immobilization and mechanical loading at the joint. Their review suggested that all tendons benefit from controlled loading, which promotes healing by fostering the development of structural tissue. Additionally, others have sought to analyze tendon graft recovery after surgery using FDG-PET/CT. An MRI can visualize the structure of a graft at a given moment in time; utilizing positron emission tomography (PET) with ^{18}F-labeled fluorodeoxyglucose (^{18}F-FDG) would allow us to see the metabolic activity in the graft. Utilizing PET in addition to CT reconstruction allows for a better visualization of the graft and how it would heal under different conditions.

The rationale for mechanical loading lies in its ability to stimulate extracellular matrix synthesis while minimizing excessive scar tissue formation. However, the timing and intensity of loading are crucial—excessive stress too early in the recovery phase may disrupt collagen organization and weaken the tendon’s tensile properties.

Although tendons demonstrate a predictable healing pattern, individual factors such as patient age, metabolic conditions (e.g., diabetes), and overall health can significantly influence recovery. Future research should continue to explore optimal rehabilitation protocols, particularly regarding the balance between immobilization and early mobilization in tendon repair.

CONCLUSION

Patellofemoral injuries most commonly occur during acute traumatic knee injuries. Anatomical differences such as those found in younger populations with higher joint laxity and in female populations with a greater quadriceps angle are commonly associated with knee joint instability and increasing the risk of a patellofemoral injury. These anatomical differences, along with trochlear dysplasia, patella alta, and elevated TT-TG distance, place people at a higher risk to dislocate their patella. Upon dislocation, the medial patellofemoral ligament is commonly injured and will place the patient at an even higher risk for subsequent dislocations. Injuring the medial patellofemoral ligament will compromise the integrity of the patella's primary stabilizer, and as such, the patient will be at a higher risk of reinjury.

That being said, it is very important that following a patellar dislocation event, the secondary and surrounding stabilizers will need to be strengthened or stabilized. Patients who underwent isolated MPFL reconstructions and other minor procedures are encouraged to begin weight bearing as soon as possible, as it has been found that early motion is good for articular cartilage health.[15,37,69] Our review of the literature involving tending healing indicates that continuous passive motion should begin as early as 2 days after surgery, and weight bearing may begin around 4 weeks after surgery. A patient should begin physical therapy to strengthen the surrounding stabilizers as soon as pain permits. The quadriceps are a common target for physiotherapy, and the literature suggests this should be targeted either in conservative treatment or post-operative rehabilitation. Manske RC et al. have suggested the hip should be another area to focus on in the process of recovery and rehabilitation as it plays a role in maintaining proximal control of the knee.[15] Stefancin et al. pointed out that there is very little supporting literature to target solely the VMO for physiotherapy, and patients are better off strengthening the quadriceps muscle as a whole.[1]

Considering that patellofemoral injuries consist of 3-4% of all traumatic knee injuries, the field is lacking in literature regarding effective treatment.[41] We sought to review what we believed were the best studies conducted on surgical techniques and found there is no definitive technique regarded as the "gold standard" for treating patellofemoral dislocations. Across the studies we have reviewed, the graft, tensioning technique, fixation technique, etc., varied with very similar results. It is agreed upon that since the medial patellofemoral ligament is commonly injured in lateral patellar dislocations, it should be addressed in most surgical cases.[6,57]

Studies varied in grafting sites between the gracilis tendon, quadriceps tendon, and semitendinosus tendon, while some utilized synthetic grafts. We found the gracilis tendon autograft to be a popular graft choice in the studies reviewed.[43,45,46,50,53,59,60] Enderlein et al. have suggested that the gracilis tendon, weaker than the semitendinosus autograft, is closer to the MPFL in strength and stiffness.[43] Research on cadaveric knees conducted by Joyner, Patrick W., et al. also demonstrated the gracilis tendon autograft to be a reasonable choice for graft, as it had a tensile strength greater than the native MPFL.[74] The synthetic graft was the next most commonly used graft type.[44,47,51] Studies performed by Peter G et al. and by Fink C et al. utilized the quadriceps tendon graft as it eliminated the risk of injury at the patellar site caused by a graft insert.[52, 54]

Most of the cases reviewed utilized Schlottle's point as the location for the femoral insertion of the tendon graft. This anatomical landmark closely resembles the native insertion point of the mediopatellofemoral ligament. As for the patellar attachment, cases observing results for the single-bundle technique will be inserted at the proximal ⅓ of the patella. Cases observing results for a double-bundle technique will be inserted at the proximal ⅓ of the patella and another at the center of the patellar edge. Based upon literature reviews conducted by Migliorini F., Trivellas A, Colarossi G et al., and Singhal, R, et al., the double-bundle does appear to yield better post-operative outcomes for patients.[79,80,93]

Additionally, the literature agrees that MPFL reconstruction is rarely the only procedure that needs to be done in cases of recurrent patellofemoral instability. In many cases, a patient needing to undergo surgery to correct persistent patellofemoral instability presents morphological problems at the patella, which put them at high risk of recurrent dislocations. As such, we find it best to consider repairing the MPFL combined with other surgical techniques to address anatomical defects such as patella alta by lowering the tibial tubercle, an increased TT-TG distance by medializing the tibial tubercle, patellar dysplasia by sulcus deepening trochleoplasty, and patellar tilt by lateral retinacular release. In cases where the patient is not a highly competitive athlete or when there are no indications that the patient is at a high risk of redislocation due to anatomical defects, we believe patients should exhaust conservative treatment options before considering surgical intervention.

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