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Current Concept Review

Risk factors and treatment rationale for patellofemoral instability in the pediatric population

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ABSTRACT

Patellofemoral instability (PFI) is one of the most common musculoskeletal problems in physically active children and young adults. PFI may significantly limit physical activity and increase the risk of developing arthritis long term. Identification and appropriate management of PFI is crucial in preventing long-term sequelae in the pediatric population. The purpose of this article is to review current concepts in PFI in young patients, focusing on epidemiology, risk factors, and treatment rationale.

Key Concepts:

1) Patella femoral instability (PFI) is most common in young, physically active female patients with predominance during adolescence between the ages of 13 and 18.
2) Non-contact sports injuries are the most common mechanism of PFI injuries.
3) Treatment of PFI involves non-operative and operative management with the goal of patellofemoral joint stability and high functionality.
4) Surgical management is indicated for recurrent PFI. For first-time dislocation, selection of operative management depends on presence of risk factors for recurrent instability, such as trochlea dysplasia, patella alta, ligamentous laxity, and age as well as the presence of osteochondral injury.

Introduction

Patellofemoral instability (PFI) is defined as the condition that is associated with partial subluxation or complete dislocation of the patella—almost always laterally—from the trochlear groove [1,2]. It is estimated that PFI accounts for approximately 2% to 3% of all knee injuries, predominantly impacting the pediatric population, especially adolescents [2]. The incidence of PFI has been estimated to be 43 per 100,000 in patients under the age of 16 and rises to 147.7 per 100,000 in adolescents ages 14 to 18 [3–5]. In much younger children, complex PFI patterns are observed often as part of syndromic conditions, such as Kabuki syndrome, Downs syndrome, and nail-patella syndrome [6]. On the other hand, it is posited that the disproportionate incidence of PFI in the adolescent population may be due to engagement in high-risk activities due to the early specialization and participation in sports, especially basketball, soccer, and football [1,4,7]. Additional reasons theorized to account for the adolescence predominance of PFI include dramatic skeletal changes and changes in ligamentous laxity that influence the mechanics and alignment of the knee joint and overall lower extremities [4,7].

The underlying mechanism of PFI is complex and multifaceted. Trauma typically induces PFI, however certain anatomical characteristics may lend individuals particularly vulnerable to this instability [7]. Anatomical risk factors include, but are not limited to, trochlea dysplasia, patella alta, ligamentous laxity, limb malalignment, patellar tilt, immature physes, and an increased Q angle [2,3,6–8]. Prior patellar dislocation or contralateral PFI, a family history of PFI, and young age at the first instability event are additional factors that place individuals at a higher risk of PFI [2,8].

Both nonoperative and operative treatment options exist for PFI. First-time dislocations in children of the patella were almost universally treated nonoperatively with a regimen of physical therapy, bracing, and activity modifications [3,6,7]. However, following an initial instability event, re-dislocation rates ranges from 15% to 44% [8,9], and surgical intervention is often required to resolve the persistent instability [3]. More recently, it is recognized that in pediatric patients

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with certain risk factors, conservative treatment will likely be futile, and earlier surgical intervention after the first dislocation event is optimal [3,7,9,10]. Prompt treatment is essential as it appears that decreases the risk of subsequent instability events and patellofemoral arthritis is a sequela of recurrent patellar dislocations [3].

The present review aims to summarize PFI demographics, risk factors, and treatment rationale.

Risk factors

Age

Children between the ages of 13 and 18 years old are at increased risk for PFI compared to the general population [7,11]. Identifying the true incidence of PFI in pediatric patients is challenging given the difficulty in diagnostic criteria and variety of symptoms. A population study over 21 years estimated the cumulative incidence of first-time lateral patellar dislocation to be 23.2 per 100,000 person-years with an average age of 21 years old [4]. Patients under 13 years old had a cumulative incidence of 13.5, with a sharp increase to 147.7 for patients between 14 and 18 years old and a peak at 15 years old. The incidence significantly declined for older patients [4]. Other studies support the notion that children are particularly susceptible to PFI, including a prospective study in Helsinki which identified an incidence rate of 43 per 100,000 person-years for children under the age of 16 years old [5]. A prospective study utilizing data from the Kaiser Permanente health care system in San Diego identified an incidence rate of 33 per 100,000 person-years for children between 10 and 17 years old [12]. Another study investigating acute, traumatic patellar dislocation among the United States Military Service members found an incidence rate of 64 per 100,000 person-years for individuals under 20 years old [13]. One possible reason for youth predominance is the rapid skeletal growth changes that occur during late childhood and adolescence. Rapid growth during these years may result in temporary changes in lower extremity mechanics, alignment, and ligamentous laxity [14]. Special consideration must be given to skeletally immature patients when determining appropriate treatment. Particularly, attention to the growth plate status is paramount for planning surgical intervention that includes physis-sparing techniques to prevent interference with symmetric growth [7]. Even though the exact age of increased risk has yet to be discerned, most studies identify adolescence as a period of high risk for patellofemoral instability.

Gender

Young females are believed to have an increased risk for PFI [12]. Sanders et al. reported that females under 13 had an incidence rate of 17.5 per 100,000 person-years compared to 9.6 per 100,000 person-years for males, which was statistically significant. Other epidemiologic studies showed that female children had a 33% higher risk for PFI between the ages of 10 and 17 years old and were 61% more likely to have PFI under the age of 20 [12,13]. Recent data showed that PFI secondary to acute trauma has no significant difference in incidence rates between males and females [15]. Using the National Electronic Injury Surveillance System database, a catalog of all emergency department visits in the United States, Waterman et al. demonstrated no statistical difference in first-time PFI events between males and females under 19 years old [2]. It is not entirely known why females appear to have a higher risk. There is limited evidence in the field, but certain theories have correlated potential characteristics with higher incidence of PFI. For instance, PFI relating to chronic laxity has a higher incidence in females compared to males [16]. Additionally, Fithian et al. did observe that females who presented with a history of PFI had a slightly greater degree of lower extremity torsional malalignment, though physical and radiographic indices did not reflect the same significant difference [12].

Sports participation

Young and physically active patients are at the highest risk for PFI with sports being the most common mechanism of injury. Studies have shown that up to 51% to 88% of young adults experiencing acute patellar dislocation were participating in sports at the time of injury [2,12,16]. The most common sports were football, soccer, running, volleyball, softball, and baseball [2]. In the study by Nietosvaara et al., 66% of young patients with acute patellar dislocations (n = 72) had sports-related injuries. Of the 44% with non-sports-related injuries, falling down (13), jumping (10), and walking (7) accounted for the most common causes. In the same study, it was reported that 96% of the patellar dislocations resulted from an indirect mechanism and 4% resulted from a direct blow to the knee [5]. Zheng et al. further supported this statement by showing that 80% of young patients with PFI (n = 492) experienced non-contact injuries [16]. While there are very few studies evaluating pediatric non-sports-related mechanisms of injuries, adult studies have shown that up to 24% of patients develop PFI due to activities of daily living (ADL) [2].

Anatomic and biomechanical factors predisposing to PFI

The medial patellofemoral ligament (MPFL) is considered the primary static stabilizer to lateral patellar translation, providing 50% to 60% of the medial stabilizing force necessary to prevent lateral dislocation with applied tension [17,18]. In addition to the MPFL, recent anatomic dissections have illuminated the presence of the medial quadriceps-tendon-femoral ligament (MQTFL), an additional medial stabilizer that inserts onto the tendon of the quadriceps muscle [18,19]. As such, the medial patellofemoral complex (MPFC) is the term commonly used to describe the structure that comprises the MPFL and the MQTFL.

When the knee is fully extended, the patella is superior to the trochlea with minimal femoral engagement. Knee extension causes slight lateral deviation of the patella and maximal MPFL strain [20]. The MPFL's contribution to patellar stability is crucial between 0 and 30 degrees of knee flexion. As the knee flexes between 0 and 20 degrees, the MPFL relaxes, enabling lateral patellar laxity. At this point, the patella is at the greatest risk for lateral dislocation [21]. Once 20 to 30 degrees of knee flexion occurs, the patella begins engaging the trochlear groove, and the bony surface of the joint captures the patella thus enabling adequate stability [11,20,21].

PFI is multifactorial in cause, and children with PFI often have intrinsic anatomical characteristics predisposing them to dislocation. Dejour identified 4 significant factors associated with PFI, including (1) trochlear dysplasia, (2) patella alta, (3) excessive TT-TG distance, and (4) patellar tilt [17]. Other factors associated with pediatric PFI are ligamentous laxity, weakness of the vastus medialis, high Q angles (> 15 degrees), femoral anteversion, and genu valgum [3,7,24].

Among osseous abnormalities, trochlear dysplasia correlates most strongly with PFI [21,25] and it is defined as a pathologic alteration in the shape of the femoral trochlea— resulting in a flat or shallow trochlear groove with or without an associated supratrochlear prominence. Radiographically, trochlear dysplasia can be identified with the "crossing sign" in which the trochlear track intersects the anterior femoral condyle along with a large sulcus angle [26,27]. Classification according to the Dejour criteria can guide risk and treatment modalities for trochlear dysplasia [27]. Though the Dejour Trochlear Dysplasia types vary across studies [28], in a cohort of 111 children with PFI, Seeley et al. observed Dejour Type A trochlear dysplasia in 23%, Type B in 28%, Type C in 11%, Type D in 5%, and 33% of patients with no trochlear dysplasia. There was no significant difference in type of trochlear dysplasia across ages or sex of patients [29]. Furthermore, in their meta-analysis, Barzan et al. report that over 50% of pediatric patients with PFI had a form of trochlear dysplasia (when classified as per the Dejour criteria, Types A, B, C, and D), with a significantly

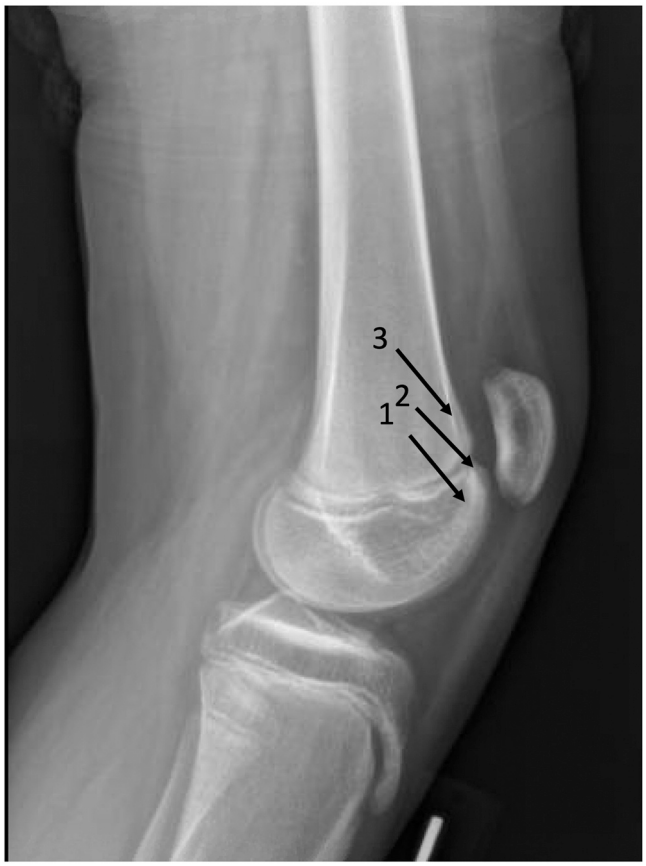

Figure 1. Trochlear dysplasia, 1 = crossing sign, 2 = supratrochlear spur, 3 = double contour.

greater ($P < .01$) average bony sulcus angle of 150º when compared to controls [28]. This is consistent with literature suggesting that ≥145º of sulcus angle is the threshold for predicting PFI in skeletally immature children [30]. The presence of low (Dejour Type A) or high grade (Dejour Type B, C, or D) trochlear dysplasia significantly increased the risk of patellar dislocation recurrence ($P < .0001$), but Jaquith and Parikh report no difference in recurrence rate based on the magnitude of dysplasia in pediatric patients [8] (Fig. 1).

Relative to the trochlear groove, the superior aspect of the distal femur has very shallow grooves that allow for increased patellar mobility. Patella alta can be identified by measuring patella height using ratios of the patella size compared to tibial landmarks on radiographs. The Caton-Deschamps Index (CDI), Insall-Salvati Index (ISI), and the Blackburne-Peel Index have all been used to determine height [11]. Patella alta occurs most commonly in adolescents, age 10–17, with an incidence rate of 29 per 100,000 compared to 5.8 per 100,000 in the general population, with young females being at highest risk for patellar dislocation [31–33]. Patella alta is found in up to 50% of patients with acute PFI [34,35]. One study comparing adult knees with and without a history of recurrent PFI reported higher rates of patella alta in the recurrent PFI cohort (60% vs 20.8%) [36]. However, multiple studies involving children under 18 years old did not show a significant correlation between patella alta and recurrent PFI [3]. While patella alta is seen to play a role in adult PFI, it may not be a significant isolated factor in pediatric patients [28].

The TT-TG distance is a radiographic measurement that determines the lateralization of the tibial tubercle (TT) in relation to the trochlear groove (TG). This measurement is a surrogate for the Q angle, which is the angle between the quadriceps and patella tendon [7]. In skeletally mature patients, TT-TG distances greater than 15–20 mm are associated with PFI and recurrent dislocations [37]. A study comparing adult knees with and without a history of recurrent PFI reported higher rates of elevated TT-TG distances in those with a history of recurrent PFI (42% vs 3.2%) [36]. Given that TT-TG distances change with chronological age in the pediatric population, Dickens et al. observed that as children age, they had higher TT-TG distances, showing a strong logarithmic association with patient age ($P < .001$). Using this association, Dickens et al. developed a percentile-based growth chart in order to better depict average TT-TG distances in the pediatric population [37]. Magnetic resonance imagings (MRIs) of adolescents with PFI found a significantly greater TT-TG length in children with PFI than those without (16.3 vs 11.7 mm) [38], and a meta-analysis reported an average TT-TF distance of 15.5 mm in children with PFI. This was significantly greater than the average of 9.4 mm in controls [19]. Further studies are required to better understand physiologic patellofemoral biomechanics in the pediatric population.

Ligamentous laxity is broadly defined as an increased range of motion across a joint when compared to the range of motion in the general population. Though most pediatric patients with ligamentous laxity have no genetic abnormality, it is present in children with genetic disorders of the connective tissue and syndromic disorders such as Down syndrome [39,40]. Pediatric patients with joint hypermobility and ligamentous laxity have been shown to be at increased risk for PFI [41–43]. Though not entirely known, it is suggested that during rapid adolescent growth, children may face simultaneous musculotendonous tightening coupled with ligamentous laxity. As musculotendonous units cross the knee, the tightness may lead to patellofemoral compression and subsequent PFI [44]. In an age- and sex- matched case series of 82 patients with recurrent unilateral patellar dislocations with 82 patients without recurrent patellar dislocations, 51% of the PFI patients had a hypermobile patella compared to the 6% in the control group, showing a significant difference ($P < .00001$) [7,45]. The Beighton score is commonly used to assess joint hypermobility in pediatric patients and has shown to be a highly reliable tool that shows substantial to excellent inter- and intrarater reliability [46,47].

Management

First-time patellar instability may present in previously healthy and anatomically normal knees or patients with chronic conditions that may predispose them to PFI, as described previously. Management aims are to prevent re-dislocation, decrease pain, residual instability, and allow for return-to-activity, remain constant [48,49]. First-time PFI is traditionally managed non-operatively; however, surgical management is more common in the pediatric cohort. Nwachukwu et al. showed that conservatively managed first-time patellar dislocation has a significantly higher rate of dislocation (31%) when compared to surgically managed dislocations in pediatric patients with first-time patellar dislocation (22%, $P = .04$) [50]. Despite the higher risk of re-dislocation, non-operative treatments for first-time PFI have still yielded good results, and thus, no consensus on surgery versus conservative management of first-time PFI has been reached [48].

In an attempt to answer whether surgical management is warranted

Table 1
Variables associated with recurrent ipsilateral PFI in young patients (adapted from Christensen et al., risk factors and time to recurrent ipsilateral and contralateral patellar dislocations).

Risk factor	Odds ratio	95% confidence interval (CI)	*P* value
Trochlear dysplasia	18.1	9.9–34.5	< .001
Patella alta	10.4	5.8–19.1	< .001
Age < 18 years	2.4	1.5–3.9	< .001
TT-TG distance	2.1	1.1–3.9	.029
Female sex	1.5	1.1–2.4	.047

PFI, patellofemoral instability.

for a pediatric patient with first-time patellofemoral instability, the most important factor appears to be the total number of patellar dislocations experienced by the patient. Young patients with only one dislocation have a 17% risk of persistent instability while patients with multiple dislocations have at least a 49% risk [11,12]. As stated above, other important factors are young age, a family history of patellar dislocation, patellofemoral malalignment, and abnormal patellar configuration [51,52]. Patients with known MPFL injury confirmed on MRI have even higher dislocation rates [53]. A population-based study over 20 years reported that trochlear dysplasia, patella alta, age under 18 at first dislocation, elevated tibial tuberosity to trochlear groove (TT-TG) distance, and female sex were all associated with recurrent patellar dislocations (Table 1) [54]. Children and adolescents demonstrating these characteristics at first patellar dislocation may be better candidates for early surgical intervention [7].

The role of non-operative management

Under most circumstances, conservative management is recommended for acute first-time patellar dislocation in skeletally immature patients without risk factors [34,50,55–58]. A systematic review including 20 studies and 425 skeletally immature patients determined no significant difference in clinical outcomes between conservative and surgical management for first-time PFI. The results were similar in patients with trochlear dysplasia [56]. Another systematic review concluded that nonoperative management is preferred in acute patellar dislocations unless there is evidence of chondral injury, osteochondral fracture, or large MPFL defects [24]. These results should be interpreted with caution as these studies include also older surgical techniques such as medial plication and MPFL repair that are probably less effective compared to MPFL reconstruction. A randomized clinical study by Palmu et al. demonstrated that 75% of children treated conservatively with acute PFI had clinical improvement compared to 67% treated surgically. The results showed that both groups had no significant difference in re-dislocation rate [59]. Similar results were obtained by Buchner et al who found no significant difference between surgical and conservative groups when evaluating re-dislocation rates, function, or subjective outcomes [57]. Further evidence by Lewallen et al. found an 62% success rate for nonoperative treatment for first-time patellofemoral dislocation in children. Despite this initial outcome, 51% of the patients eventually developed recurrent instability that necessitated surgery [3]. In general, first-time PFI is treated conservatively unless there are risk factors as described above or a large osteochondral fracture is present on X-ray or MRI [15].

Early treatment aims to reduce edema, strengthen the surrounding musculature, and improve knee range of motion [11]. Immobilization with casting, bracing, or splinting may be required for several weeks, though it should be considered that long-term immobilization prevents the strengthening of muscles, which is crucial [48]. Becher et al. suggest that the use of an elastic and dynamic patellar realignment brace may be beneficial for patients with PFI, as it supported early weight-bearing [60]. Sinikumpu and Nicolaou advocate for the use of a dynamic brace with lateral patella stabilization, though for no more than a few weeks [48]. Additionally, taping has been reported to help with symptoms, but does not have any effect patellar realignment [61]. Physical therapy for PFI should strengthen the quadriceps and gluteal muscles while improving proprioception. Studies have shown that closed-chain exercises involving the gluteal muscles can increase external rotation of the femur and ultimately decrease the Q angle during knee flexion and extension [62] (Fig. 2).

Surgical management of first-time dislocations

Surgical techniques that medialize the patella include MPFL repair,

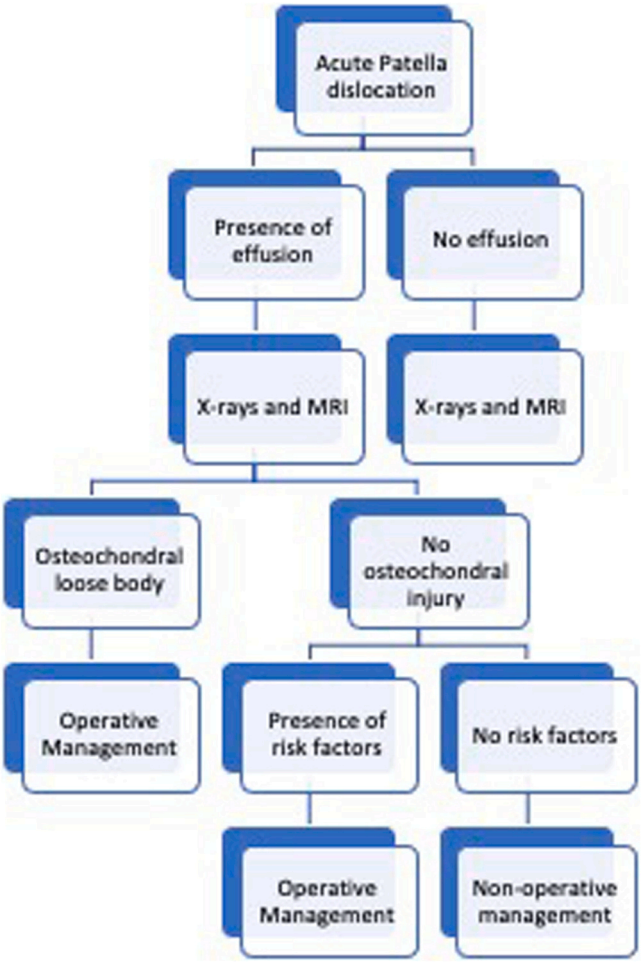

Figure 2. Management of acute patellar dislocation.

MPFL reconstruction, and medial retinacular reefing [64]. There are several techniques described for MPFL repair with and without augmentation that can be performed arthroscopically or open [65]. Although repair and reconstructive techniques both improve PFI in pediatric patients, the repair is associated with a lower complication rate but worse patient outcomes [65]. A recent systematic review and meta-analysis showed that MPFL reconstruction decreases recurrent dislocations compared to MPFL repair or nonoperative treatment, but it has higher possibility of complications [66]. Reported complications include increased risk for patella fracture, femoral tunnel enlargement, and loss of motion [67,68]. In a randomized control trial comparing MPFL repair and conservative treatment knee-bracing in children with acute first-time patellar dislocation, Askenberger et al. reported that the MPFL repair significantly reduced re-dislocation rates, but it did not improve knee function when compared with the conservative knee-braced group [30]. While proven to be effective, MPFL reconstruction as an isolated procedure in the setting of severe trochlear dysplasia may have inferior results in PFI [69–71]. Though there are benefits, MPFL repair is falling out of favor as it has not yielded significantly better outcomes when compared to conservative treatments [72].

Another technique used in patellar medialization is medial capsule reefing. The medial patellar capsule is shortened with reefing sutures and is often performed with transposition of the distal vastus medialis oblique (VMO) tendon to the lateral border of the patella [73]. Capsular reefing has variable re-dislocation rates in young patients occurring in up to one-third of patients undergoing the surgery.

MPFL reconstruction involves debridement of residual tissue and placement of a graft (autograft or allograft). Allografts and autografts

used are hamstring, patellar tendon, quadriceps, and adductor magnus [55]. Not only the type of graft is variable, but also the technique and implants used for fixation, placement of the attachment sites, and tensioning of the graft differ. In a survey of pediatric surgeons who specialize in PFI, the majority of surgeons reported utilizing an interference screw for graft fixation at the femur in skeletally immature patients [75]. In a systematic review and meta-analysis of 12 randomized control trials comparing non-operative treatment, MPFL repair, and/or MPFL reconstruction, MPFL reconstruction was found to decrease recurrent dislocation when compared with MPFL repair or nonoperative treatment. Furthermore, MPFL reconstruction was found to be the best treatment plan to prevent postoperative re-dislocation, reducing revision rates, and improving knee function score [64]. Furthermore, Zheng et al. concurrently reported that patients with MPFL reconstruction had a higher Kujala score and lower risk of re-dislocation when compared to non-operative treatment [75]. Other common femoral fixation techniques in skeletally immature patients included suture anchor fixation and fixation with no hardware use [75].

Summary

Patellofemoral instability is one of the most common orthopedic conditions affecting pediatric and adolescent patients. Individuals aged 13 to 18 years old and females are at the highest risk for PFI. The incidence and prevalence of PFI reduce with age. While PFI is most caused by acute, traumatic patellar dislocation due to athletic participation, several anatomical factors may predispose pediatric patients towards chronic and recurrent PFI. Treatment of first-time acute patellar dislocation is often conservative in skeletally immature patients without osteochondral fragmentation or multiple risk factors for recurrence. Those who fail conservative therapy may be candidates for patellar stabilization surgeries depending on their pathoanatomical contributing factors. Most studies are based on an adult population, therefore further investigation is needed in the skeletally immature individuals given the factors that are particular to this group such as skeletal morphology, ligamentous laxity, growth plates and psychological aspects, to name a few. Regardless of age, PFI should be addressed in a comprehensive and individualized manner, correcting all components predisposing to instability.

Additional links

- POSNA Study Guide: Patellar Dislocation: (Acute)
- AAOS OrthoInfo: Patellar (Kneecap) Instability

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Author contributions

Paschos Nikolaos K: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Jayne Christopher:** Investigation, Methodology, Writing – original draft, Writing – review & editing. **Mavrommatis Sophia:** Writing – original draft, Writing – review & editing. **Shah Ayush:** Writing – review & editing. **Medina Giovanna:** Validation, Writing – review & editing.

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Not applicable

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