Patellofemoral Instability in Children and Adolescents: Current Concepts Review

J. Javier Masquijo, Miguel Carabajal Mattar
Department of Pediatric Orthopedics and Traumatology, Sanatorio Allende, Córdoba, Argentina.

ABSTRACT
Patellofemoral instability (PFI) is a common knee disorder in the skeletally immature patient. PFI presents challenges in this patient population that require an understanding of anatomy and biomechanics to formulate a treatment plan aimed at preventing re-dislocation and facilitating return to activity. In this review, the different presentations and therapeutic alternatives will be analyzed, providing a practical guide for the comprehensive management of this complex clinical condition.
Keywords: Knee; patella; dislocation; patellofemoral instability; adolescent.
Level of Evidence: V

Inestabilidad patelofemoral en niños y adolescentes: revisión de conceptos actuales

RESUMEN
La inestabilidad patelofemoral es un trastorno frecuente de la rodilla en el paciente esqueléticamente inmaduro. Este cuadro plantea diversos desafíos en esta población que requieren una comprensión de la anatomía y la biomecánica para formular un plan de tratamiento que prevenga la reluxación y permita el regreso a las actividades. En esta revisión, se analizan las distintas formas de presentación y las alternativas terapéuticas, y se ofrece una guía práctica para el manejo integral de esta compleja condición clínica.
Palabras clave: Rodilla; rótula; luxación; inestabilidad patelofemoral; adolescente.
Nivel de Evidencia: V

INTRODUCTION

Patellofemoral instability (PFI) is a multifactorial condition that is disabling and causes chronic knee pain in children and adolescents. This disorder encompasses a broad spectrum of conditions ranging from mild subluxation to irreducible lateral dislocation. PFI is relatively common, affecting an estimated 5.8 to 29 out of every 100,000 children aged 10 to 17 years.[1] The first episode of dislocation usually occurs during the second decade of life and accounts for approximately 2% to 3% of all acute knee injuries.[2] Acute patellar dislocation (APD) is a debilitating condition, with the recurrence rate ranging from 8.6% to 88% after conservative treatment, depending on individual patient factors.[3-5] Several predisposing risk factors have been identified, including female sex, trochlear dysplasia, increased femoral anteversion, increased external tibial torsion, weakness of the vastus medialis obliquus muscle, increased Q-angle, increased TT-TG (tibial tuberosity-trochlear groove) distance (between the deepest portion of the anterior tibial tuberosity and the deepest portion of the femoral trochlea), ligament laxity, high patella and genu valgus.[6] The long-term risk of progressive cartilage damage after the first episode of dislocation is significant; patients are up to six times more likely to develop osteoarthritis between the ages of 30 and 40. [7]

Received on May 21st, 2024. Accepted after evaluation on May 28th, 2024 • Dr. J. JAVIER MASQUIJO • javimasquijo@yahoo.com.ar https://orcid.org/0000-0001-9018-0612
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Currently, medial patellofemoral ligament reconstruction (MPFL) is the most common surgical treatment.[8,9] However, a subset of patients may require additional procedures to correct angular deviations, rotational disturbances, high patella, or distal malalignment. In this review, we discuss the various forms of presentation and therapeutic alternatives and provide practical guidance for the comprehensive management of this complex clinical condition.

ANATOMY OF THE MEDIAL PATELLOFEMORAL COMPLEX (MPFC)

The term MPFC is used to describe the main soft tissue stabilizer of the patella, consisting of fibers that insert into the patella (MPFL) and the quadriceps tendon (medial quadriceps tendon-femoral ligament). Despite its variable insertion into the extensor mechanism, the midpoint of this complex is located at the junction of the medial quadriceps tendon with the articular surface of the patella, indicating that both patellar tendon and quadriceps tendon attachments can be used for anatomic reconstruction.[10] The femoral origin is located in the "valley" formed between the adductor magnus tubercle and the medial epicondyle, leading some authors to suggest that it encompasses an area rather than a specific insertion point.[11-18]

From a biomechanical point of view, the most significant length changes of the MPFC occur between 0° and 20° of flexion, while more isometric behavior is observed between 20° and 90°. The attachment points along the extensor mechanism show diverse behaviors in relation to length, highlighting that the superior fibers of the medial quadriceps tendon-femoral ligament exhibit greater length variability throughout the range of motion.[19] Some studies suggest that, while the MPFL is the primary restrictor of lateral translation in early knee flexion, the medial quadriceps tendon-femoral ligament is responsible for preventing lateral translation in extension.[20]

In skeletally immature patients, the anatomy of the MPFC is similar to that of the adult population. The femoral insertion is located 6.9-8.5 mm distal to the physis, while the superior fibers of the MPFC insert 5-12 mm proximal to the superior pole of the patella, at the quadriceps tendon.[23-25]

DIAGNOSIS

The diagnosis of PFI is primarily established through clinical evaluation, including detailed patient anamnesis and physical examination, supplemented by imaging studies. A thorough in-office analysis helps categorize the patient into one of the possible clinical scenarios associated with the condition. However, interpreting radiographs and advanced studies is essential to evaluate the underlying anatomic factors that often accompany the different forms of PFI.

APD can result from indirect trauma, where the knee is subjected to a valgus force with internal rotation of the femur, or from direct trauma that displaces the patella laterally away from the femoral trochlea.[26] Patients usually seek medical attention after experiencing the first episode of dislocation and report pain at the insertion site of the MPFL, apprehension, and joint effusion. Patients with more chronic cases or multiple episodes of dislocation may report a sensation of instability or anterior knee pain. [27,28]

The physical examination should include a comprehensive evaluation of the lower limbs, including coronal and sagittal axis, limb length, rotational profile, and muscle strength. Specific maneuvers are recommended, such as the apprehension test, displacement test, J-sign, patellar tilt test, and patellofemoral tracking.[1,29] The assessment of generalized ligament laxity using the Beighton score[30] is an important decision-making tool in preoperative planning (Table).

Imaging evaluation should include AP, lateral, and axial radiographs of the patella. When a coronal alteration of the mechanical axis is suspected, it is important to add lower limb telemetry.[31-34] The evaluation of remnant growth is also essential.[35] MRI is the study of choice in patients with APD, since it allows the detection of osteochondral lesions, intra articular loose bodies that may go unnoticed in radiographs; soft tissue lesions and the morphology of the patellofemoral joint. MRI has been shown to be useful in measuring TT-TG distance and sagittal patellofemoral engagement index, and assessing the patient's rotational profile.[36-39] In our practice, we routinely order an MRI in the first episode, although we feel that it could be omitted in cases of low-energy dislocation when the patient presents clinically without joint effusion.

Table. Preoperative evaluation of the patient with patellofemoral instability.

Preoperative evaluation		
Physical examination		Description/significance
Inspection		
	Evaluation of soft tissue swelling and muscle atrophy	
	Evaluation of deformity in the coronal plane	Standing - genu valgum
	MMII length discrepancy assessment	Prone decubitus by segments (femur-tibia)
	Evaluation of the rotational profile	In prone position - external tibial torsion/femoral anteversion
	Knee range of motion	Normal: 0-130°
	Gait analysis	
	Evaluation of patellar tracking (J-sign)	Distal malalignment, trochlear dysplasia
	Assessment of generalized ligament laxity	Beighton's test (>6/9 abnormal)[30]
	Evaluation of syndromic features	Down's, Larsen's, Rubinstein-Taybi, nail-patella, Ehlers-Danlos, Marfan's, etc.
Palpation		
	Tap test	Intra articular effusion
	Pain/crepitations	Chondral injury in the patellofemoral joint
	Displacement test	> 2 quadrants: insufficiency of the medial stabilizers
	Tilt test	Retraction of the lateral retinaculum
	Q-angle	Distal misalignment
	Apprehension sign	Instability
	Extensor mechanism	Straight leg raise
	Additional knee tests	ACL, PCL, collateral ligaments and meniscus
Images		
	Radiographs: AP, lateral, and axial	Patellar height: Caton Deschamps/Normal Index <1.3[31]
		Ruling out fractures or the presence of foreign bodies.
		Skeletal maturity/bone age assessment
	Lower limb teleradiology	Assessment of misalignment (coronal and sagittal)
	Magnetic resonance imaging	Assessment of articular cartilage condition
		Determination of growth plate state (open/closing/closed)
		Bone contusion pattern identification
		TT-TG distance measurement[36]
		Calculation of the Sagittal Patellofemoral Engagement index[39]
		Evaluation of trochlear dysplasia
		Identification of associated injuries, such as meniscal lesions and additional ligament injuries

ACL = anterior cruciate ligament; PCL = posterior cruciate ligament; TT-TG (tibial tuberosity-trochlear groove).

Computed axial tomography has been used to study joint morphology and rotational plane deformities. It has recently been shown to be useful for examining trochlear dysplasia and for preoperative planning.[40] However, we do not routinely request it in the pediatric population due to the high radiation exposure and lower information yield compared to that of MRI.[41,42] In recent years, there has been a great deal of interest in risk stratification for recurrence after the first episode of APD.[43-45] The goal is to identify individuals at high risk of developing recurrent instability who may benefit from early surgery. As has been the case with other joints, risk stratification models for APD could eventually lead to better evidence-based treatment recommendations. [46,47]

CLASSIFICATION

There are four main forms of instability: I) first episode of dislocation: when the first traumatic event occurs. It can be subdivided into: A) without intra articular free fragment and B) with intraarticular free fragment; II) recurrent PFI: two or more repeated traumatic events. After the first episode, the events usually require less energy. There are predisposing anatomical factors, such as female sex, trochlear dysplasia, increased femoral anteversion, increased external tibial torsion, weakness of the vastus medialis oblique, increased Q-angle, increased TT-TG distance, ligament laxity, high patella and genu valgum; III) habitual/obligatory dislocation: episodes of dislocation at each knee flexion or extension with spontaneous reduction. It can be subdivided into: A) habitual dislocation in flexion and B) habitual dislocation in extension; IV) irreducible lateral dislocation: permanent dislocation not reducible manually.

TREATMENT

Acute patellar dislocation

Historically, patients suffering from a first episode of APD without the presence of intra-articular loose bodies have been managed with conservative treatment.[48] However, recent studies have questioned this approach, proposing stabilization of the patella in patients at high risk of recurrence.[49] The algorithm used by the authors of this article is detailed in Figure 1.

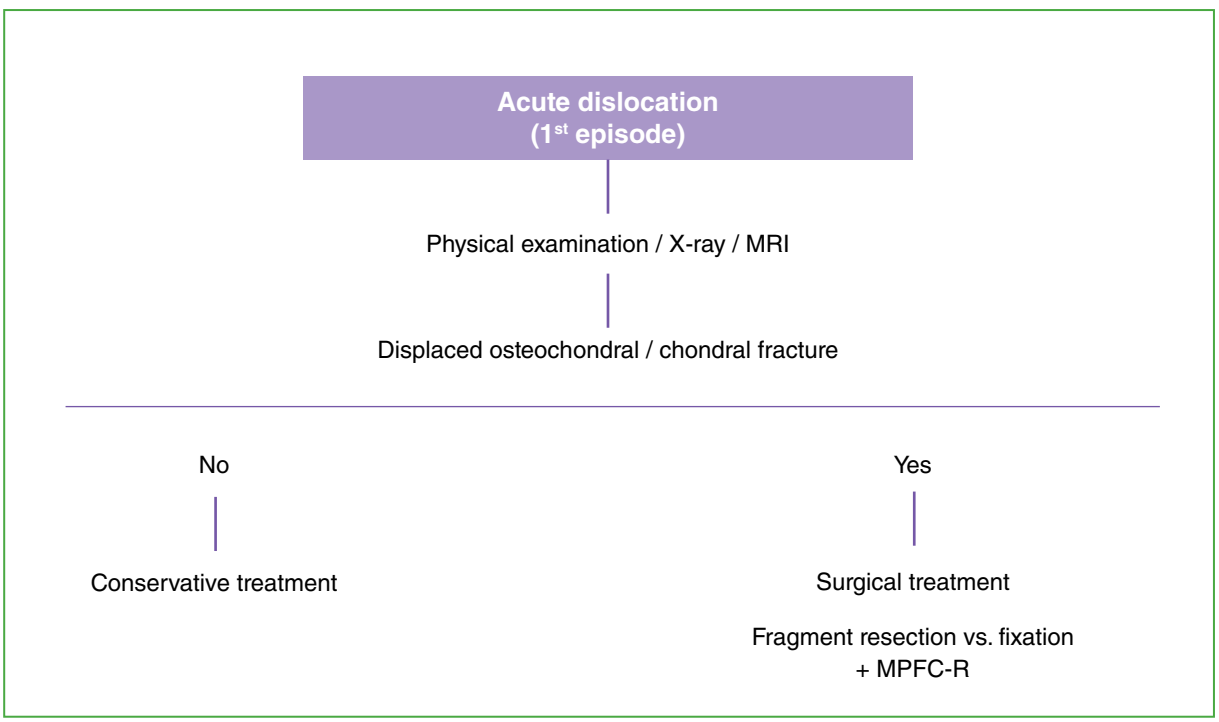

Figure 1. Therapeutic algorithm for patients with acute patellar dislocation.
MPFL-R = medial patellofemoral complex reconstruction.

Conservative treatment consists of a period of immobilization for 2 to 3 weeks followed by rehabilitation for 6-10 weeks. The goals of the rehabilitation program are divided into different stages:[50] 1) resolution of pain, effusion, and inflammation; 2) recovery of motion and flexibility; 3) recovery of muscle strength; 4) recovery of coordination and motor patterns; and 5) sport-specific athletic action.Return to activity is usually authorized around 12 weeks post-injury, once the patient is asymptomatic, with no effusion or tightness, and with quadriceps strength comparable to that of the contralateral lower limb.

According to published studies, functional outcomes and recurrence rates after conservative treatment are variable. Conservative treatment protocols differ significantly among authors, as do the functional scales used. Additionally, individual patient risk factors are not consistently reported, making comparisons between studies difficult. Palmu et al.[51] prospectively evaluated 71 patients under 16 years of age (74 knees) who had suffered a first episode of APD. Twenty-eight knees were treated conservatively and monitored for 14 years. Although the functional outcomes at the last follow-up were satisfactory in 75% of cases, 71% experienced at least one further episode of dislocation. Regalado et al.[52] analyzed the outcomes of 20 adolescents and found that nearly one in three (27%) were dissatisfied, with a re-dislocation rate of 35% at three years and 73% at six years. In a recent systematic review of 2,086 patients, Longo et al.[53] reported a mean Kujala score of 75.6 at follow-up <5 years and 87.5 at follow-up >5 years. The recurrence rate was 36.4%.

Patients with an osteochondral fracture and one or more intra-articular loose bodies require surgical treatment. In these cases, the fragment should be evaluated for repositioning or removal based on its size, location, and viability. Osteochondral fragments >1 cm located on a weight-bearing articular surface typically require reduction and internal fixation (Figure 2), while smaller fragments can be removed.[54] In adolescents who experience a first episode of dislocation with an osteochondral fracture requiring excision or fixation, there is consensus that instability should be treated concurrently.[38,55] Additionally, there is evidence that MPFL reconstruction offers better results than repair techniques.[56]

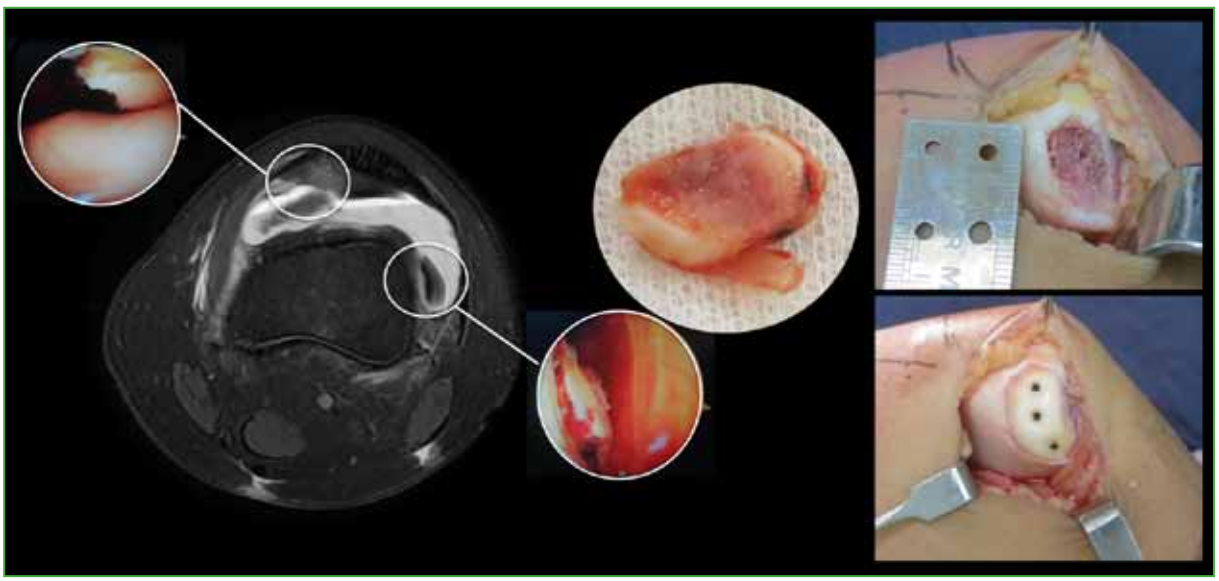

Figure 2. 13-year-old patient who suffered a first episode of dislocation and osteochondral fracture of the medial facet of the patella and underwent reduction and osteosynthesis with Smart Nails® (ConMed Linvatec Ltd., Tampere, Finland).

Recurring PFI

Recurrent PFI is defined as two or more episodes of dislocation. Multiple treatment options are available for this disorder, with the choice depending on the underlying cause of the instability and the degree of skeletal maturity. MPFL reconstruction has gained popularity due to its excellent outcomes.[57-59] However, certain associated anatomical factors, such as distal malalignment of the extensor apparatus, high patella, trochlear dysplasia, genu valgum, or rotational abnormalities, may create an unfavorable environment for grafting. When there is isolated failure of the medial stabilizers of the patella, reconstruction is the indicated treatment. In cases of distal malalignment, combining MPFL reconstruction with distal realignment of the extensor apparatus has yielded favorable outcomes. [60]

Medializing osteotomy of the anterior tibial tuberosity is a procedure designed to medialize the extensor apparatus and reduce contact forces at the patellofemoral joint in skeletally mature patients. However, in skeletally immature patients, this technique may cause damage to the growth plate, so realignment by subperiosteal patellar tendon transfer is preferred.[61] In cases of high patella, instability, and distal malalignment, it is appropriate to combine medialization and distalization of the extensor apparatus using soft tissue techniques or osteotomies, depending on the degree of skeletal maturity.

In skeletally immature patients with coronal plane alterations, such as genu valgum, our preference is to perform axis correction by guided growth with tension band plates. Subsequently, when this material is removed, we proceed to stabilization of the patella. If skeletal maturity has been reached, we opt for realignment by osteotomy followed by patella stabilization in a single surgery. It is essential to individualize the treatment according to the anatomical deformity, making the evaluation of predisposing factors indispensable for accurate management of this condition. The algorithm used by the authors is described in Figure 3.

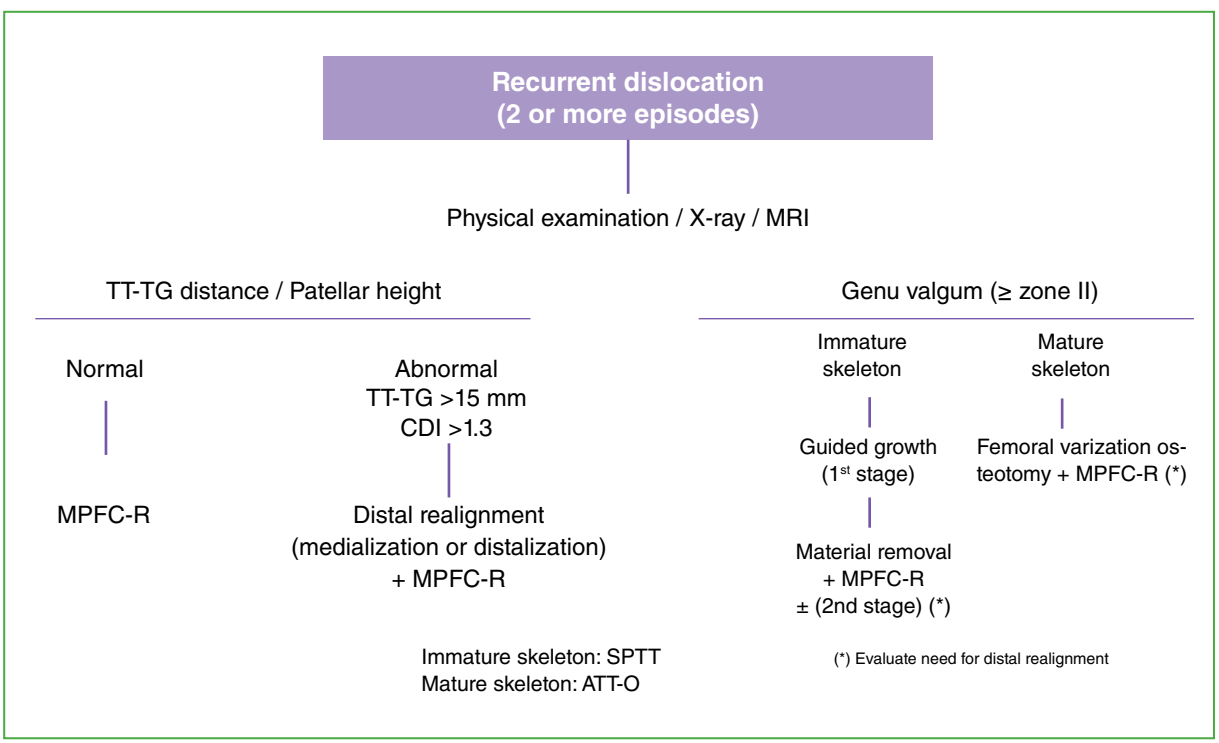

Figure 3. Therapeutic algorithm for patients with recurrent patellofemoral instability.
TT-TG (*tibial tuberosity-trochlear groove)* = distance between the deepest portion of the anterior tibial tuberosity and the deepest portion of the femoral trochlea; MPFL-R = medial patellofemoral complex reconstruction; SPTT = subperiosteal patellar tendon transfer; ATT-O = anterior tibial tubercle osteotomy.

Technique preferred by the authors

The patient is placed in the supine position. 1 g of cephalothin is administered intravenously as antibiotic prophylaxis, half an hour before the incision. Spinal anesthesia is administered, and a pneumatic tourniquet is placed. Asepsis and antisepsis of the area are performed, and surgical fields are placed according to the technique. The affected extremity is exsanguinated using an Esmarch bandage, and a tourniquet is applied at 250 mmHg. The superomedial patellar and femoral approaches, as well as the arthroscopic portals, are delineated with a sterile pen (Figure 4).

Figure 4. Reconstruction of the medial patellofemoral complex with semitendinosus allograft.

The classic anterolateral and anteromedial arthroscopic portals are created, and diagnostic arthroscopy is performed to identify loose bodies and evaluate the patellofemoral chondral surfaces. Any osteochondral or chondral lesions are addressed at this point. Preferred sources for allografts are the semitendinosus or fibularis longus. It is important to ensure that the allograft is at least 240 mm in length. After thawing, the allograft is washed with a mixture of antibiotics and saline containing 1 g of vancomycin in 1 liter of saline. Tension is applied to the allograft using the graft preparation board, and a stitch is placed on each side of the graft with Vicryl® #1. A 3 cm incision is made at the superomedial pole of the patella. Dissection is performed to visualize the medial border of the quadriceps tendon. The plane between the medial retinaculum and the joint capsule is identified, taking care not to damage the capsule. Fluoroscopy is used to accurately identify Schöttle's radiographic landmark in skeletally mature patients or in the epiphyseal region just distal to the growth plate in patients with an open physis. A guide is introduced in a proximal-to-distal (approximately 20°) and posterior-to-anterior direction. A 7 mm diameter drill bit is used at low speed to create a 25 mm femoral tunnel. The graft is secured in the femoral tunnel with a 7 x 25 mm PEEK (Polyether-Ether-Ketone) interference screw. It is recommended to fix the graft with the proximal end slightly longer than the distal end for proper fixation to the quadriceps tendon. Adequate graft fixation is confirmed by applying longitudinal tension to the graft. Using a hemostatic forceps, both ends of the graft are passed through

the plane between the capsule and the medial retinaculum. During medial exposure of the patella, care is taken to avoid arthrotomy by leaving the junction of the synovial lining intact. A gouge is used to decorticate the surface of the medial border of the patella. A 3.5 mm anchor is placed at the junction of the proximal third and the distal two-thirds of the patella. A single anchor is used instead of one or two intraosseous tunnels to avoid creating a large defect that may increase the risk of patellar fracture. The patella is then centralized in the trochlea with the knee flexed at 30°-40°, and the length of the graft is adjusted and secured to the patella. An additional suture is made with Vicryl® #1 between the patella and the allograft tendon to reinforce the fixation. Next, with the knee in extension, the patella is checked to ensure that it can be manually moved one quadrant laterally, confirming the correction of instability without excessive pressure on the patellofemoral joint.

For fixation to the quadricipital tendon, a hole is created in the medial border of the tendon, 10-15 mm from the superior pole of the patella. The upper end of the allograft is passed through this hole and manually fixed with a FiberWire® suture. Patellar mobility is verified using the moving patellar apprehension test, and any excess graft is removed. The vastus medialis obliquus muscle is advanced and sutured to the medial border of the patella with Vicryl® #1 sutures. The area is thoroughly irrigated with saline, and the arthroscope is reintroduced to ensure adequate patellar tracking. After irrigation, the incisions are closed.

Crutches and a knee immobilizer are indicated for two weeks. Weight-bearing is allowed as tolerated with the leg in extension until adequate quadriceps control is achieved. Full range of motion exercises are allowed immediately. Return to sports and high-impact activities is generally authorized after six months and is subject to clinical and radiographic evaluations, which may vary depending on concomitant procedures. This authorization is granted once the patient is asymptomatic, with no effusion or apprehension, full range of motion, muscle strength symmetry close to 85% with respect to the contralateral limb, no objective instability during the examination, and excellent dynamic stability observed when performing sport-specific exercises without hesitation. In skeletally immature patients, standing lower limb radiographs (telemetry) are taken at one-year follow-up to evaluate possible growth disturbances.

Habitual dislocation

Habitual dislocation presents in two forms: a) in extension, where the patella spontaneously dislocates each time the knee is extended (usually between 0° and 30°), and b) in flexion, where dislocation occurs when the knee is flexed (usually between 60° and 90°). These cases are rare and tend to occur mainly during the first decade of life.[63]

Habitual dislocation in extension is characterized by distal misalignment of the extensor apparatus, observed through an increased TT-TG distance, high patella, and trochlear dysplasia.[64] Surgery for these cases should address distal realignment by medializing and distalizing the extensor apparatus, complemented by reconstruction of the medial stabilizers (Figure 5). In patients who have reached skeletal maturity and present with severe trochlear dysplasia, treatment may also include trochleoplasty.

Habitual dislocation in flexion is characterized by shortening and atrophy of the quadriceps tendon and severe retraction of the lateral structures (iliotibial band, lateral retinaculum, and vastus lateralis).[65,66] Additionally, these patients often have distal malalignment. Treatment of this subtype of instability usually begins with distal realignment and continues with elongation of the lateral retinaculum, followed by lengthening of the vastus lateralis tendon. If, after these steps, the patella continues to dislocate laterally during knee flexion, a formal Z-lengthening of the quadriceps tendon is performed to address the shortening of the extensor mechanism and neutralize the lateral force vector on the patella during knee flexion. This procedure should be complemented by reconstruction of the medial stabilizers.

Irreducible dislocation

Irreducible or fixed lateral dislocation is a rare condition in which the patella is located laterally to the external femoral condyle and cannot be manually repositioned onto the trochlea (Figure 6). This condition can manifest idiopathically or in association with other congenital conditions, such as Larsen syndrome, Rubinstein-Taybi syndrome, Down syndrome, nail-patella syndrome, chondrodysplasia punctata, fibular hemimelia, and arthrogryposis.[63] In both cases, the extensor apparatus may have a more lateral position, leading to flexion contracture, loss of active knee extension, external tibial rotation, shortening of the quadriceps, and severe contracture of the lateral structures.[67,68]

In these cases, the surgical approach is similar to that used for cases of habitual flexion instability (Figure 5).

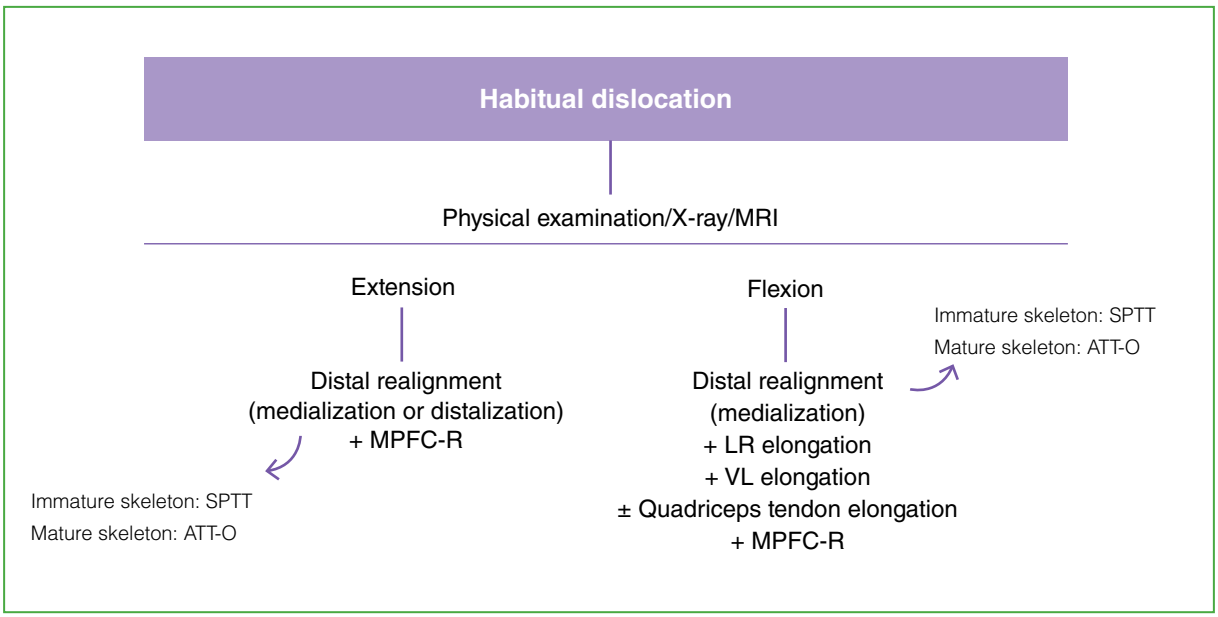

Figure 5. Therapeutic algorithm for patients with habitual dislocation in extension and flexion.
MRI = magnetic resonance imaging; MPFL-R = medial patellofemoral complex reconstruction; SPTT = subperiosteal patellar tendon transfer; ATT-O = anterior tibial tubercle osteotomy; LR = lateral retinaculum; VL = vastus lateralis.

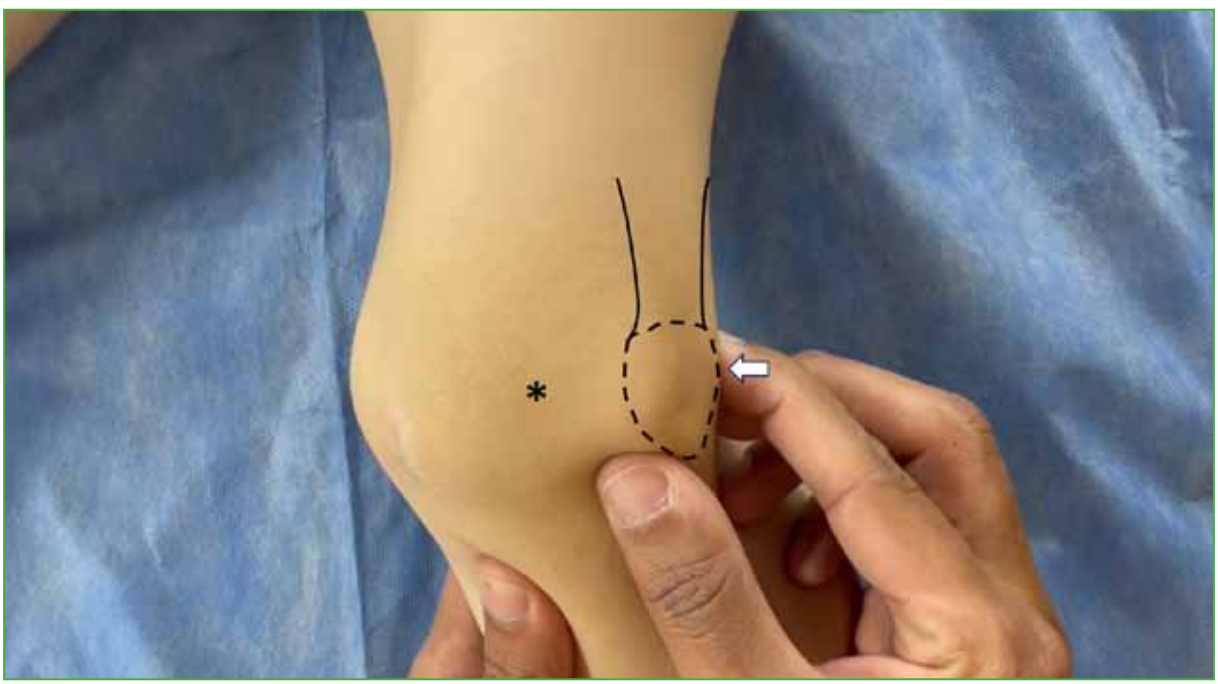

Figure 6. Fixed/irreducible lateral dislocation. The asterisk marks the center of the femoral trochlea and its relationship to the patella and extensor apparatus.

CONCLUSIONS

PFI is a common condition in children and adolescents. Its diverse presentations, variations in joint morphology, and associated factors make its management challenging. Accurate assessment and proper diagnosis are crucial to ensuring optimal joint function. Continued interest in better understanding this disorder and optimizing therapeutic approaches has contributed to improving the prognosis of these lesions in pediatric patients. Adopting an evidence-based approach and following diagnostic and therapeutic protocols will help provide patients with higher-quality treatment and reduce the incidence of complications, thereby promoting the development of their daily activities.

Conflict of interest: The authors declare no conflicts of interest.

M. Carabajal Mattar ORCID ID: https://orcid.org/0000-0002-0301-0867

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