Review article

Patellar instability in children and adolescents

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ABSTRACT

Paediatric patellar instability encompasses many anatomic entities located along a continuum of knee extensor mechanism abnormalities. Major or minor clinical manifestations may occur at a variable age. In major forms with irreducible patellar dislocation or habitual patellar dislocation during knee flexion, shortness of the quadriceps is a consistent feature. A comprehensive aetiological work-up is in order, as syndromic conditions are common. Early surgical treatment is mandatory and should be performed by an experienced paediatric orthopaedic surgeon, as the procedure is technically challenging. Minor forms are more common; they are characterised by patellar dislocation or subluxation near terminal knee extension. The diagnosis may be difficult, particularly at the acute phase. Surgery is needed in patients with recurrent dislocation or functional impairments. The semiology of patellar instability has undergone considerable development in recent years, and a three-dimensional evaluation of patellar position can now be obtained using magnetic resonance imaging. Individually tailored surgical treatment “à la carte” remains a valid approach in 2013. However, new techniques for medial patello-femoral ligament reconstruction have modified the management strategies for adults and superseded many stabilisation procedures. Adapting these new techniques to paediatric patients and developing new procedures constitute major challenges.

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1. Introduction

Patellar instability is a complex disorder of the knee extensor mechanism that was long poorly understood, as shown by the huge diversity of suggested treatments: over 100 different stabilisation procedures have been described for adults. The stakes are particularly high in paediatric patients, who exhibit the most severe forms requiring early management. In addition, patellar instability may occur in the setting of severe multiple or syndromic birth defects.

Recent detailed descriptions and biomechanical studies of the medial patello-femoral ligament (MPFL) constitute a major advance, as they have suggested new management strategies that have superseded many of the earlier procedures. The role for MPFL procedures in customised treatment strategies for paediatric patients remains undefined. These procedures cannot be viewed as a panacea. As with anterior cruciate ligament surgery in children, specific paediatric techniques have been developed for MPFL reconstruction, the optimal sequence, however, remains to be determined.

2. Specificities and novel procedures related to anatomic and biomechanical considerations

In 1995, Garin produced a detailed description of the embryological, anatomic, and biomechanical factors involved in patellar instability [1]. These factors will not be discussed here. Instead, we will review the new findings that may influence our management strategies.

2.1. Embryological studies

Embryological studies by Glard et al. indicate that the shape of the trochlear groove, a key feature of bipeds, is governed by genetic factors [2]. Trochlear biometrics is determined at the early foetal stages. Femoral torsion and the femoral neck-shaft angle, in contrast, develop under the influence of mechanical factors, which predominate over the genetic background. These studies support early management, as well as the inclusion of epiphyseal trochleoplasty into the surgical armamentarium.

2.2. MPFL

The MPFL is a well-defined anatomic structure that was identified recently. This ligament plays a crucial role as the main stabiliser of the patella between 0° and 30° of knee flexion. The MPFL is
intimately mingled with the various layers of the medial retinaculum and contributes 50% to 80% of lateral patellar translation control [3]. MPFL rupture is a nearly consistent feature in patients with occasional patellar dislocation. The MPFL is not tubular; it resembles a triangular band with the base on the upper half of the patella and the tip on the femur. There is now general agreement that the femoral attachment of the MPFL in children is epiphyseal, a few millimetres distal to the growth plate [4,5]. The MPFL is not isometric: it is taut when the knee is fully extended and slack in flexion when the patella is engaged in the trochlear groove [6]. Many adult orthopaedic surgeons feel that the role for the MPFL is crucial [7]; however, in the more severe forms of patellar instability seen in paediatrics, the contribution of the MPFL remains to be determined.

2.3. Anterior distal femoral physis

The anterior distal femoral physis clearly marks the transition zone between the supra-trochlear femur and the cartilaginous trochlea. This important fact explains why metaphyseal elevation trochleoplasty involves only the supra-trochlear region and, by definition, remains outside the cartilage (with, in addition, a risk of migration during growth). Neither metaphyseal-epiphyseal elevation as described by Albee nor open-physis groove-deepening trochleoplasty should be performed, as these procedures produce a Salter–Harris type IV transphyseal lesion associated with a high risk of anterior epiphysiodysis and genu recurvatum.

3. Pathophysiology/factors responsible for instability

3.1. Major primary bone factors: dysplasia of the trochlea and patella

Dejour et al. showed that trochlear dysplasia is characterised radiographically by the crossing sign [8]: on the strict lateral view, the line along the trochlear floor intersects the anterior contours of the medial and lateral condyles. The crossing sign indicates a flat trochlea and is found in 96% of patients who have had at least one episode of true patellar dislocation (objective patellar instability) compared to only 3% of controls [8].

The crossing sign is not sufficient, however, to characterise a trochlea that is not only flat, but also convex. The supra-trochlear spur, or trochlear prominence, must be considered also, as well as the double contour formed by the projection of the hypoplastic medial side of the trochlea. These three radiological features are used to define the four types of trochlear dysplasia [8] (Fig. 1).

In children, trochlear ossification is incomplete, and the lack of ossification is greatest in the youngest patients, with the result that classification of the dysplasia may be impossible without a detailed analysis by magnetic resonance imaging (MRI) [9]. Furthermore, on axial views, the interpretation of trochlear remodelling requires great caution. An ultrasound study by Nietosvaara et al. documented changes in trochlear cartilage thickness between 12 and 18 years of age [10]. The cartilaginous trochlea of an abnormal knee is flatter than the bony trochlea, which makes the cartilaginous trochlear angle a better parameter for separating normal from abnormal knees. The positive correlation between the trochlear angle and patellar height when the knee is extended supports a role for developmental disorders, with decreased forces being applied to the trochlea in patients with patella alta.

The analysis of trochlear dysplasia cannot be separated from that of patellar dysplasia. A typology of patellar dysplasia is more difficult to develop, however. A pebble-shaped or hunter’s-cap patella is often associated with the B and D types of trochlear dysplasia.

Other bone factors, which develop secondarily, may increase the risk of patellar instability. Examples include excessive anterior femoral torsion and genuvalgum. These factors change during growth.

3.2. A muscular factor: shortness and rotation of the quadriceps muscle and misalignment of the extensor mechanism

In quadriceps dysplasia, the muscle is abnormally short and rotated externally as a result of insufficient internal rotation of the
myotome. This factor may constitute the primum movens of patellar instability and dictates the magnitude of the clinical symptoms. In very severe forms of congenital patellar dislocation, the quadriceps follows the chord of the arc formed by the knee flexion and induces flexion, external rotation, and valgus of the knee (Fig. 2). The abnormal shortness of the quadriceps precludes knee flexion when the patella is centred manually in the trochlea.

In contrast, in patients with occasional patellar dislocation, the quadriceps may be only slightly shortened, without any marked rotation, and the only manifestation may be patella alta with limited engagement in the trochlear groove, excessive mobility and, in some cases, patellar tilt in extension. Patella alta is defined as a Caton–Deschamps patellar height index $>$ 1.2. This simple and reproducible index has been validated in paediatric patients [11]. A drawback of the Caton–Deschamps index, however, is that it locates the patella relative to the tibia and not to the trochlea.

Rotation of the myotome may be apparent only at the distal end of the muscle, with an excessively lateral attachment site on the tibia. Thus, the extensor mechanism has a bayonet-like trajectory, which forms the classic Q angle (Fig. 3). The misalignment can be measured on axial computed tomography (CT) images as the distance between the tibial tuberosity and the trochlear groove. This distance varies in normal individuals but should not exceed 20 mm. This muscle factor has received less attention since the development of MPFL reconstruction techniques but remains important in patients with severe patellar instability responsible for permanent or frequent dislocation, as in this situation, the quadriceps rotates the leg externally, thus, worsening the misalignment.

3.3. A capsular and ligamentous factor: deficiency of the MPFL

The medial retinaculum and MPFL are the only direct links between the femur and patella. Chronic MPFL distension may occur in severe patellar dislocation, whereas occasional patellar dislocation may result in acute traumatic MPFL distension.
A difference with adults is that, in children, the MPFL avulsion site at the acute phase is usually located at the patella (61% of cases in a study by Kepler et al. [5]), although nearly half the lesions are complex and involve multiple sites [12]. In an MRI study, 56% of knees exhibited muscular lesions, including oedema, hematomas, and ascension of the vastus medialis obliquus (VMO), a major dynamic stabiliser of the patella [12]. VMO ascension is a marker for severe MPFL injury and may promote recurrent patellar dislocation.

The MPFL contributes to control patellar tilt and translation. MPFL distension can be evaluated clinically based on the patellar apprehension test and on the recently introduced tests described below. Patellar tilt and translation can be measured on MRI or CT images (taken with the knee extended and the quadriceps contracted or relaxed).

Constitutional joint hypermobility should be looked for routinely as a “secondary” factor promoting patellar instability. Knee hypermobility manifests as genu recurvatum with patella alta and excessive external rotation of the patella in the knee.

4. Classification/clinical patterns

We will not discuss purely traumatic patellar dislocation in adolescents, in which knee anatomy is normal. Based on the classification system described by Dejour et al. and Garin et al. distinguished four clinical patterns: permanent dislocation, habitual dislocation whenever the knee is flexed, objective patellar instability, and potential patellar instability [1]. However, potential instability is a vague and controversial condition that is beyond the scope of this conference. In addition, congenital patellar dislocation occurs antenatally and manifests as irreducible fixed knee flexion, which is noted at birth [13,14]; this condition should not be confused with permanent patellar dislocation, which is developmental [13]. Finally, habitual dislocation upon knee extension involves a different mechanism from that involved in habitual dislocation in knee flexion. Thus, we will distinguish five main clinical patterns that represent varying degrees of the same continuum. Age at onset of the clinical manifestations varies with the magnitude of the anatomic abnormalities (Fig. 4).

4.1. Congenital dislocation

Congenital dislocation is a distinct entity characterised by a variable degree of fixed flexion with marked external rotation within the knee, producing a pattern of functional genu valgum [14] (Fig. 2). This extremely uncommon condition is characterised by permanent and irreducible patellar dislocation that can be difficult to diagnose (with ultrasonography being useful in this regard). The quadriceps, which is severely shortened and externally rotated, follows the chord of the arc and therefore, acts as a powerful flexor and external rotator of the knee. Lateral contraction of the ilio-tibial tract and in some cases of the biceps femoris muscle is a common feature. The trochlea is flat and the patella hypoplastic. This condition makes walking nearly impossible, particularly when both knees are affected.

4.2. Permanent dislocation

Permanent dislocation usually manifests after the child learns to walk and before 5 years of age (there is no fixed flexion at birth). Frequent falls, a limp, and discomfort during knee flexion, usually without pain, are the main symptoms. The quadriceps is short but the height of the patella is normal. The trochlea may consist only in the rounded surface of the lateral condyle, on which a pebble-shaped patella with a single convex facet is moulded. The medial side of the trochlea may be missing. The knee is divided sagittally in some cases, as seen in nail-patella syndrome, and the quadricipital recess may be virtually non-existent.

4.3. Classical habitual dislocation during knee flexion

Classical habitual dislocation during knee flexion is characterised by normal patellar position when the knee is extended with consistent dislocation of the patella each time the knee is flexed, starting at a variable angle. The dislocation can be reduced by extending the knee, which causes no pain or apprehension. Shortness of the quadriceps can be evaluated by measuring the angle of maximal knee flexion when the patella is forced manually to remain within the trochlear groove. The quadricipital malrotation component may predominate, with the shortness chiefly affecting the vastus lateralis. The trochlea is usually flat. This pattern of patellar instability is fairly well tolerated. The symptoms usually appear between 5 and 8 years of age and consist of knee instability and difficulty with running and learning sports.

4.4. Habitual dislocation during knee extension

Habitual dislocation during knee extension is characterised by patellar subluxation or dislocation when the knee is extended and at the very beginning of knee flexion. The patella returns to its normal position with continuing knee flexion, at an angle that varies with the severity of the condition (marked flexion in severe forms and J sign in mild forms; see below). Shortness of the quadriceps may manifest only as patella alta (tilted during knee extension); severe B or D type dysplasia may be present, with the patella having to overpass the lateral slope of the trochlea before recovering its normal position during knee flexion.

4.5. Occasional, episodic or recurrent dislocation

Occasional, episodic or recurrent dislocation (previously known as “objective patellar instability”) is the mildest form of patellar instability and also the most common. Symptom onset occurs during pre-adolescence or adolescence, often as an acute event [15], triggered by a sporting activity [16]. There is a marked female predominance. At a distance from the episode of dislocation, apprehension is the most prominent symptom. Pain occurs after the episodes of dislocation or subluxation but is often not the main symptom, in contrast to the semiology in adults. The pain must be differentiated from the classic knee pain syndrome seen in female adolescents.

5. Physical examination

Patients with congenital or permanent patellar dislocation should be investigated for a syndromic condition (arthrogryposis, bone dysplasia, and other syndromes).

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Fig. 4. Classification of clinical patterns of patellar instability in children and adolescents. Severe dislocation with shortness of the quadriceps (dark frame) is distinguished from minor instability occurring near full extension.
Children who have constitutional hypermobility syndrome with a Beighton hypermobility score greater than 6/9 [17] should undergo investigations for cardiac, skeletal, and ocular abnormalities. Height measurement, an analysis of the facial features, and examination of the nails and elbows may suggest a syndromic condition requiring evaluation by a geneticist [18] (Fig. 5).

When the patellar is small, an antero-posterior radiograph of the pelvis may suggest small patella syndrome (as described by Scott and Taor) or nail-patella syndrome (a form of osteo-oncho dysplasia), in which investigations for kidney disease should be performed (Fig. 6).

5.1. A comprehensive examination of the knee is mandatory

A comprehensive examination of the knee is mandatory (motion ranges, alignment, muscle wasting, joint laxity, meniscal sign). Here, we will review a few important specific signs.

5.2. Evaluation of patellar tracking during flexion and extension

Normally, the patella tracks along a straight line and remains perfectly centred. The J sign (or comma sign) is defined as sub-luxation or lateral deviation of the patella during terminal knee extension with a return to the correct position within the first 30° of flexion.

5.3. Patellar apprehension test

The patient is supine with the knee extended. Manual pressure is applied medially to push the patella laterally. The test is positive if this manoeuvre causes apprehension in the patient, who tries to remove the examiner’s hand. This manoeuvre causes apprehension but no pain: it is negative in patients with congenital or habitual patella dislocation.

5.4. Patellar transversal mobility

The distance over which the patella can glide laterally is assessed relative to the width of the trochlea, which is divided into four quadrants. The knee is either extended or flexed to 30°. With the knee extended, there is a firm endpoint to lateral translation of the patella (similar to the sensation during Lachman’s test) when the MPFL becomes taut, as easily demonstrated on the normal knee. Tanner’s test is a variant that measures both lateral and distal gliding of the patella with the knee flexed to 30° [19].

5.5. Patellar tilt test

The examiner uses both thumbs to apply pressure to the lateral edge of the patella, thus, engaging the patella in the trochlear groove, and simultaneously uses both forefingers to lift the medial

Fig. 5. Main clinical abnormalities to look for as part of the work-up for a cause or underlying syndromic condition.

Fig. 6. Radiograph of the pelvis in 2 patients with a small patella. A. View of half of the pelvis showing an iliac horn (nail-patella syndrome). B. View of half of the pelvis showing agenesis of the ischial tuberosities (Scott and Taor syndrome).
Fig. 7. When detectable on the lateral radiograph, trochlear dysplasia provides valuable diagnostic orientation.

patella edge. The angle of the patella with the horizontal plane is then measured.

These three manoeuvres serve to assess MPFL distension. We believe that there is little to be gained in children from the use of the many other signs described in the literature, such as pain upon patellar compression into the trochlear groove, crepitus during patellar gliding, patella facet pain, etc.

6. Management at the acute stage

Irreducible patellar dislocation is only exceptionally diagnosed after an acute event, and this section therefore deals only with occasional dislocation (or habitual dislocation in extension) in adolescence. The reported annual incidence of patellar dislocation in patients younger than 16 years of age is 43/100,000 [16]. The first episode of patellar dislocation causes haemarthrosis due to the tearing of the medial retinaculum and MPFL, which in turn governs the risk of recurrent dislocation. Luhmann reported that patellar dislocation accounted for 58% of all cases of haemarthrosis in female paediatric patients [15]. The classic set of radiographs (with four views, antero-posterior, lateral, notch, and axial) should be examined carefully for a concomitant osteochondral fracture, which is found in 30% of patients with acute patellar dislocation [16] (Fig. 7). When present, this fracture usually involves the medial edge or crest of the patella and less often the middle third of the lateral condylar arc in the weight-bearing zone. The fracture is caused by impingement of the articular surfaces and is more likely to occur in patients without patella alta and with moderate trochlear dysplasia.

The emergent management of the first episode of patellar dislocation is usually non-operative: a cast or splint is worn for 4–6 weeks with the knee in slight flexion, after which a specific rehabilitation programme is applied. Palmu et al. found no beneficial effects from repairing the torn medial restraints at the acute phase after the first dislocation episode in children and adolescents: thus, the recurrence rate (as high as 70%) was similar in the surgical and non-operative groups [20]. A family history of patellar dislocation predicted recurrent dislocation.

Most surgeons agree that emergent surgical treatment is warranted only in patients who have an osteochondral fracture. Detecting such a fracture is particularly important; as in contrast to adults, children have very high fracture healing rates after repositioning of the avulsed fragment, even when surgery is delayed [21]. Surgery is in order when the fragment is larger than 5 mm2 or is located in a weight-bearing zone (Fig. 8). We do not recommend stabilising procedures at the acute phase, as they may be either incomplete or excessive; instead, we advocate deferred stabilisation.

The classic radiographic axial views in 30°, 60° and 90° have limited reproducibility as they are taken at highly variable degrees and therefore, fail to detect poor patellar engagement in the trochlear groove within the first few degrees of knee flexion. Slice imaging is a better option. CT provides an assessment of patellar tilt with the quadriceps contracted or relaxed; however, this method involves patient exposure to radiation. MRI is undergoing
considerable development and is gradually superseding CT and CT-arthrography as a means of obtaining higher-resolution images of the cartilage.

7. Surgical procedures

7.1. Section of the lateral retinaculum

7.1.1. In patients with permanent patellar dislocation

This is the first step and is performed as part of the lateral approach to the knee. The division must be extensive, from the lower muscle fibres of the vastus lateralis proximally to the tibia distally. Filling of the large defect left by this procedure is controversial [14] and deemed unnecessary by many authors.

7.1.2. In patients with occasional patellar dislocation

Section of the lateral retinaculum is never performed alone. Some surgeons routinely perform this procedure, whereas others use it only when the lateral restraint is tight (as assessed by manual pressure). Either extra-synovial section or a lengthening plasty can be performed. This procedure can be done arthroscopically, although bleeding must be carefully controlled [22].

7.2. Correction of shortness of the quadriceps

7.2.1. The Judet quadricepsplasty procedure

The Judet quadricepsplasty procedure (Fig. 9) consists of extensively releasing all the quadriceps attachments to the femur and pelvis. A long lateral incision is performed. Muscle fibre release is extra-periosteal and extended very far proximally: in many cases, only after detachment of the vastus lateralis from its attachment on the trochanter can the quadriceps slip freely downward. The anterior and reflected tendons of the rectus femoris muscle must also be separated from their proximal attachment sites: we achieve this step via a short anterior incision, exposing the antero-inferior iliac spine. During muscle release, the myotome can be rotated internally around the femur; it is often necessary to release adhesions between the skin and muscle that prevent this rotation. Quadriceps release is considered complete when the knee can be fully flexed with the patella maintained in the trochlear groove. The success of this procedure is largely dependent on the quality of postoperative care, which is considerably improved by the use of epidural analgesia. During the day, splinting is used for 45 days to alternate limb position every 4 h between 90° of flexion (started as soon as the patient awakes) and extension.

7.2.2. VY lengthening plasty of the quadriceps tendon (Codivilla technique) [23]

This procedure involves no muscle resection, in contrast to the quadricepsplasty technique suggested by Thompson to correct knee stiffness [24]. The quadriceps tendonis separated from the vastus muscles by performing two vertical incisions that extend proximally as far as possible into the tendinous portion of the muscle and converge to form an inverted V. VY suture of the tendon is then performed with the knee in 90° of flexion. The vastus muscle expansions are folded to the midline, where they are sutured. Post-operatively, the knee is immobilised in a long-leg cast with 90° of knee flexion for 4 weeks. This procedure is less extensive than the Judet quadricepsplasty technique and has been reported to produce good outcomes [25]. Its main drawback is that the decrease in muscle trajectory, and therefore strength, can result in deficient active extension of the knee. In addition, true rotation of the myotome cannot be performed.

7.3. Distal procedures involving the tibial tuberosity

7.3.1. Classic mobilisation of the bony tibial tuberosity

Classic mobilisation of the bony tibial tuberosity is advocated for adults but cannot be performed until skeletal maturation is complete. The tuberosity can be displaced both medially and downwards.

7.3.2. The Grammont procedure (soft rod technique)

The Grammont procedure (soft rod technique) consists of medialisation of the patellar tendon and periosteum [26] (Fig. 10). A cold scalpel is used to carefully peel the deep patellar tendon fibres off the cartilaginous tubial tuberosity, without severing the distal tendon attachment to the periosteum. The cartilaginous tuberosity must not be damaged. Extensor mechanism alignment is achieved with the knee in 45° of flexion. Tendon fixation is performed using a periosteal flap or direct suture to the periosteum. There is a theoretical risk of anterior tibial tuberosity epiphysiodesis with tibial slope inversion. In a study by Garin et al., tibial slope inversion occurred in 20% of cases but was probably related to vascular factors and not
7.3.3. Roux-Goldthwait procedure: medial transfer of the lateral third or half of the patellar tendon

The lateral portion of the patellar tendon is detached from the tibia and slipped under the portion that is left continuous (Fig. 11) then, attached to the medial fibrous plane. Patellar rotation in the coronal plane is a drawback of this procedure that leads some surgeons to prefer a modified technique involving the medial half or third of the patellar tendon. The continuity of half the fibres may be viewed as an advantage compared to the Grammont procedure. We rarely use the original Roux-Goldthwait procedure, which we reserve chiefly for patients undergoing Judet quadricepsplasty or approaching full skeletal maturity.

In 1921, Galeazzi described a procedure involving the transfer of the pediculated semi-membranosus tendon to the tibia through an oblique patellar tunnel. This isolated reconstruction of the medial patello-tibial ligament also results in rotation of the patella in the coronal plane.

These procedures designed to achieve distal alignment of the extensor mechanism have a role to play in the treatment of permanent or usual patellar dislocation. Nevertheless, they may be losing ground as a result of the development of proximal alignment techniques, such as MPFL reconstruction.

7.4. MPFL reconstruction and overlapping medial retinaculum suture

MPFL reconstruction was introduced only very recently into paediatric practice. Creation of a femoral tunnel as advocated in adults is not recommended in patients with open physes: growth would result in metaphyseal tunnel migration towards the diaphysis, and an epiphyseal tunnel would be difficult to create given the proximity of the physis and absence of reliable anatomic landmarks. We prefer the techniques that involve femoral fixation in the soft tissues; these techniques also avoid the complications related to tunnels (e.g., pain and ballooning).

7.4.1. The Chassaing technique [22]

The gracilis tendon is passed through the full thickness of the posterior portion of the medial retinaculum near its femoral attachment site, where the tendon folds back on itself in a U-shape. The gracilis tendon is anchored to the patella sub-periosteally.

7.4.2. The Deie technique [28]

This method designed specifically for paediatric patients involves the transfer of the semi-tendinosus tendon, which is pediculated at its tibial attachment site and passed through a reflection pulley formed by the posterior third of the tibial collateral ligament. An advantage of the Deie technique is that a small incision over the epicondyle provides a reliable anatomic landmark consisting of the proximal attachment of the tibial collateral ligament. However, this single-strand graft is not anatomic and increases the risk of patellar...
rotation when the graft is taut; in addition, graft size may be too small in adolescents (Fig. 12B).

7.4.3. Our technique [29]

In 2010, we developed a technique derived from those described by Deie and Fithian (Fig. 12A). We use the same femoral reflection pulley as Deie, but we detach the tendon distally to allow double-strand reconstruction, which more closely replicates normal anatomy and increases strength. The semi-tendinosus is harvested using strippers, via a short posterior incision on the midline. In addition to MPFL reconstruction, we perform an overlapping suture of the medial retinaculum just before wound closure. This technique is consistent with the “favourable anisometry” concept, as the graft is slightly tightened in complete knee extension and slack in knee flexion (when the patella is seated in the trochlear groove). The best indications for this procedure are habitual dislocation in extension and occasional dislocation (Fig. 12C).

Opinions vary regarding the optimal degree of knee flexion during graft fixation; we flex the knee between 20° and 30°. Adjusting the tension is the most difficult point: excessive tension may result in medial impingement, particularly, when the lateral retinaculum is divided. The pre-requisite for using this procedure is normal patella height; patella alta is associated with a risk of graft distension.

We believe that MPFL reconstruction is particularly beneficial in paediatric patients, as it provides good stability and has an excellent effect on apprehension in patients with occasional dislocation. However, data from a larger number of patients with longer follow-ups are needed to validate MPFL reconstruction. MPFL reconstruction techniques are now valid alternatives to the Insall vastus medialis advancement procedure [30] and are superseding the procedures described by Krogius, Lecene, and Slocum.

7.5. Trochleoplasties/patelloplasty

The ability of the trochlea to undergo remodelling after repairing surgery is not agreed on. It has been argued that trochlear dysplasia is a primary abnormality associated with limited potential for remodelling and that trochleoplasty is therefore warranted. Others contend that recentring surgery before 7–8 years of age is followed by sufficient remodelling as to obviate the need for trochleoplasty.

We will focus here on the two main trochleoplasty techniques used in children.

7.5.1. Trochleoplasty with elevation of the epiphysis

A strictly lateral and epiphyseal osteotomy is performed (under fluoroscopic guidance) 5 mm behind the joint surface to be lifted (Fig. 13). Osteotomes are used to achieve very gradual elevation under the effect of local structure plasticity. The elevated fragment is held in place by impacting a bone graft into the osteotomy site. This procedure lifts the most distal part of the trochlea and is indicated in children who have permanent or habitual dislocation with a flat trochlea and no supra-trochlear spur. We avoid using this procedure in older children approaching skeletal maturity (risk of intra-operative fracture and growth complications).

7.5.2. Groove-deepening trochleoplasty as described by Dejour

This procedure induces a major change in trochlear shape by restoring the two trochlear slopes and, most importantly, eliminating the supra-trochlear spur (Fig. 14). The cancellous bone under the trochlea is removed using a powered burr. The amount removed is greater centrally, so that a trough is created, causing the trochlea to collapse in the middle [31]. The best indication is therefore prominence of the trochlea (types B and D) in a patient at skeletal maturity. This procedure should be performed only after skeletal maturity is complete, which may require postponing stabilisation surgery for several months or even years in a pre-adolescent in whom trochleoplasty seems indispensable.

7.5.3. Resurfacing patelloplasty

Partial lateral patellectomy, as performed in adults, has very little usefulness in children. Patelloplasty converts the flat or concave cartilage surface to the normal shape with two slopes separated by a crest. A dorsal longitudinal bony wedge is removed more or less laterally depending on the position chosen for the future crest. A grasping forceps is used to close the dorsal opening while preserving the posterior articular hinge. Fixation is with an absorbable trans-osseous suture (Fig. 15).


8. Treatment indications and strategies

8.1. General rules

Surgery is mandatory in patients with permanent or habitual patellar dislocation. However, patients with habitual dislocation in extension do not require a procedure on the quadriceps, although the patella may need to be lowered. In patients with occasional dislocation, surgery is warranted only after two episodes of true dislocation, i.e., after failure of the non-operative treatment initiated after the first episode. However, some surgeons perform surgery after the first episode in patients with functional symptoms and marked anatomic abnormalities.

Fig. 13. Intra-operative views during epiphyseal elevation trochleoplasty (7-year-old patient with habitual patellar dislocation in flexion). A. View from the top showing a flat or slightly convex trochlea. B. Introduction of wedge-shaped bone allografts to maintain the opening. C. Supero-lateral view showing restoration of the lateral trochlear slope. D. View from the top at the end of the procedure.

Fig. 14. Intra-operative views during groove-deepening trochleoplasty (16-year-old with habitual patellar dislocation in extension). A. View from the top showing type D trochlear dysplasia with a marked cliff pattern. B. View from the bottom showing marked prominence of the lateral slope and dysplasia of the patella. C. Large chondral fragment from the weight-bearing region of the lateral condyle. D. Preparation for trochleoplasty. E. Mosaic plasty using grafts from the lateral aspect of the condyle (cartilaginous metaplasia) before trochleoplasty. F. Appearance after trochleoplasty (fixation using flexible absorbable pins).
An individually tailored surgical procedure should be performed in a single stage that combines one or more of the above-described techniques. Performing some of the techniques before the end of growth and the others at skeletal maturity is unadvisable. When the child is near the end of growth, the best strategy may be to wait a few months to allow the use of simpler and more comprehensive techniques, such as groove-deepening trochleoplasty or tibial tuberosity medialisation/distalisation.

8.2. Specific situations

8.2.1. Congenital dislocation

Surgery is considered as soon as the condition is diagnosed and is performed if possible before 1 year of age. A sound strategy consists of starting by correcting the knee flexion via a series of corrective casts followed by splints, until the knee can be almost fully extended. The surgical procedure then includes extensive quadriceps release and lateral release (section of the lateral retinaculum) (Fig. 16). Multi-level incisions in the fascia of the ilio-tibial tract and lengthening of the lateral intermuscular septum and/or biceps femoris tendon may be required. An incision is made in the joint capsule along the medial edge of the patella to release the joint and quadricipital recess. At this young age, the potential for remodelling is considerable and neither trochleoplasty nor patelloplasty are usually needed, even in patients whose trochlea and patella are very flat (and small). A Roux–Goldthwait type procedure is preferable over the Grammont procedure, to minimise the risk of extensor mechanism rupture. MPFL reconstruction can be added but should not be used to compensate for insufficient correction or stability at this stage. Adding the Insall vastus medialis advancement technique or overlapping suture of the medial retinaculum completes the treatment. Knee extension is usually restored with no residual valgus and without requiring an alignment osteotomy (Fig. 2). We believe that correcting misalignment during the same procedure is hazardous and we prefer to realign the knee later on if needed. The older the patient at management initiation, the greater the complexity of the surgical procedure and the higher the risk of failure.

8.2.2. Permanent dislocation

Corrective surgery should be offered as early as possible, even to patients with limited functional impairments, as tolerance in the medium term is consistently poor and requires multiple complex procedures associated with a higher risk of osteoarthritis. We believe that the Judet procedure to fully release the quadriceps is preferable over VY lengthening quadricepsplasty. The arthrotomy allows a detailed examination of the joint, including an assessment of congruence; if a sagittal partition responsible for agenesis of the medial trochlear slope is found (nail-patella syndrome), it should be resected. Epiphyseal elevation trochleoplasty with or without patelloplasty should be considered in patients with patello-femoral incongruence. These procedures are indispensable in patients who are treated late, as the posterior patellar surface becomes concave due to contact with the lateral condyle. When permanent dislocation is left untreated until skeletal maturity is achieved,
groove-deepening trochleoplasty is often preferable. The distal procedures are the same as in congenital dislocation. Distalisation of the patella is rarely necessary. We routinely perform MPFL reconstruction, despite the absence so far of proof of benefits in this indication.

8.2.3. Habitual dislocation in flexion
Release of the quadriceps is limited in some cases to detachment of the proximal (or lower distal) portion of the rectus femoris tendon combined with vastus lateralis release confined to the distal portion of the muscle. The goal of these procedures is to allow at least 130° of knee flexion with the patella centred in the trochlear groove.

8.2.4. Habitual dislocation in extension and occasional dislocation
In patients without true shortening of the quadriceps, the only procedures required are as follows, in the order in which they are performed: section of the lateral retinaculum guided by the severity of the contractures; patellar distalisation if needed; trochleoplasty (particularly in type B or D dysplasia); and MPFL reconstruction, which is done almost routinely [32]. Isolated MPFL reconstruction has been advocated but follow-up is too short at present to allow definitive conclusions about this strategy (Fig. 17).

9. Results
The results reported in the literature are extremely difficult to evaluate. Severe forms are rare and many case-series combine patients with congenital dislocation, permanent dislocation, and even habitual dislocation [25,27,28]. The earliest case-series include a few patients with severe patellar dislocation who were not treated until adulthood; these patients had high rates of complications, revision surgery, and failure.

Only two case-series, published in 2000 and 2008, respectively, focused on congenital patellar dislocation [13,14]. Despite early surgical treatment between 6 months and 5 years of age, the procedure failed in 1 of 6 and 1 of 8 patients, respectively. Nevertheless, knee function is rarely normal in these patients with severe syndromic conditions; thus, residual fixed knee flexion or flexion range limitation is common.

In patients with permanent or habitual patellar dislocation treated during childhood, the failure rate ranges from 10% to 30%. Failure requires revision surgery. However, in the medium term, 80% of knees are asymptomatic and nearly normal.

Finally, surgical treatment for occasional patellar dislocation during childhood or adolescence has produced good results in 75% to 80% of the cases. As surgery is customised, involving combinations of procedures selected on a case-by-case basis, the contribution of each procedure is difficult to determine. However, the failure rate can be estimated at 50% for Insall-type procedures, 5% to 15% for the distal Roux-Goldthwait and Galeazzi procedures, and less than 5% for MPFL reconstruction in children [28,29,32]. All procedures are associated with a risk of delayed patello-femoral pain.

10. Conclusion
Congenital dislocation of the patella, which is the most severe form of patellar instability, is increasingly well understood. This condition constitutes a valuable pathophysiological model that involves all the components of the knee extensor mechanism. The new classification system based on the anatomic defects is more rational. The role for the MPFL and the development of new reconstruction techniques may provide new impetus to patellar instability surgery. Nevertheless, the management strategy must be tailored to the specific features in each patient, and no single procedure is appropriate for all cases. Thus, patellar instability surgery raises a number of challenges for future paediatric orthopaedic surgeons.

Disclosure of interest
The authors declare that they have no conflicts of interest concerning this article.

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