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Management of patellar instability in skeletally immature patients

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- Surgical intervention is the treatment of choice for recurrent lateral patellar instability.

- Surgery should be considered for first time lateral patella dislocations with osteochondral fractures or underlying anatomical risk factors.

- Primary repair and nonanatomical imbrications/reconstructions have fallen out of favor due to abnormal biomechanics and high rates of recurrence. Anatomical reconstruction of the MPFL using a variety of auto and allograft tissues have yielded good outcomes and low redislocation rates.

- Physeal sparing MPFL reconstruction techniques under radiological control are safe and do not cause growth disturbance. Allografts may be indicated for hyperlax patients.

- Although no clear cutoff points exist, correction of valgus and excessive femoral anteversion should be considered when indicated.

- Osteochondral and chondral injuries are common and should be addressed during surgery for instability.

Keywords: patellar instability, medial patellofemoral ligament reconstruction, patellar dislocation, femoral anteversion

Patellar instability is an important cause of knee disability in children and adolescents. A recent population-based study found an annual incidence rate of 2.58 per 100 000 individuals for lateral patella dislocations (LPD), with higher rates in females and patients aged <19. Two thirds of the injuries were related to sports (1). Higher annual rates up to 125 per 100 000 individuals have been found in smaller studies (2).

Risk factors for patellar instability including patella alta, generalized hyperlaxity (e.g. Ehlers–Danlos syndrome), trochlear dysplasia, dysplasia of vastus medialis obliquus (VMO), increased Q angle, genu valgum, increased femoral anteversion and tibial torsion have been adequately discussed in a previous review in this journal (3).

Initial evaulation

The workup of a patient with acute patellar instability starts with a physical exam focusing on patellar tracking, presence of J sign, joint hyperlaxity, coronal extremity alignment and rotational profile of the extremity. Anteroposterior, lateral knee x-rays and Laurin views of the patella are reviewed for the presence of patellar subluxation, osteochondral fracture, trochlear dysplasia and patellar height. A magnetic resonance imaging (MRI) scan is mandatory to assess the location and extent of MPFL injury, osteochondral damage to the patella and/or lateral femoral condyle and to measure tibial tuberosity–trochlear groove (TT-TG) distance. Long

leg radiographs are used to analyze coronal extremity alignment if genu valgum is observed in the clinical exam. Assessment of the rotational profile of the extremity with a CT scan is performed only if warranted by the clinical exam. Increased internal rotation of the femoral condyles in MRIs where the knees are fixed with the patellae facing upward during the scans may be a sign of excessive femoral anteversion and is an indication for CT evaluation for the authors. The decision for conservative vs surgical treatment is made after a complete evaluation of morphology and injury. Several studies have analyzed the risk factors for recurrence after the first episode of patellar dislocation. Balcarek *et al.* have described a 'Patellar Instability Severity Score' where age, bilaterality, trochlear dysplasia, patellar tilt and height and TT-TG distance are assessed. A score greater than 4 out of a maximum score of 7 implies a higher risk for recurrence and surgery is advised (4). Jaquith & Parikh have identified trochlear dysplasia, history of contra-lateral dislocation, skeletal immaturity Caton-Deschamps index 1.45+ as the main risk factors in a population of 222 patients (5). The recurrence risk increases from 14% in a first-time dislocator with none of the above risk factors to 88% in a patient with all four factors. It seems that the combination of underlying risk factors is more important than a single anatomical abnormality and the decision to operate should be tailored for each patient. Table 1 outlines the authors' thresholds for surgical vs conservative treatment.

Conservative treatment

Traditionally conservative treatment was considered to be the standard of care in the treatment of first time LPD unless an osteochondral fracture or loose body was present. Surgery was advised for patients with recurrent instability. However, the outcomes of conservative treatment were not as good as expected. A 3-year follow-up of 111 patients treated conservatively found that although 73% did not have another episode of instability, many still reported limitations in their activities and only 26% were able to return to sport (6). The risk of recurrent instability is higher in skeletally immature patients compared to adults.

A meta-analysis of 11 randomized controlled trials and 5 cohort studies including 918 patients comparing conservative vs operative treatment found lower recurrence rates and better Kujala scores in the operative group (7). However, the difference in pain scores and episodes of subluxation was not significant.

It seems that conservative treatment may be indicated in a small subset of patients without underlying anatomical risk factors or osteochondral fractures. If nonoperative treatment is chosen, a brief period of rest and immobilization is followed by early knee range-of-motion exercises and quadriceps reeducation. A patellar brace may be helpful. Casting for extended periods of time should be avoided.

The risk of recurrent dislocation increases with length of follow-up in skeletally immature patients. Sanders *et al.* found that the cumulative incidence rate for recurrence was 11% at 1 year, 21.1% at 2 years, 37% at 5 years, 45.1% at 10 years, 54% at 15 years and 54% at 20 years (8). Therefore, it is not clear how long these patients should be followed up after the initial dislocation. As the majority of the recurrences occur in the first 5 years, this period of observation seems reasonable.

Operative treatment

There is an increasing trend toward surgical treatment of first-time LPD in patients with underlying risk factors (9). Patients with recurrent instability should be treated operatively to prevent progressive cartilage damage and improve quality of life.

Surgical treatment should be tailored to the patient, with reconstruction of the injured medial restraints and treatment of osteochondral fractures while avoiding injury to the growth plates. Lateral release or lengthening should be reserved for permanent dislocations with severe tightness of the retinaculum and should be avoided in hyperlax patients. Correction of excessive

Table 1 The authors' indications for conservative vs surgical treatment. The presence of two or more risk factors strongly favors surgery.

Consider surgery	Consider conservative treatment
Large osteochondral fragment/loose body	Small flakes on the medial patellar border
Patella subluxed in transverse imaging, patellar tilt >20°	Patella centralized in transverse imaging, patellar tilt <20°
Dejour type B, C and D trochlear dysplasia	Dejour type A trochlea
Presence of J-sign and preexisting symptoms of instability	No previous symptom of instability
Genu valgum >10°	Neutral or constitutional varus alignment
Femoral anteversion >30°	Femoral anteversion <20°
Syndromic joint hyperlaxity (Ehlers–Danlos, etc.) Beighton score >6	Beighton score <6
Patella alta (Caton index 1.3+)	Caton index 0.8–1.2
TT-TG distance >16 mm	TT-TG distance <16 mm
Contralateral patellar instability	Unilateral instability

femoral anteversion and pathological genu valgum can be performed in the same setting if needed. Comparative studies have shown the superiority of medial patellofemoral ligament (MPFL) reconstruction to traditional lateral release and medial imbrication procedures (10). Nonanatomical techniques of plication or primary repair of medial structures do not restore normal biomechanics and may increase patellofemoral joint reaction forces (11); these have fallen out of favor and have generally been replaced by more anatomical MPFL reconstructions.

MPFL anatomy in skeletally immature patients

MPFL is the main static stabilizer of the patella and provides up to 60% of the restraint to lateral translation at 0–30° of knee flexion. Recent anatomical studies have identified other structures such as the medial quadriceps tendon femoral ligament (MQTFL) that contributes to the stability near extension. Although MPFL reconstruction remains the mainstay of treatment of children with patellar instability, combined techniques that also reconstruct the MQFL have also been described (12). The medial patellotibial ligament (MPTL) and medial patellomeniscal ligament (MPML) are the distal stabilizers of the patella and have a role in preventing lateral patellar translation in flexion (13).

MPFL injury has been identified in over 90% of the patients following acute patellar dislocation (12, 13). The location of MPFL injury is at the patellar insertion site in over 80% of the children and multifocal in the rest (14, 15).

The relationship of the femoral insertion of MPFL and the distal femoral physis has been extensively studied. A systematic review of seven studies has shown that the femoral insertion is 3.7 to 10 mm distal to the physis, with a mean distance of 6.9 mm in 93% of the cases (16). The relationship of age and insertion site is controversial, with some studies finding distal and others demonstrating proximal migration with age (16). If femoral sockets are to be used in MPFL reconstruction, the starting point should be on the center of MPFL insertion and angled distally and anteriorly to avoid physeal damage and violation of the intercondylar notch (Fig. 1). The tunnel length should be limited to 20 mm (17, 18). No growth disturbance has been reported with fluoroscopically placed femoral sockets avoiding the physis (19). The patellar insertion of the MPFL has been found to be slightly distal compared to adults in smaller children, extending and sometimes passing distally to the center of the patellar length (20).

MPFL repair

The role of repair of MPFL in the treatment of first-time LPD is controversial. A randomized study involving 74 immature patients found a lower redislocation rate compared to brace treatment in patients undergoing acute repair (21). No difference between subjective and objective outcomes could be demonstrated between operative repair and brace treatment. However, the rate of redislocation was 22% in the repair group which is almost four times higher compared to most studies with MPFL reconstruction. Given that primary repair attempts to suture an already injured and attenuated ligament and does not correct underlying anatomical risk factors, the higher rates of failure are expected.

MPFL reconstruction

MPFL reconstruction in skeletally immature patients is a safe operation, with no reported growth disturbance unless a technical error occurs. A meta-analysis of seven studies including 132 children and adolescents found no growth disturbance but reported 3.8% redislocation and 11.4% subluxation events, which is higher than adults (22). Graft choice and femoral fixation method had no effect on outcome or complications in this systematic review (22). Immature patients also have a higher rate of subsequent injury to the knee after MPFL reconstruction (23).

The outcomes of MPFL reconstruction in children and adolescents are favorable. A systematic review of 15 studies comprising 517 procedures found improved Kujala scores and return to sport at 6.1 months. The redislocation rate was 5% and 4% of the patients required further surgery (24).

Figure 1

Femoral tunnel drilling under image intensifier control during physeal sparing MPFL reconstruction.

MPFL reconstruction with free tendon grafts

Hamstrings are the most commonly used grafts for MPFL reconstruction. The doubled gracilis tendon is adequate for most patients and the semitendinosus can be preserved. Femoral fixation is made in a single socket at the anatomical insertion distal to the physis. Technical details described in the previous section are important to avoid injury to the distal femoral physis, medial collateral and cruciate ligaments. A variety of patellar fixation methods using single or double sockets, and anchors in a groove on the medial patella have been described (Fig. 2). Nelitz *et al.* (25) have shown no recurrence and good Kujala scores after anatomic MPFL reconstruction using a gracilis tendon graft, regardless of the presence of patella alta or increased TT-TG distance. Double tunnels in the patella better mimic the anatomy of the MPFL and have slightly lower recurrence rates; however, they are associated with increased risk of patellar fracture (26).

MPFL reconstruction is a very powerful tool but over tensioning the graft may lead to increased patellofemoral contact pressure, loss of knee motion and in severe cases medial subluxation of the patella. The reduction of the patella in the trochlea should be verified arthroscopically and a lateral mobility of one-fourth patellar width in extension should be preserved when tensioning the graft.

MPFL reconstruction with pedicled quadriceps tendon grafts

A pedicled quadriceps tendon graft with the patellar insertion intact has also been used for MPFL reconstruction. This technique is advantageous in children with small patella and avoids the problems of patellar tunnels and consequent risk of articular penetration or fracture. The graft can either be fixed in a femoral socket anatomically, or may be sutured to the adductor magnus tendon in a quasi-anatomical fashion. Nelitz *et al.* (27) have reported on the 2.6-year follow-up of 25 children undergoing anatomical MPFL reconstruction with a pedicled quadriceps tendon graft. They found no recurrence, and 80% of the patients were satisfied with the procedure. Return to sports was possible for most of the patients at 5 months. A systematic review of nine studies in children and

young adults undergoing MPFL reconstruction using pedicled quadriceps tendon grafts also found favorable outcomes with no redislocations/reoperations and 3% residual positive apprehension test (28).

Adductor sling fixation with free grafts

Adductor magnus based MPFL reconstructions aim to avoid drilling tunnels near the distal femoral physis. A free tendon graft is looped around the adductor magnus and fixed to the patella in tunnels or in a boney groove on the medial side. However, high rates of redislocation and revision (20% and 21%, respectively) have been reported with this technique, probably due to the nonanatomical placement of the graft and reliance on soft tissue fixation (29).

A modification of this technique with the distal end of the hamstring tendon left on intact on the tibia and looping the proximal end around the adductor magnus and securing it to the medial patella has also been reported to have slightly higher (13%) redislocation rates (30).

Adductor magnus tendon MPFL reconstruction

A distal pedicled adductor magnus tendon can also be used in skeletally immature patients to avoid a bony femoral fixation near the physis (31). A partial or total strip of adductor magnus tendon is harvested, leaving the distal insertion of the tendon intact. Care must be taken not to injure the superficial femoral artery during harvest. The pedicled tendon graft is passed under the vastus medialis and fixed to the medial margin of the patella using an osseous or a soft tissue technique.

Malecki *et al.* reported on 26 patients treated with this technique (32). The authors found favorable clinical outcomes that were maintained throughout the observation period over 10 years without inducing degenerative changes.

Allograft reconstructions

Allograft tissues have been proposed as an alternative to autografts for MPFL reconstruction, especially for
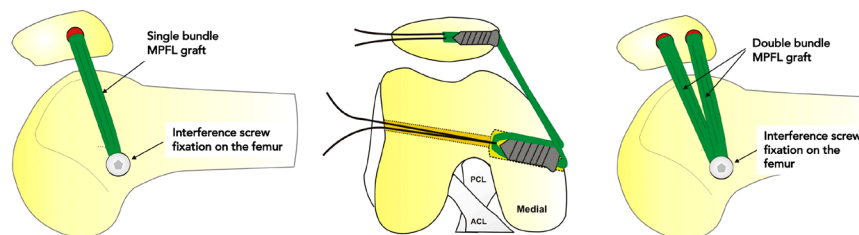
Figure 2

Schematic illustration of single- and double-bundle MPFL reconstructions.

patients with pathological hyperlaxity (Beighton score >6) and syndromic patellar instability (33). Hohn and Pandya reported similar outcomes (8% recurrence and 16% complications) with the use of allografts compared to autografts in their series of 25 children and adolescents undergoing MPFL reconstruction at 2-year follow-up (34). Another series of 24 knees undergoing MPFL reconstruction using gracilis allografts reported 12.5% recurrent instability without growth disturbance (35). In the largest study performed up to date, Reddy reported the outcomes of 76 allograft MPFL reconstructions in hyperlax children with a mean Beighton score of 7 (36). The mean Kujala score was 89 and the recurrence rate was found to be 9% at 3 years. The advantages of absence of donor site morbidity and loss of flexor strength of allografts should be balanced against the increased cost, poor incorporation and the risk of disease transmission and infection. The authors recommend the use of allografts in cases with generalized hyperlaxity due to pathologic collagen synthesis (e.g. Ehlers–Danlos syndrome).

Derotation osteotomies

Rotational abnormalities of the lower extremity such as excessive femoral anteversion and tibial external rotation have been implicated as risk factors for patellar instability and failure of operative treatment. CT scans provide the most objective measurements of these deformities. Different methods to measure femoral anteversion and tibial rotation produce variable results and the surgeon should familiarize himself or herself with the differences between the techniques and use a standard technique for measurement (37). Most of the studies on transverse plane correction have been performed in young adults with closed physes.
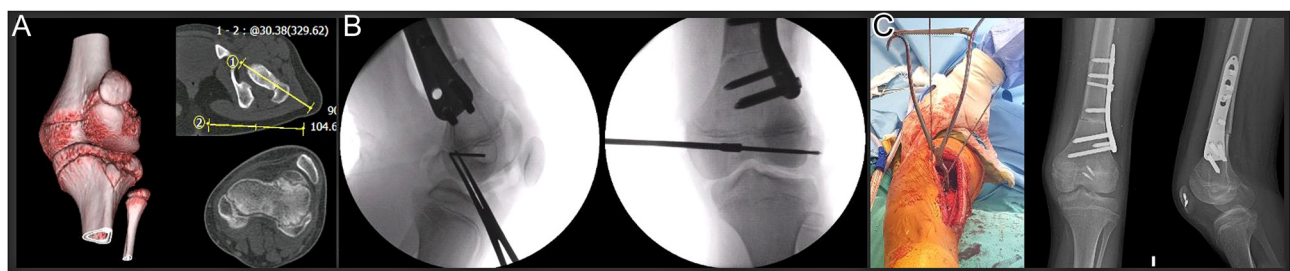
Derotation osteotomy combined with MPFL reconstruction has been shown to have better clinical outcomes and less residual J-sign compared to isolated MPFL reconstructions (Fig. 3). Twenty-five degrees has been proposed as a cutoff point in skeletally mature patients (38). Failed MPFL reconstructions in patients with increased anteversion also benefit from revision MPFL reconstruction combined with DFO (39). A recent systematic review of six studies reported DFO was indicated for 20˚–30˚ anteversion in skeletally mature patients with patellar instability; however, femoral anteversion >30˚ is generally considered to be a cutoff point for DFO (40). Mild anteversion around 20˚ does not seem to adversely affect the outcomes of MPFL reconstruction (41).

Correction of tibial external rotation has been reported less frequently. External tibial torsion >35˚ is considered to be an indication for tibial osteotomy, and can be performed in the proximal or distal tibia. A fibular osteotomy is usually needed and prophylactic peroneal nerve decompression has been advised for the correction of severe deformities (42).

Correction of valgus

Genu valgum is an important factor for patellar instability due to increased Q angle and the lateral vector of the quadriceps mechanism. Genu valgum >10°, mechanical axis in or outside the lateral knee compartment, and a mechanical lateral distal femoral angle (mLDFA) <84° in a skeletally immature patient have been recommended for correction of valgus deformity (43). Growth modulation techniques are minimally invasive and can be used in children with at least 1 year of remaining growth; however, the best outcomes are achieved in girls <12 and boys <14 years of age. Kearney *et al.* (44) have treated 26 valgus knees associated with patellar instability with hemiepiphysiodesis and reported resolution of symptoms of pain and instability in 69% of the patients with correction of aLDFA to normal. The authors did not perform any procedure to realign the extensor mechanism in this series, the cutoff point for surgery was <79˚ or smaller for aLDFA. Tan *et al.* (45) performed isolated medial hemiepiphysiodesis to treat patellar instability 20 patients with valgus knees. Sixteen

Figure 3

Combined distal femoral derotation osteotomy and MPFL reconstruction in a patient with bilateral patellar instability. (A) Preoperative CT scan demonstrating subluxed patella and femoral anteversion of 30˚ in a 13-year-old girl. (B) Drilling of the MPFL femoral tunnel, MPFL graft was placed in a groove on the medial border of the patella and suture anchors were used for fixation. (C) K-wires depict the amount of correction achieved intraoperatively, x-rays show healing of the osteotomy at 6 weeks.
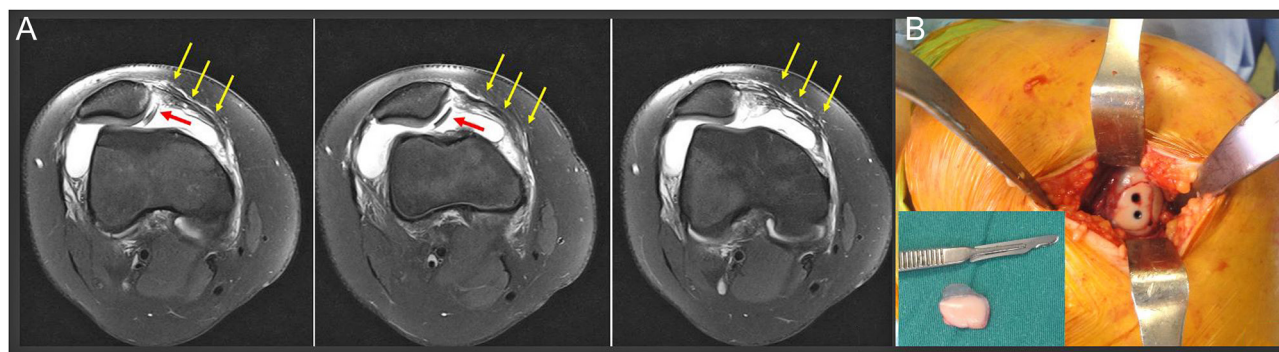
Figure 4

(A) Loose osteochondral fragment originating from the lateral femoral condyle (red arrows) following LPD. Injury to the MPFL can be seen (yellow arrows). (B) Fixation of the fragment with two headless screws.

patients had no further instability at the final follow-up, but the authors concluded that this procedure was effective in less deformed knees. Parikh *et al.* (46) reported the use of a transphyseal screw placed from the lateral cortex to achieve medial hemiepiphysiodesis combined with gracilis autograft reconstruction of MPFL using patellar and femoral tunnels in eight patients. All but one patient with Down syndrome achieved satisfactory outcomes. Guided growth correction of valgus also provides a significant correction of the TT-TG distance (47), which is beneficial in patients with open growth plates where tibial tuberosity osteotomies are contraindicated. The eight plates used for guided growth impede with MPFL reconstructions and require a certain amount of time to achieve the desired correction; therefore, they may not always be an option in patients with painful recurrent patellar instability. In this case, distal femoral osteotomy proximal to the physis may be indicated. Distal femoral osteotomies may also be utilized in teenagers after skeletal maturity (48) but should probably be combined with MPFL reconstructions.

In summary, the authors recommend correction of genu valgum in children with open physes with guided growth. A distal femoral osteotomy should be considered in skeletally mature adolescents for genu valgum exceeding 5°.

Osteochondral fractures and cartilage injuries

Osteochondral fractures may occur in the medial facet/central ridge of the patella and the lateral femoral condyle at the time of dislocation (49). The prevalence of these osteochondral lesions has been reported to be between 17 and 30% for the lateral femoral condyle (50) and up to 76% for the patella (51).

Isolated treatment of osteochondral fractures without addressing the instability results in high rates of recurrence and the need for secondary surgery (up to 61% in one series) and should be avoided (52). Current

thinking is that both the fracture and instability should be treated in the same surgical episode with modern reconstruction techniques (53).

Osteochondral injury is associated with the development of arthritis, with rates up to 48% at 25 years (54) follow-up, and should be addressed at the time of MPFL surgery.

Small impression fractures on the lateral edge of the condyle can be debrided, while larger lesions extending to the weight-bearing area need to be fixed or managed with cartilage restoration techniques (Fig. 4). A variety of fixation methods including metal and bioabsorbable screws, arrows, pins, sutures and fibrin glue can be used. No superiority of one technique over the others has been demonstrated. Metal screws provide superior compression but carry the risk of chondral damage if the fragment subsides and may necessitate secondary removal. Biodegradable implants provide inferior compression and fixation strength and may cause cystic/allergic reactions during resorption. Although over 90% healing rates have been reported (55), secondary surgery for trimming of protuberant nails or chondral debridement may still be needed. The fixation of pure chondral fragments is controversial, but given the younger age and greater healing potential of these patients, it may be attempted in acute lesions. A recent multicenter study found 56% complete healing in MRI scans after fixation of these pure chondral fragments with bioabsorbable screws in adolescents (56).

Patellar lesions usually involve the median ridge and the medial facet. These lesions need to be fixed if adequate bone stock is present, and a conflict with the MPFL reconstruction sockets should be avoided. The same applies for patients undergoing mosaicplasty; fixation of the MPFL graft should be modified if a conflict with the mosaicplasty sockets emerges.

Conclusion

The paradigm of conservative treatment for first-time LPD has changed in recent years for patients with

underlying anatomical risk factors. MPFL reconstruction using physeal sparing techniques is safe and results in low recurrence rates. Coronal and transverse plane deformities should be corrected. Cartilage repair/restoration should be an integral part of the surgical treatment.

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