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REVIEW

Imaging assessment of patellar instability and its treatment in children and adolescents

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Abstract Transient patellar dislocation is a common entity in children and adolescents, characterized by lateral dislocation of the patella, usually with spontaneous reduction. Many predisposing conditions have been described, including trochlear dysplasia, excessive lateral patellar tilt, patella alta and lateralization of the tibial tuberosity. Associated injuries are bone bruises of the patella and lateral femoral condyle, tears of the medial retinaculum that include the medial patellofemoral ligament (MPFL), tears of the vastus medialis obliquus muscle, injuries of articular cartilage, and intra-articular bodies. Children who are refractory to conservative management, have a large cartilage defect, or are at substantial risk for recurrent dislocations are candidates for surgical procedures to prevent future dislocations. Procedures can include MPFL repair or reconstruction, tibial tubercle repositioning and lateral retinacular release. The purpose of this review is to illustrate the imaging findings of transient patellar dislocation in the acute setting, the normal imaging appearance after surgical intervention, and post-surgical complications.

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Introduction

Transient patellar dislocation occurs when the patella dislocates, usually laterally, with respect to the trochlea. Typically the patella reduces spontaneously when the knee is extended following the injury [1]. The majority of transient patellar dislocation occurs secondary to trauma, either from a direct blow to the knee or secondary to an indirect injury [1, 2]. The most common indirect, noncontact injury that causes transient patellar dislocation is external rotation of the leg with the foot planted. This results in valgus overload on the extensor mechanism [1]. This injury is common during sports participation, and approximately 60% of first-time dislocations occur during sports-related activities [3, 4]. There is a small subset of patients with habitual patellar dislocation who dislocate during normal activity [1]. Various classification schemes categorize patients based upon the degree of injury that precipitates a patellar dislocation [1]. Patients with patellar dislocation caused by less forceful injury often have a greater number of predisposing factors and usually need more extensive surgical correction [1].

The overall incidence of first-time transient patellar dislocation in all ages is 5.8 per 100,000; however this increases to 29 per 100,000 in 10- to 17-year-olds, the group with the highest incidence [2]. After a single episode of transient patellar dislocation is managed conservatively, up to 50% of patients experience continued anterior knee pain [2]. In patients treated with nonoperative conservative management, the rate of recurrent transient patellar dislocation ranges from 15% to 44% [2]. After the second dislocation, there is a 50% chance of future dislocations [2]. Additionally, age at presentation, initial management, and anatomical factors predict the likelihood of future dislocations [5]. Recurrent dislocations increase the risk for persistent symptoms and degenerative changes of the patellofemoral joint [3–5].

Transient patellar dislocation is a relatively common cause of anterior knee pain in children and adolescents and is associated with long-term pain and sport-limiting extensor mechanism impairment in pediatric athletes [1]. Therefore, it is important for radiologists who image children and adolescents to be familiar with the imaging findings associated with transient patellar dislocation, the common surgical procedures used to treat this entity, and the potential postoperative complications.

Factors that predispose to patellar instability

Numerous anatomical factors predispose a child to patellar instability (Table 1). Osseous and soft-tissue structures both act as stabilizers of the patella and alterations in any of these can predispose a child to patellar dislocation. Some of these features can be acquired; however most causes are congenital or developmental [6].

Table 1 Factors that predispose to patellar instability

Osseous
- ○ Patella alta
- ○ Patellar subluxation
- ○ Patellar tilt
- ○ Patellar dysplasia
- ○ Trochlear dysplasia
  - ▪ Shallow trochlear groove
  - ▪ Shallow inclination of the lateral trochlea
- ○ Lateralization of the tibial tubercle
- ○ Femoral anteversion
- ○ Genu valgum
- ○ Pes planus

Soft-tissue
- ○ Hypoplasia of the vastus medialis muscle
- ○ Increased quadriceps angle
- ○ Laxity of the medial retinaculum
  - ▪ Deficiency of the medial patellofemoral ligament
  - ▪ Absence of the medial patellofemoral ligament
- ○ Tightness of the lateral retinaculum
- ○ Contracture of the iliotibial band
- ○ Generalized ligamentous laxity (e.g., Ehlers–Danlos syndrome)

Osseous stabilization

Embedded within the quadriceps tendon, the patella is the largest sesamoid bone in the human body [6]. The posterior articular surface is divided into medial and lateral facets by a vertical osseous ridge [6]. Eighty percent of people have an additional narrow facet on the far medial side of the patella, called the odd facet, which is sometimes covered with articular cartilage [6]. The Wiberg classification (Fig. 1), initially a radiographic classification system that has subsequently been adapted to other modalities, is used to describe the relative medial and lateral patellar facet sizes, categorizing the patella into three types [6]. Wiberg type II is the most frequent type, accounting for up to 65% of patellae, followed by type III (approximately 25%), and type I (approximately 10%) [7]. However, no classification system of patellar shape is universally accepted and there is some disagreement as to whether a Wiberg type III patella (prominent lateral facet with a small convex medial facet) predisposes to instability. Other dysplastic patellar variations are associated with instability, as are abnormalities of patellar position [6].

A high-riding patella, termed patella alta, also is associated with patellar instability. The Insall–Salvati ratio is the most commonly accepted radiographic method used to assess the vertical position of the patella. On a lateral radiograph, the length of the patellar tendon is compared to the length of the patella, with a diagnosis of patella alta if the ratio is greater than 1.2 [8]. MRI criteria for patella alta have also been described. The shortest length of the deepest portion of the patellar tendon is measured and compared to the length of a line drawn between the anteroinferior and posterosuperior edges of the patella on a single mid-sagittal image. Patella alta is considered if the ratio is greater than 1.32 in men and 1.52 in women (Fig. 2) [9]. However, these criteria are the result of

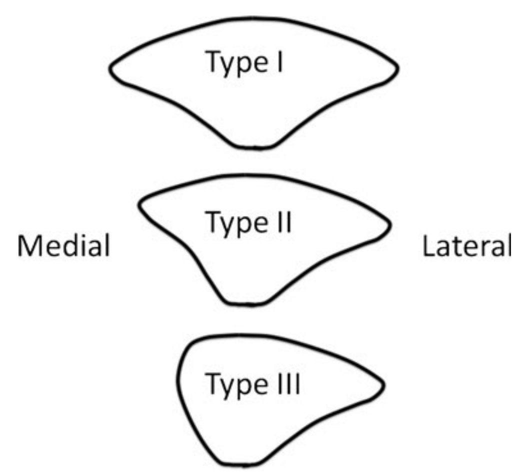


Fig. 1 Wiberg patellar classification. In a type I patella, the medial and lateral patellar facets are similar in size and are both concave. In type II, the medial patellar facet is shorter than the lateral facet, and both facets are concave. In the type III patella, the medial facet is much shorter than the lateral facet and is also convex

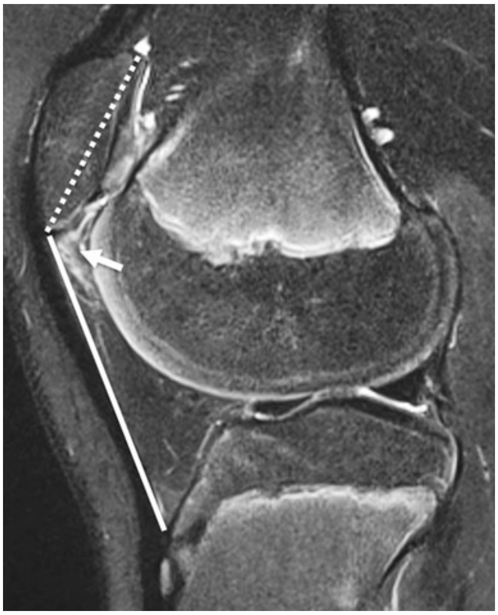


Fig. 2 Patella alta and lateral patellar subluxation on MR imaging in a 10-year-old girl with prior patellar dislocations. Sagittal fast spin-echo (FSE) T2-weighted (TR/TE [repetition time/echo time] 4,350/67 ms) fat-saturated MR image shows patella alta. The patellar tendon length (*solid line* along the shortest length of the deepest portion of the patellar tendon) measures 5.9 cm, and the length of the patella (*dotted line* between the anteroinferior and posterosuperior edges of the patella) measures 3.4 cm. Patellar tendon length (5.9 cm)/patellar length (3.4 cm)=1.7, which meets the MR imaging criterion for patella alta. (In adults patella alta is considered if the ratio is greater than 1.32 in men and 1.52 in women; some authors consider any ratio of greater than 1.3 as patella alta in children). There is edema-like signal intensity in the superolateral portion of the Hoffa fat pad (*arrow*) secondary to fat pad impingement between the patellar tendon and lateral femoral condyle (often referred to as patellar tendon–lateral femoral condyle friction syndrome)

studies in adults [9]. The discrepancy between the upper limits of normal on radiographic versus MR imaging evaluation of the Install–Salvati ratio might reflect the difference in measurement technique of patellar length, which on a lateral radiograph is the summation of the entire width of the patella, whereas on MR imaging it is drawn on a single mid sagittal slice. If the patella has any obliquity in the long axis, then a single mid sagittal MR image will not show the superior-most or inferior-most borders. This might account for the relatively shorter measurement of patellar length on MR imaging and therefore higher tendon length to patellar length ratio [9]. The differences in the measurement of the patellar tendon, which is directly measured on MR imaging versus indirectly measured on radiographs, may also account for some of the difference [9].

Some authors conclude that patella alta in children exists when the Install–Salvati ratio as measured on MR imaging is greater than 1.3 [10]. Seeley et al. [10] found that after lateral patellar dislocations, children with patellar-side medial patellofemoral ligament (MPFL) injuries had statistically significant higher Install–Salvati ratios than children with femoral or midsubstance MPFL injuries.

Lateral patellar subluxation and lateral patellar tilt, factors that can be determined by axial imaging, also are associated with patellar instability. A variety of techniques are used to obtain axial radiographs of the patella, and various methods are described to assess subluxation and tilt. The assessment of the patellofemoral joint on axial radiographs should be based on an image obtained in 20°–45° of knee flexion, such as the Merchant view, (obtained with the child in a supine position with 45° of knee flexion), and not the sunrise view, which is obtained with greater than 90° of knee flexion with the child in the prone position [6]. The lateral patellofemoral angle is formed by a line drawn along the anterior aspects of the medial and lateral surfaces of the trochlea and another line drawn along the lateral facet of the patella [6]. In the normal knee, the angle formed by these two lines opens laterally (Fig. 3). If the lines are parallel or if the angle opens medially (Fig. 3), there is patellar tilt [6]. Axial MR or CT images can accurately show the position of the patella relative to the trochlea (Fig. 2). Some authors consider any deviation from patellar centering within the trochlea as abnormal [6, 11]. However, factors such as full knee extension, various degrees of quadriceps

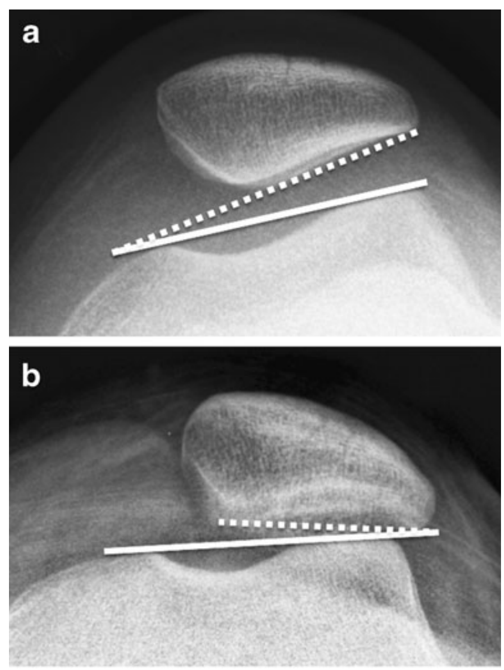


Fig. 3 Assessment of patellar tilt on axial radiographs of the left knee. **a** Imaging in a 12-year-old girl with a normal lateral patellofemoral angle and no patellar tilt. The angle between the *solid line* drawn along the anterior aspects of the medial and lateral surfaces of the trochlea and the *dotted line* drawn along the lateral patellar facet opens laterally, which is normal. **b** Imaging in a 14-year-old boy with multiple prior patellar dislocations. The angle between the *solid line* drawn along the anterior aspects of the medial and lateral surfaces of the trochlea and the *dotted line* drawn along the lateral patellar facet opens medially, which is abnormal and indicates patellar tilt

contraction, and a joint effusion can affect patellar position and tilt [6, 11].

The posterior surface of the patella articulates with the trochlea of the distal femur. The latter is formed by the anterior-most articular surfaces of the femur anterior to the femoral condyles. Centrally, the trochlear groove (the central depression at the intersection of the anterior medial and lateral femoral condyles) provides a corresponding surface for the vertical (or median) ridge of the patella [6]. The degree of contact between the articular surfaces of the patella and trochlea increases with knee flexion. Trochlear groove depth and inclination of the lateral trochlea both are important factors for stabilization of the patella [6]. Several radiographic measurements have been proposed to evaluate trochlear morphology, the most established of which is the measurement of lateral trochlear inclination. The utility of these radiographic angles has been questioned because they do not evaluate the cephalad portion of the trochlea, which is considered important for patellar stabilization.

MR imaging can assess this portion of the trochlea and thus measurements of trochlear depth and lateral trochlear inclination have been developed. When there is a geometric abnormality of the shape and depth of the trochlear groove, particularly at the cephalad portion, the term trochlear dysplasia is used [12]. Pfirrmann et al. [12] described the following for the measurement of trochlear depth on MR imaging: (1) The anterior–posterior lengths of the femoral condyles are added together and divided by two; (2) The anterior–posterior distance between the deepest point of the trochlear groove and a line paralleling the posterior outlines of the femoral condyles is measured and is subtracted from the value obtained in (1) (Fig. 4). In their study, a trochlear depth of 3 mm or less on an axial MR image obtained at 3 cm above the joint line was shown to have 100% sensitivity and 96% specificity for the diagnosis of trochlear dysplasia (Fig. 4) [6, 12]. However the use of a standard 3-cm distance above the joint line might not be an appropriate distance in younger children. Lateral trochlear inclination also can be assessed on MR imaging by the angle formed between a line drawn along the subchondral bone of the lateral trochlea on the most cephalad axial slice that shows trochlear articular cartilage, and a line drawn along the subchondral bone of the posterior surfaces of the femoral condyles (Fig. 5). Using this MR imaging measure of lateral trochlear inclination, one study showed that an angle <11° was 93% sensitive and 87% specific as an indicator of patellar instability [13].

Another parameter that affects patellar stability is the position of the tibial tubercle, which is the site of patellar tendon insertion. Lateralization of the tibial tubercle may require surgical correction [14]. The tibial tubercle–trochlear groove (TT–TG) distance is a parameter that many orthopedic surgeons use in the management and pre-surgical planning for patients with patellar instability. This distance can be measured on both axial CT and MR images; however it has been more extensively studied on CT [14]. The TT–TG distance can be measured on axial CT images

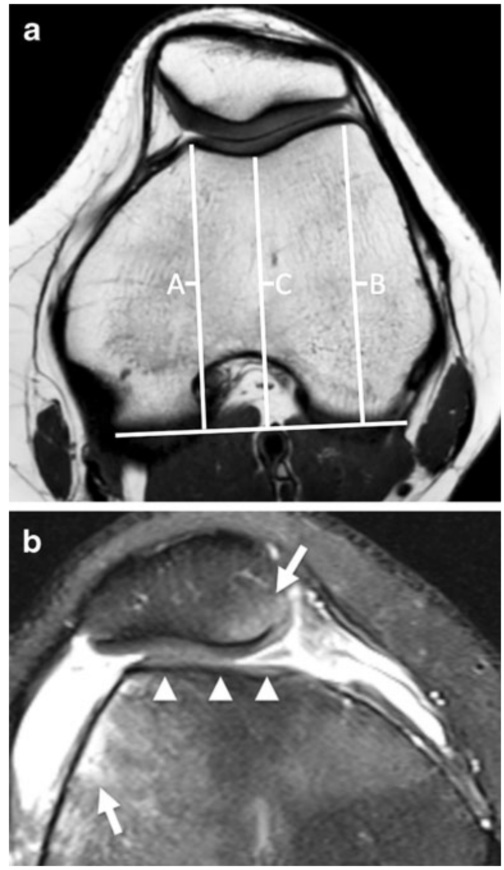


Fig. 4 MR imaging assessment of the trochlear groove. **a** Axial proton-density (TR/TE 3,000/40 ms) MR image of the left knee in a 16-year-old girl, 3 cm above the knee joint. The trochlear depth is obtained by first measuring the anterior–posterior lengths of the medial femoral condyle (*A*=64 mm in this girl) and the lateral femoral condyle (*B*=66 mm in this girl) and the distance of the deepest portion of the trochlea to a posterior condylar line (*C*=61 mm in this girl). Then the trochlear depth is obtained using the following formula: trochlear depth = ([A + B]/2) − C. In this girl the trochlear depth=([64+66]/2) − 61=4 mm. A value of less than 3 mm is considered abnormal [12]. **b** Axial MRI of the right knee of a 14-year-old boy with prior patellar dislocation. Axial fast spin-echo T2-weighted (TR/TE 5,930/62 ms) fat-saturated image obtained approximately 3 cm above the joint line shows a flat trochlear groove (*arrowheads*). A trochlear groove depth <3 mm at this location has been shown to correlate with trochlear dysplasia. The edema-like signal within the medial patella and lateral femoral condyle (*arrows*) is the result of a recent transient patellar dislocation. *TE* echo time, *TR* repetition time

in the following manner: A cursor is placed on the most anterior portion of tibial tubercle (this is the tibial tubercle position). Then, without moving the cursor, one scrolls cephalad to the axial image with the deepest osseous trochlear groove. The position of the tibial tubercle is translated to this more cephalad image and is marked. On this same image with the deepest trochlear groove, a posterior condylar line is drawn tangential to the posterior aspect of the femoral condyles. Next, perpendicular lines are drawn from both the deepest portion of the osseous trochlear groove and from the position of the tibial tubercle to the

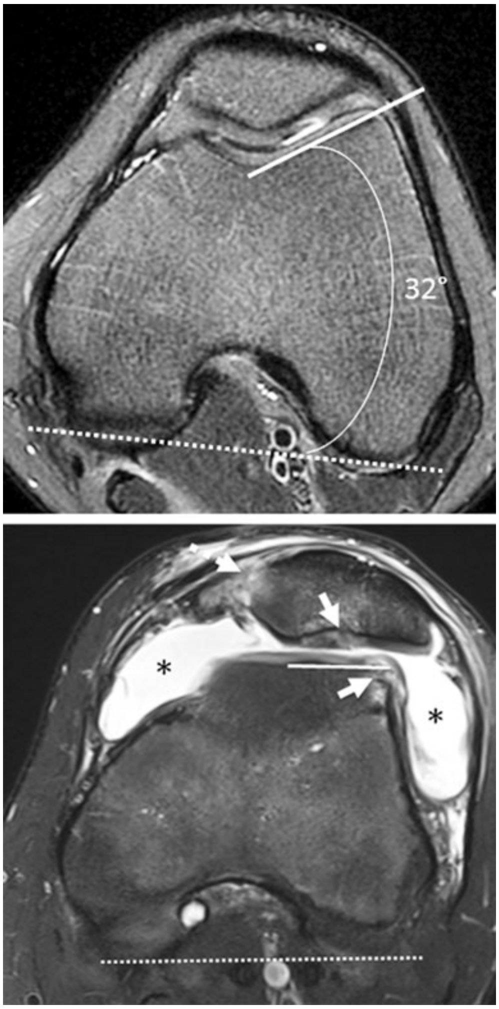


Fig. 5 Normal lateral trochlear inclination measured in the left knee of a 16-year-old girl with chronic knee pain. **a** Axial fast spin-echo T2-weighted (TR/TE 3,000/65 ms) MR image at the cephalad-most slice showing cartilage demonstrates that the angle between a line drawn along the subchondral bone of the lateral trochlea (*solid line*) and a line draw along the subchondral bone of the posterior aspects of the femoral condyles (*dotted line*) is approximately 32° (normal ≥11°). **b** Imaging in a 15-year-old boy with multiple episodes of patellar dislocation of the left knee with abnormal lateral trochlear inclination. Axial T2-weighted (TR/TE 3,000/67 ms) MR image from the cephalad-most slice showing cartilage shows the line drawn along the subchondral bone of the lateral trochlea (*solid line*) is approximately parallel to a line drawn along the subchondral bone of the posterior aspects of the femoral condyles (*dotted line*). There are articular cartilage injuries of the patella (*arrow*) and lateral trochlea (*arrow*) with edema-like signal in the marrow, injury to the medial patellofemoral ligament at its patellar insertion (*dotted arrow*), a large joint effusion (*asterisks*) and post-traumatic synovitis, most prominently in the lateral gutter. *TE* echo time, *TR* repetition time

posterior condylar line. The perpendicular distance between these two parallel lines establishes the TT–TG distance (Fig. 6).

Various studies have reported normal ranges of the TT–TG distance, from 9.4±0.6 mm to 13.6±8.8 mm. Patients with patellar instability have greater values [14]. A general guideline for the TT–TG distance can be considered as: normal <15 mm, borderline 15–20 mm and abnormal >20 mm [15]. However there are differences in the values that orthopedic surgeons use; some use a TT–TG distance of greater than 15 mm and others use a more conservative value of 20 mm as a criterion for performing medialization procedures [16, 17]. Similar to patellar position, most of the studies that evaluate the TT–TG distance have been performed in adults, and this distance has been shown to increase with age. Therefore, some authors have begun to develop age-based normal values of the TT–TG distance for children in order to accurately assess what is normal or abnormal [14].

Initial studies suggested that measurements of the TT–TG distance are comparable between CT and MRI [18]. However subsequent studies have shown differences between CT and MR imaging measurements that range 2.8–3.8 mm. These seemingly minor disparities may be important given the small differences between what is considered a normal versus abnormal lateral offset [19, 20]. Discrepant measurements may relate to the differences in patient position when scanned with CT versus MR imaging with a dedicated coil [19]. Another confounding factor that might affect TT–TG values between the different imaging modalities is the landmarks used to measure this distance. Those used in CT are standardized, while those used in MR imaging are not [21]. On MR imaging the TT–TG distance can be measured with similar osseous landmarks to those described for CT, but better visualization of soft-tissue structures with MR imaging has led some authors to evaluate lateral offset with the more functional patellar tendon–trochlear groove (PT–TG) distance. The PT–TG distance is obtained on axial MR images in a similar manner to that described for CT, except that the center of the patellar tendon on the most superior axial slice, where the patellar tendon attaches to the tibia, is used as the distal landmark (PT), rather than the anterior-most portion of the osseous tibial tubercle (TT). Additionally, the deepest portion of the cartilaginous rather than the osseous trochlea is used as the TG location (Fig. 6) [21]. Wilcox et al. [21] compared the osseous TT–TG and soft-tissue functional PT–TG distances on MR images and found that the these distances are not equivalent, and in some cases differed by more than 4 mm. The authors concluded that both measurements are useful for the measurement of lateral offset of the extensor mechanism but that greater inter- and intra-observer reliabilities for the PT–TG distance may provide a more consistent measurement for surgical planning [21].

Given the differences between the TT–TG distance as measured on CT versus MR imaging, and the variability between the TT–TG and PT–TG distances, one should be cautious when applying the normal values for TT–TG distance from one study to another. Also, because the TT–TG distance increases with age, determination of age-based normal values of the TT–TG distances on MR imaging is suggested [14]. A

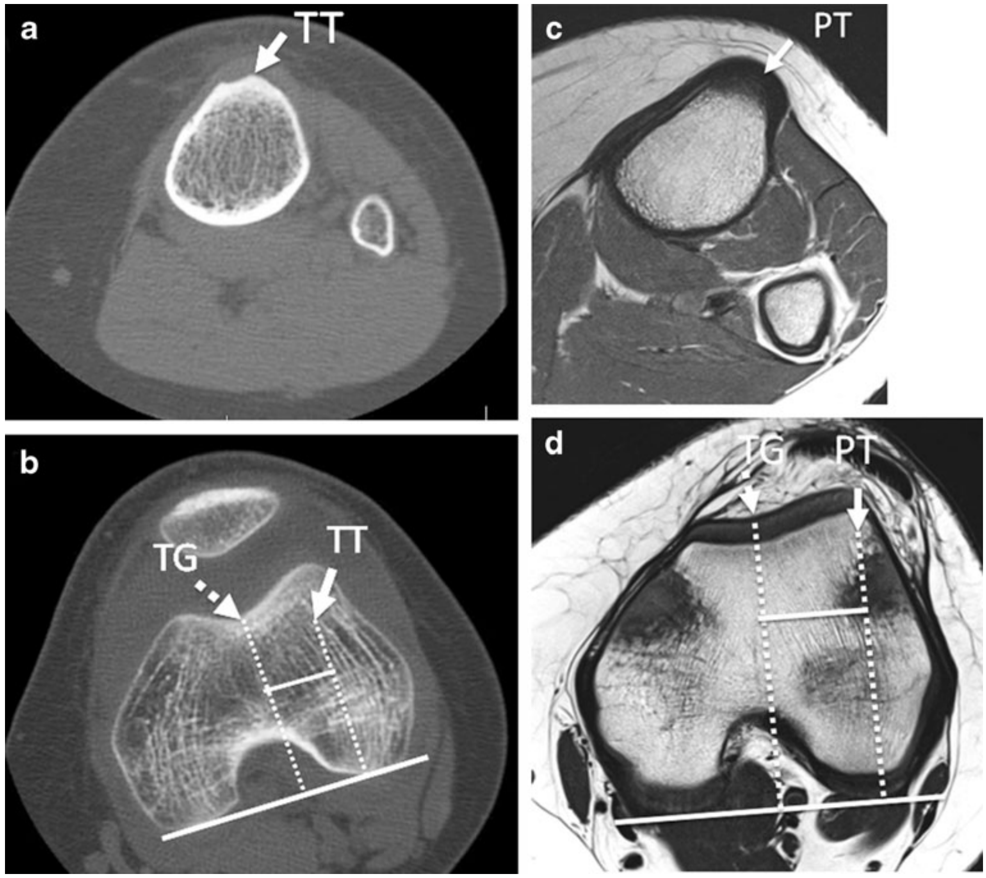


Fig. 6 Tibial tubercle–trochlear groove distance on CT in a 9-year-old girl and the patellar tendon–trochlear groove distance on MRI in a different 10-year-old girl. **a** Axial CT image at the level of the anterior-most aspect of the tibial tubercle (*arrow*). The cursor is kept in this location while scrolling cephalad to the image with the deepest osseous trochlear groove (**b**). **b** On the axial slice from the same CT scan with the deepest osseous trochlear groove, the position of the tibial tubercle (*TT*) is marked (*solid arrow*). The long solid line is a reference line drawn along the posterior osseous aspect of the femoral condyles. Dotted lines are drawn perpendicular to this reference line at the location of the deepest aspect of the osseous trochlear groove (*TG*, *dotted arrow*) and at the location of the tibial tubercle (*TT*, *solid arrow*). The distance between these parallel lines (*short solid line*) defines the tibial tubercle–trochlear groove distance. The distance in this example is 9 mm, which is normal. The distance varies with age, but a general guideline is: normal <15 mm, borderline 15–20 mm and abnormal >20 mm. **c**, **d** Measurement of patellar tendon–trochlear groove distance on MR imaging. **c** Axial proton-density (TR/TE 2,960/38 ms) MR image at the superior-most location where the patellar tendon attaches to the tibia. A cursor is placed on the central portion of the patellar tendon (*arrow*), which is kept in this location while scrolling cephalad to the image with the deepest cartilaginous trochlear groove (**d**). **d** Axial MR image with the deepest cartilaginous trochlear groove. The position of the patellar tendon (*PT*) determined from image in (**c**) is marked (*solid arrow*). A posterior condylar line is drawn along the posterior cartilage of the femoral condyles (*long solid line*). Lines (*dotted lines*) are drawn perpendicular to this reference line at the location of the deepest aspect of the cartilaginous trochlear groove (*TG*, *dotted arrow*) and at the location of the patellar tendon (*PT*, *solid arrow*). The distance between these parallel lines (*short solid line*) is the patellar tendon–trochlear groove distance. In this child, this measures 22 mm, which is considered abnormal. However, definite normal values of the patellar tendon–trochlear groove distance have not been established. *TE* echo time, *TR* repetition time

newer approach is described by Hingelbaum et al. [22], who have proposed using MR imaging to measure a TT–TG index. This index divides the TT–TG distance by a measurement of the size of the joint from the trochlear groove to the tibial tubercle, thus giving a measurement that takes into account the overall proportionate size of the knee [22]. Further study is needed to determine the usefulness of this alternative approach.

Soft-tissue stabilization

Condensations or thickenings of the fibers of the medial retinaculum form retinacular ligaments, the most important of which is the medial patellofemoral ligament (MPFL) (Figs. 7 and 8). The MPFL is considered the strongest passive medial stabilizer of the patella and contributes up to 60% of the medial restraining force [6]. The

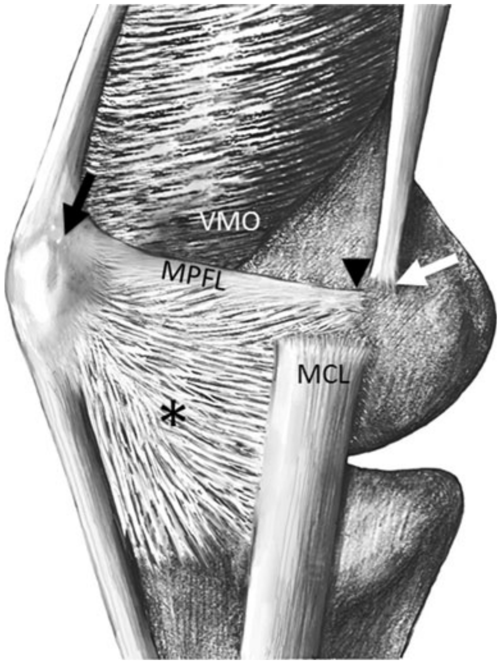


Fig. 7 Medial stabilizing soft-tissue structures of the knee. The medial patellofemoral ligament (*MPFL*), which is a thickening of the medial retinaculum (*asterisk*), courses obliquely from its femoral attachment (*arrowhead*) to its patellar attachment (*black arrow*). The patellar attachment is on the superior two-thirds of the patella. The fibers of the MPFL blend with the fascia of the vastus medialis obliquus muscle (*VMO*) at the patellar insertion. At the femoral attachment (*arrowhead*), the MPFL often inserts with or posterior to the attachment of the medial collateral ligament (*MCL*). The fascia of the VMO and superior-most fibers of the MCL are not shown in order to illustrate the entire course of the MPFL. The insertion of the adductor magnus tendon (*white arrow*) is posterior to the insertion of the MPFL

MPFL courses obliquely from its attachment on the medial distal femur anterior to the adductor tubercle (the insertion site of the adductor magnus muscle) at or near the superior aspect of the medial epicondyle (the insertion site of the medial collateral ligament), to attach onto the

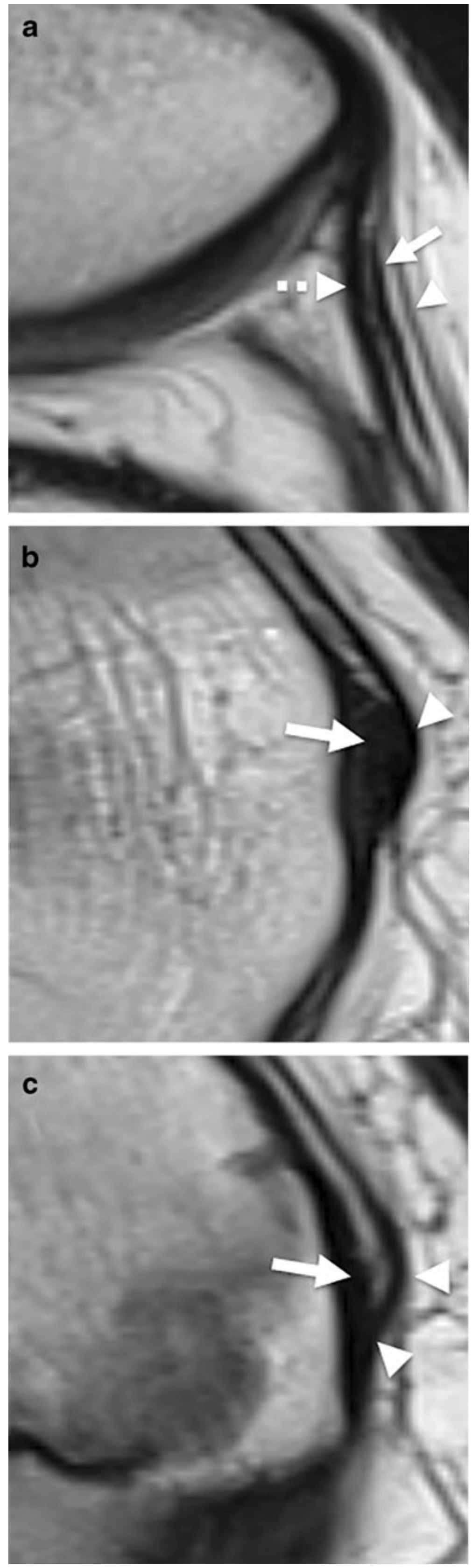


Fig. 8 Normal MR imaging anatomy of the medial patellofemoral ligament (MPFL). **a** Axial proton-density (TR/TE 3,110/40 ms) MR image of the right knee in a 17-year-old girl shows the normal trilaminar appearance of the medial patellar ligamentous complex near the patellar insertion. The superficial-most layer (*arrowhead*) is the crural fascia, the middle layer (*solid arrow*) is made of the tendinous fibers of the vastus medialis obliquus muscle, and the deepest layer (*dotted arrow*) is the MPFL. **b** Axial proton-density (TR/TE 2,450/32 ms) MR image in a 14-year-old girl shows the deep fibers of the MPFL (*arrowhead*) merging with the fibers of the medial collateral ligament (MCL) (*arrow*) at their femoral insertions. **c** An image superior to (**b**) shows that some of the superficial fibers of the MPFL (*arrowheads*) wrap around the MCL (*arrow*) and attach more posteriorly on the medial femoral epicondyle. *TE* echo time, *TR* repetition time

superior two-thirds of the medial aspect of the patella, with smaller attachments to the aponeurosis of the vastus medialis obliquus muscle (VMO) and inferior aspect of the patella (Figs. 7 and 8) [6, 7]. An anatomical–cadaveric correlation study by Dirim et al. [23] showed that at its patellar attachment site, superficial fibers of the MPFL are partly covered and intermingle with tendinous fibers of the VMO. This close proximity of the MPFL with the more superficial fibers of the tendon of the VMO account for the bilaminar appearance that is often seen on MR images [23]. When the even more superficial crural fascia is also seen, there is a trilaminar appearance on MR imaging (Fig. 8) [23].

Active stabilization of the patella is performed by the quadriceps muscles and tendons, which merge just above the patella [6]. For medial stabilization, the most important of these is the vastus medialis muscle, particularly the VMO fibers [6]. These arise from the distal medial inter-muscular septum and adductor tubercle of the distal femur and insert on the proximal and medial aspect of the patella, balancing the normally dominant lateral forces (Figs. 7 and 8) [6].

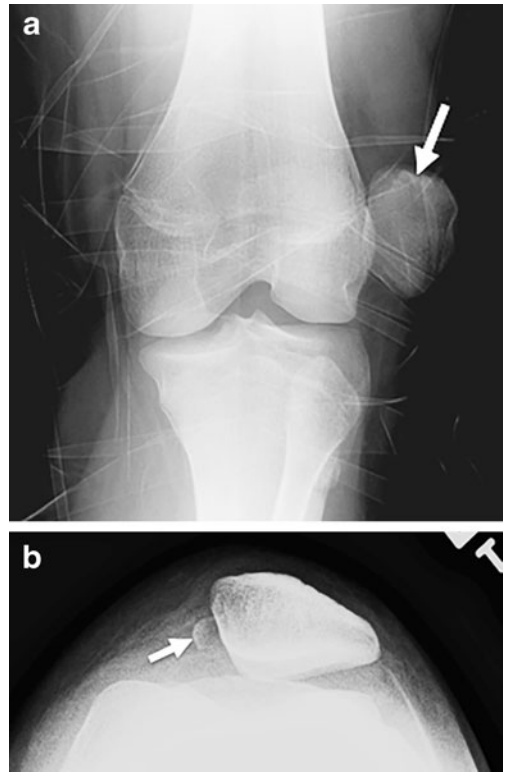


Fig. 9 Radiography in a 15-year-old boy with anterior knee pain after injury. **a** Anteroposterior radiograph of the left knee shows lateral patellar dislocation (*arrow*). Dislocation of the patella is usually transient and is therefore not typically seen at the time of imaging. **b** Axial radiograph obtained tangential to the patellofemoral joint after reduction of the patellar dislocation shows an osseous fragment (*arrow*) adjacent to the medial patella, which resulted from avulsion of the medial patellofemoral ligament

Imaging findings in acute transient patellar dislocation

Osseous findings

Conventional radiography is typically the initial imaging modality in children with transient patellar dislocation. In addition to anteroposterior (AP) and lateral radiographs, an axial radiograph of the patella should be obtained in children with known or suspected transient patellar dislocation. Radiographs in these children often show nonspecific joint effusions and soft-tissue swelling. A dislocated patella can be seen (Fig. 9); however this is a rare finding because the patella typically reduces spontaneously when the knee is extended prior to radiographic evaluation. More commonly radiographs show small osseous fragments off the medial pole of the patella as a result of osteochondral fracture or MPFL avulsion (Fig. 9). Radiographs can also depict predisposing factors for transient patellar dislocation (Fig. 3).

Osseous injuries to the patella can occur during the dislocation or relocation movements. As the patella dislocates fractures can result from the tensile forces of the medial stabilizers or from shear forces as it dislocates across the lateral trochlea; as the patella relocates fractures can result from compressive forces as it strikes the lateral femoral condyle [6]. These fractures are best identified on axial radiographs (Fig. 9) or on multiplanar CT and MR imaging. Less commonly fractures of the lateral femoral condyle occur [6]. The typical bone contusion pattern that involves the medial pole of the patella and lateral femoral condyle — as the patella strikes the lateral femoral condyle during relocation — is readily seen on MR images as hyperintense signal on fluid-sensitive sequences and as hypointense signal on T1-weighted images within the bone marrow (Fig. 10) [6]. Additionally, impaction fractures with cortical disruption at the extra-articular but intra-capsular aspect of the lateral femoral condyle can result in a large hemarthrosis or lipohemarthrosis (Fig. 11).

Articular cartilage injuries and intra-articular bodies

Articular cartilage injuries are common after patellar dislocation. A review of MR imaging findings in children after first-time patellar dislocation showed that osteochondral injuries occurred at the patella in 76%, the lateral femoral condyle in 24%, and in both locations in 6.5% [24]. As with osseous injuries, articular cartilage injuries can occur from tensile and shear forces on the patella during the dislocation or from shear and compressive forces between the patella and lateral femoral condyle during the relocation [6]. The most common site of articular cartilage injury after patellar dislocation is the medial facet of the patella (Fig. 10) [25]. Other sites of articular cartilage injury include the median ridge and lateral facet of the

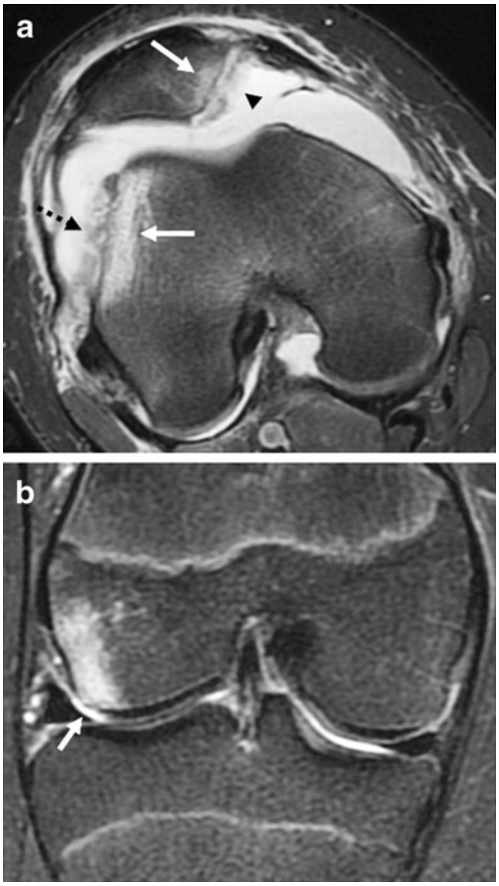


Fig. 10 Anterior right knee pain and prior transient patellar dislocation in an 11-year-old boy. **a** Axial fast spin-echo (FSE) T2-weighted (TR/TE 3,000/60 ms) fat-saturated MR image shows edema-like signal in the medial patella and lateral femoral condyle (*white arrows*). There is an irregular appearance of the articular cartilage of the medial facet (*black arrowhead*), with extensive cartilage injury and disruption of the cartilage from the subchondral bone. There is a large joint effusion and post-traumatic synovitis (*dotted black arrow*). **b** Coronal FSE T2-weighted (TR/TE 3,000/60 ms) fat-saturated MR image of the same knee shows a full-thickness articular cartilage defect of the far lateral femoral condyle (*arrow*) and associated hyperintense focal femoral bone marrow edema pattern consistent with bone contusion. The area of marrow edema pattern demarcates the site of impaction between the medial patella and the lateral femur, which can occur during the patellar dislocation or relocation. *TE* echo time, *TR* repetition time

Fig. 11 Hemarthrosis in a 17-year-old boy with lateral patellar dislocation. Sagittal fast spin-echo T2-weighted (TR/TE 4,000/70 ms) fat-saturated MR image shows a mildly depressed impaction fracture of the lateral femoral condyle (*arrow*) and a large hemarthrosis, which manifests as a fluid-fluid level (*arrowhead*). Extensive edema-like signal is present within the lateral femoral condyle (*asterisk*). *TE* echo time, *TR* repetition time

patella, and the anterior third of the lateral femoral condyle and lateral trochlea (Figs. 10, 12, and 13) [6, 25]. MR imaging is well suited to depict articular cartilage injury. It can detect low-grade injuries, which demonstrate abnormal signal intensity within cartilage, as well as higher-grade injuries such as partial and full-thickness fissures or fractures, chondral flaps and delamination injuries (Figs. 10, 12, and 13).

Various methods are used to grade articular cartilage injuries. The Outerbridge classification is a commonly used intraoperative 0–4 grading system, as follows: 0 = normal cartilage, 1 = cartilage softening, 2 = partial thickness lesion that does not reach subchondral bone and is <1.5 cm in diameter, 3 = lesion that extends to subchondral bone and is >1.5 cm diameter and 4 = full-thickness lesion that exposes subchondral bone [26]. Because accurate assessment of the depth of a cartilage lesion determines treatment, other more detailed systems have been developed, such as the International Cartilage Repair Society (ICRS) grading system. Modified forms of the Outerbridge and ICRS grading systems have been adapted to MR imaging (Table 2) [26]. The grading system used may vary between institutions but at a minimum the size of an articular cartilage injury should be described in two dimensions and the depth of the articular cartilage injury (less than 50%, partial but greater than 50%, full thickness with or without underlying osseous changes) should be reported [26]. A second-look arthroscopy study in children with cartilage injuries that resulted from patellar dislocation showed that lower-grade articular cartilage injuries tend to progress to higher-grade injuries with recurrent dislocation episodes, while low-grade injuries without recurrent dislocations often remain unchanged [25]. However, this same study also showed that more complicated intersecting cracks in the articular cartilage can progress to higher-grade lesions even without recurrent dislocations [25].

In addition to traditional spin-echo sequences, several advanced MR imaging techniques have been developed to evaluate articular cartilage [27]. T2 relaxation time mapping allows for the generation of a color map (Fig. 12) that depicts variations in the water content within the articular cartilage.

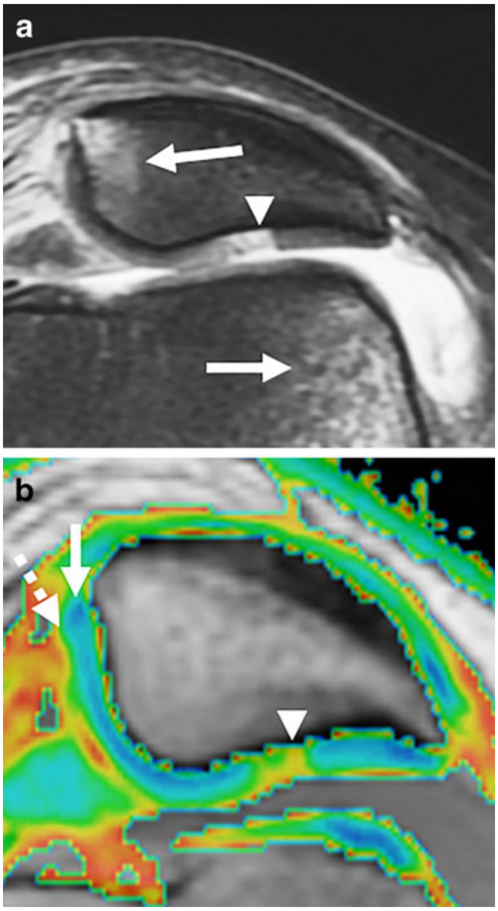


Fig. 12 Articular cartilage injury in a 17-year-old girl with prior transient patellar dislocation. **a** Axial fast spin-echo T2-weighted (TR/TE 3,000/60 ms) fat-saturated MR image of the left knee shows edema-like signal intensity in the medial patella and lateral femoral condyle (*arrows*). There is a focal full-thickness articular cartilage defect of the lateral patellar facet (*arrowhead*), which is less common than injury to the medial patellar facet but can also occur during dislocation or relocation. **b** Axial T2 map from the same knee obtained at the same level as (**a**). The color scale utilizes *red*, *orange* and *yellow* for longer T2 relaxation times and *green* and *blue* for shorter T2 relaxation times. There is a normal laminar appearance to the articular cartilage of the medial facet, with progressively longer T2 relaxation times from the cartilage adjacent to the subchondral bone (*solid arrow*) to the more superficial articular cartilage (*dotted arrow*). A disruption of the normal laminar appearance within the lateral facet (*arrowhead*), with focal longer T2 values, corresponds to the full-thickness cartilage injury. *TE* echo time, *TR* repetition time

This might allow detection of early or subtle cartilage injury when no surface contour deformity is present [27]. Delayed gadolinium-enhanced MR imaging of cartilage (dGEMRIC), T1 rho, and sodium imaging are other advanced techniques that allow for evaluation of microscopic changes of articular cartilage and earlier detection of injury [27]. However clinical practice is currently focused on substantial cartilage injury with a displaced fragment that needs to be removed, with possible debridement, microfracture or refixation.

◀ **Fig. 13** Articular cartilage injury and intra-articular body in an 11-year-old girl with recurrent transient patellar dislocations, anterior left knee pain and a new locking sensation after injury during a recent basketball game. **a** Axial fast spin-echo (FSE) T2-weighted (TR/TE 4,400/74 ms) fat-saturated MR image shows an intra-articular osteochondral body (*solid arrow*) posterior to the lateral femoral condyle. There is a full-thickness articular cartilage defect (*arrowhead*) at the donor site within the medial-most medial patellar facet. A residual chondral flap (*dotted arrow*) with insinuating synovial fluid extends to the median eminence. A large joint effusion (*asterisks*) also is present. **b** Anteroposterior knee radiograph of the same knee, obtained 19 months after the initial MR imaging examination, shows distal migration of the intra-articular body (*arrow*). **c** Coronal FSE T2-weighted (TR/TE 3,000/62 ms) fat-saturated MR image confirms the osteochondral body (*arrow*), which is surrounded by a small amount of joint fluid (*arrowheads*) and has migrated inferiorly into the popliteal recess. *TE* echo time, *TR* repetition time

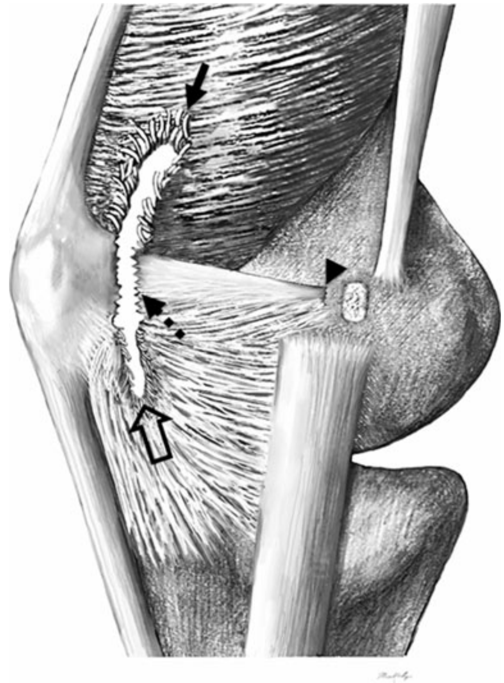


Fig. 14 Diagram of soft-tissue injury involving the medial patellofemoral ligament (MPFL). The MPFL can tear at its femoral insertion (*black arrowhead*) and at or near the patellar insertion (*dotted arrow*), as well as within the midsubstance. Tears commonly involve the patellotibial portion of the medial patellar retinaculum (*open arrow*) and less commonly extend into the fibers of the vastus medialis obliquus muscle (*solid arrow*)

When articular cartilage injuries are detected, an extensive search for intra-articular bodies that necessitate surgical management should be performed. These bodies can migrate within the joint and often are located remotely from the site of cartilage injury. They are commonly displaced into the suprapatellar, posterior or lateral joint recesses; however they sometimes migrate into the popliteal recess or into recesses beneath the menisci and are thus more difficult to detect (Fig. 13). Also, if a blood clot fills a cartilage defect, then the site of a full-thickness cartilage injury can be difficult to detect.

Soft-tissue injuries

Medial patellofemoral ligament tears can occur at the patellar or femoral attachments, mid-substance or in multiple locations (Figs. 14, 15, and 16) [6]. In a recent MR imaging study of children after acute patellar dislocation, 78% had MPFL tears, 31% of which were at the patellar insertion site, 14% at the femoral insertion site, and 33% at both femoral and patellar attachments [10]. In this study, mid-substance attenuation was graded separately and was seen in 55% of children [10]. In the setting of an acute MPFL tear, fluid-sensitive MR images show increased signal intensity within and around the medial patellar ligamentous complex, with partial or complete disruption of fibers. Chronic MPFL tears are more difficult to detect because they lack edema-like signal, but these can show focal or diffusely attenuated or abnormally thickened fibers. The ligament fibers may be elongated, wavy or irregular [28]. Remote MPFL tears may have proliferative changes at the patellar and femoral insertion sites [28].

Table 2 International Cartilage Repair Society (ICRS) Arthroscopic and MR imaging classifications of cartilage injury [26]

ICRS arthroscopic grade	MR imaging grade
0: Normal	
1a: Mild softening or surface fibrillation	1: Abnormal cartilage signal
1b: Superficial fissures	
2: Lesion with <50% depth	2: Lesion with <50% depth
3a: Lesion with >50% depth, not reaching the calcified layer	3: Lesion with >50% depth
3b: Lesion with >50% depth, reaching the calcified layer	
3c: Lesion with >50% depth, reaching but not penetrating subchondral bone	
3d: Lesion with >50% depth with blistering/bulging of cartilage	
4: Lesion with extension into the subchondral bone	4: Osteochondral lesion

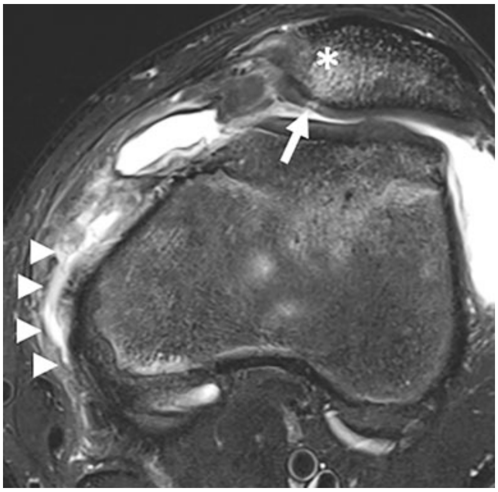


Fig. 15 Medial patellofemoral ligament (MPFL) tear in a 15-year-old boy with left knee pain after transient patellar dislocation. Axial fast spin-echo T2-weighted (TR/TE 4,110/72 ms) fat-saturated MR image shows a complete tear of the MPFL at its femoral insertion (*arrowheads*). Note the edema-like signal within the medial patella (*asterisk*), a small full-thickness focal articular cartilage injury of the medial patellar facet (*arrow*) and trochlear dysplasia. *TE* echo time, *TR* repetition time

Description of MPFL tears detected on MR imaging should include characterization of the tear as partial or complete, the location of the tear (patellar insertion, midsubstance, femoral insertion, or multiple sites), and if there is an associated avulsion fracture fragment. Some authors have described an increased risk of recurrent patellar dislocation based upon the site of MPFL tears in men; however studies in children do not support this association [10, 29].

Because of their close relationship, disruption of the MPFL can be associated with VMO muscle tears (Figs. 14 and 16). VMO muscle tears show fluid intensity within and around muscle with disruption of the muscle fibers (Figs. 14 and 16). The most common MR imaging findings of VMO muscle injury after patellar dislocations are interstitial edema, hemorrhage and partial tearing of the muscle fibers. Additionally, the degree of uplifting of the VMO from the femur in the region of the adductor tubercle has been shown to be a predictor of the severity of MPFL injury but not a direct predictor of recurrent dislocations [10].

Management of transient patellar dislocation

Non-surgical

The decision to treat an acute patellar dislocation conservatively versus with surgical repair is controversial [5, 30, 31]. A Cochrane collaboration review published in 2015 found that although some evidence supports surgical over non-surgical treatment of primary patellar dislocation, the quality of evidence is very low and "well-designed studies recording adverse events and long-term outcomes are needed" [32]. Not surprisingly, treatment algorithms for management of an initial patellar dislocation are not uniform [33]. Some clinicians consider conservative management to be the appropriate treatment after a first episode of transient patellar dislocation if there is no osteochondral fracture fragment, if the patella is stable on clinical examination, and if there is at most partial injury of the medial stabilizers of the patella [33]. Large intra-articular osteochondral fragments (>15 mm) are typically considered a contraindication to conservative management [30]. If conservative management after a first-time transient patellar

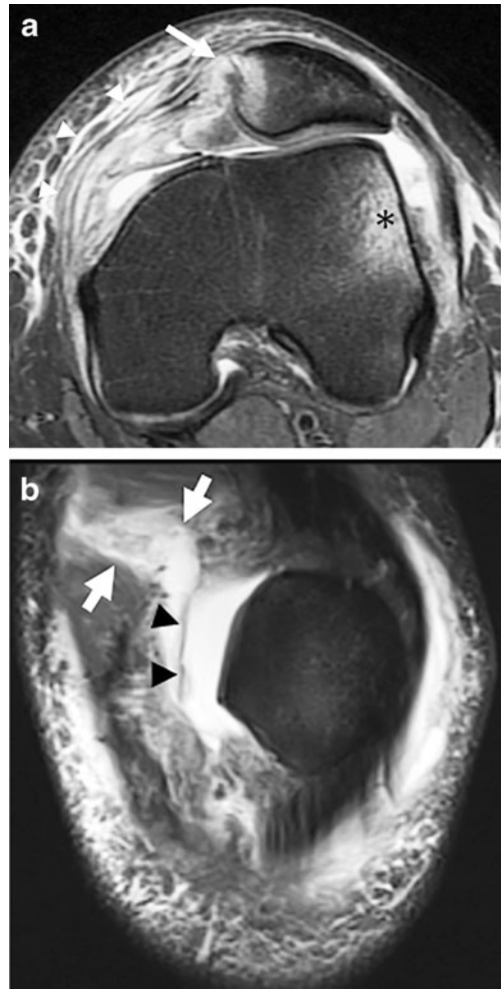


Fig. 16 Medial patellofemoral ligament (MPFL) disruption in a 16-year-old boy with a history of left knee transient patellar dislocation. **a** Axial fast spin-echo (FSE) T2-weighted (TR/TE 3,000/60 ms) fat-saturated MR image shows complete disruption of the MPFL at its patellar insertion (*arrow*). Edema-like signal, reactive or from hemorrhage, insinuates between the fibers of the midsubstance of the medial retinaculum (*arrowheads*). There is a bone contusion in the lateral femoral condyle (*asterisk*). **b** Coronal FSE T2-weighted (TR/TE 3,000/60 ms) fat-saturated MR image shows extension of the tear of the vastus medialis obliquus muscle (*arrows*). The MPFL is stripped off its patellar insertion (*arrowheads*). *TE* echo time, *TR* repetition time

dislocation is considered clinically appropriate, these children often are placed in a patellar-stabilizing orthotic after the initial swelling goes down. Early mobilization has been shown to decrease pain and to be beneficial for the muscular, ligamentous, cartilaginous and osseous structures surrounding the knee [1, 5]. A physical-therapist-directed muscle-strengthening rehabilitation program is then initiated with the goal of strengthening the medial stabilizers of the patella [5, 30, 31].

Surgical

Given the high rate of recurrent patellar dislocations, many patients, especially those with intra-articular bodies or major tears of the medial stabilizers, are initially treated with surgery [33]. Additionally, patients treated conservatively after a primary patellar dislocation often go on to surgical management if they sustain recurrent dislocations. The number of surgical techniques used to treat patellar instability continues to increase, and there are many variations among surgeons and institutions [1]. The most commonly performed surgeries include lateral retinacular release, MPFL repair or reconstruction, and patellar repositioning procedures. These procedures can be performed alone or in combination, with the goal of restoration or improvement in medial patellar stabilization and of correct patellar alignment [1].

Lateral retinacular release is typically performed as an adjunct to MPFL reconstruction or patellar realignment procedures in an effort to reduce lateral tension on the patella [34]. However some studies support a role for isolated lateral retinacular release in adolescents with recurrent patellar dislocations [35]. The procedure is performed arthroscopically, with a full-thickness incision made through the lateral joint capsule and lateral retinaculum [36]. Postoperative MR images often show laxity and thickening of the lateral retinaculum (Fig. 17).

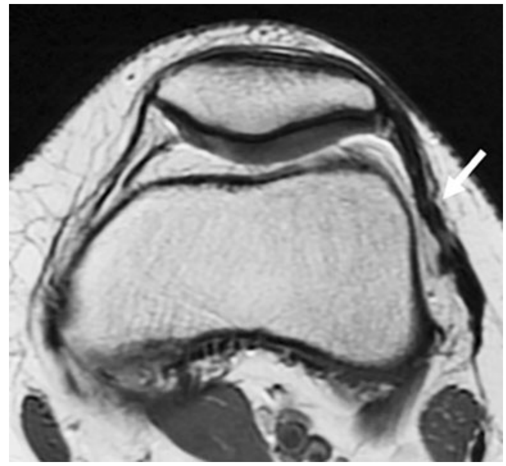


Fig. 17 Lateral retinaculum release surgery in a 16-year-old girl with prior left knee transient patellar dislocation. Axial proton-density (TR/TE 3,000/40 ms) MR image shows thickening and laxity of the lateral retinaculum (*arrow*) after surgery, an expected postoperative finding. *TE* echo time, *TR* repetition time

Because the MPFL is the most important medial stabilizer of the patella, repair and reconstruction techniques of this structure have become the mainstay of surgical procedures used to address patellar instability [1, 34]. Repairs of the MPFL can be performed at the site of patellar or femoral disruption by suturing the torn fibers to the periosteum or by attaching the fibers with bone anchors to the patella or femur [1]. Interstitial tears can also be repaired with sutures [1]. MR images after a primary MPFL repair often show susceptibility artifact from sutures or bone anchors. The repaired MPFL should show low signal intensity on T1- and T2-weighted sequences and the fibers should be intact [37].

Some orthopedic surgeons no longer perform MPFL repair and only perform reconstruction. Typical indications for reconstruction include recurrent instability, native soft-tissue laxity, deficient bony stabilizers and more severe tears of the MPFL [1]. MPFL reconstruction techniques fix a single or double graft to the medial distal femur and the medial patella. The current trends in MPFL reconstruction attempt to restore isometry, and therefore patellar and femoral fixation sites are placed near the anatomical insertion sites of the native MPFL [1, 34]. The femoral insertion site remains just distal to the physis or physeal scar throughout growth [38]. There is an ever-increasing variety of techniques for each component of the reconstruction. An autograft might be harvested from the hamstring tendons, adductor tendons, quadriceps tendon, or the iliotibial band, or alternatively an allograft might be used. Some authors propose that allografts are particularly useful in patients with underlying connective-tissue disorders such as Ehlers–Danlos syndrome because of the inherent laxity of autografts in these patients; however this point is debated [39, 40].

Fig. 18 Diagram of medial patellofemoral ligament reconstruction using a patellar tunnel. A hamstring graft is looped through a medial patellar tunnel and attached to the medial femoral epiphysis with an interference screw, just distal to the patent physis or physeal scar

Patellar fixation can be accomplished with a patellar tunnel (Figs. 18, 19, and 20), bone anchors (Fig. 21), or, if a portion

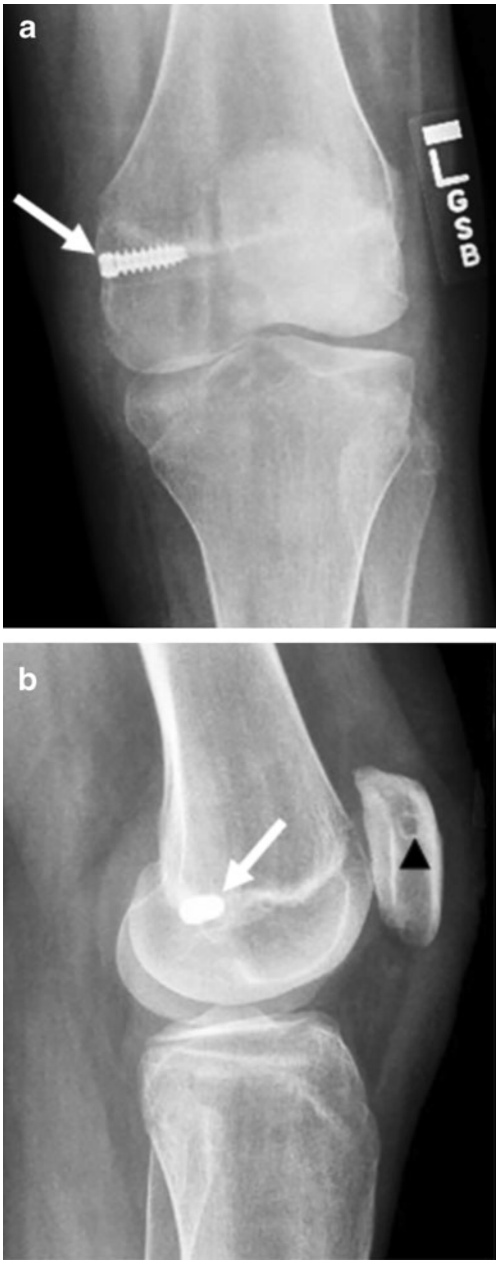


Fig. 19 Medial patellofemoral ligament reconstruction using a patellar tunnel in a 17-year-old boy with left knee transient patellar dislocation. Anteroposterior (AP) (**a**) and lateral (**b**) radiographs show a radiopaque interference screw (*arrows*), which anchors the graft within the femoral tunnel. Note that the position of the femoral tunnel is distal to the medial aspect of the physeal scar on the AP radiograph but the tunnel at Schöttle's point is above the superimposed central portion of the physeal scar on the lateral view (see discussion in text). The graft (not visible) loops through a tunnel in the patella, which has a horizontal (*arrowhead*) and a vertical portion (not seen)

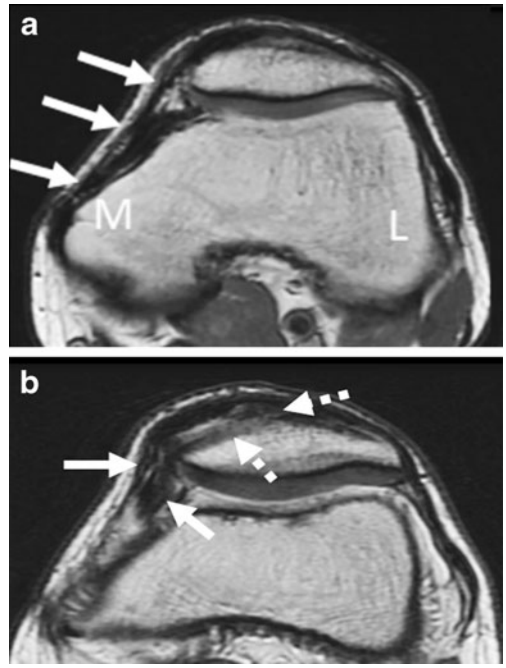
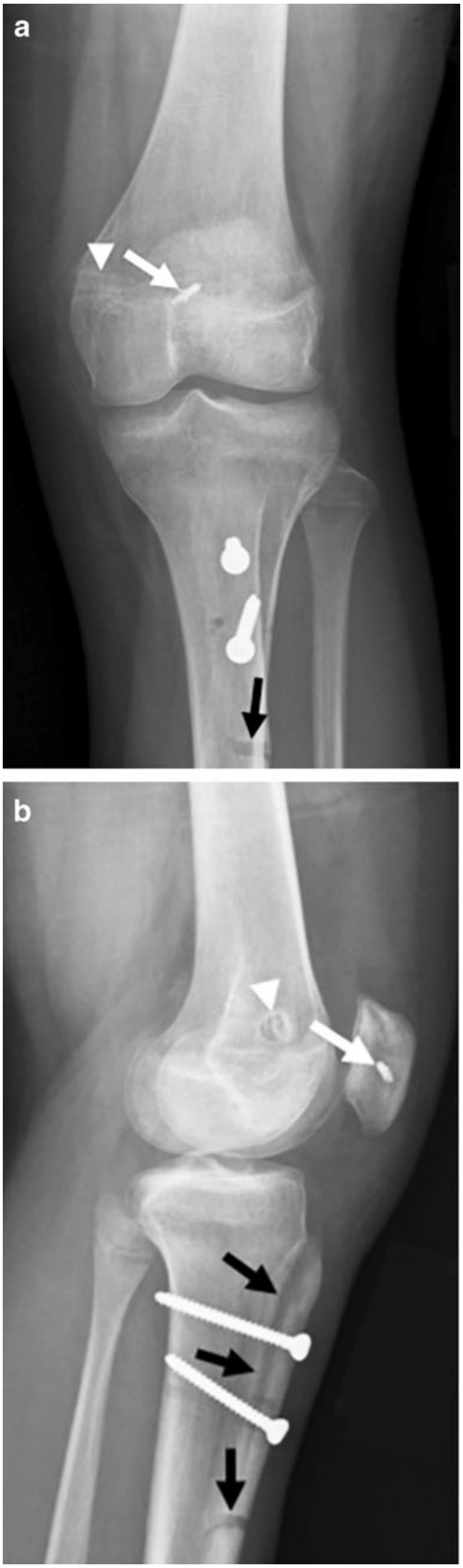


Fig. 20 Postoperative MRI of medial patellofemoral ligament reconstruction using a patellar tunnel in a 16-year-old girl with left knee transient patellar dislocation. Sequential axial proton-density (TR/TE 3,000/50 ms) MR images from superior (**a**) to inferior (**b**) show a hamstring autograft (*arrows*) that extends from the medial femoral condyle to a loop through a surgically created patellar tunnel (*dashed arrows* in **b**). The graft is secured at its femoral insertion by an interference screw (not shown). *L* lateral, *M* medial, *TE* echo time, *TR* repetition time

of the child's native quadriceps tendon is used as the graft, the distal tendon can be left attached to the patella with the more proximal portion brought inferiorly and attached to the medial retinaculum and the femoral insertion of the MPFL (Fig. 22) [41]. Femoral fixation also can be performed with various methods including tunnel formation and use of an interference screw (metallic [Fig. 19] or bioabsorbable [Fig. 21]), post and washer fixation, direct suturing or bone anchor placement. At our institutions, surgeons most often utilize a hamstring autograft that is looped through a tunnel in the patella and fixated with an interference screw in the femur, with the goal of restoring isometry (Figs. 18, 19, and 20).

Fig. 21 Postoperative radiography after a medial patellofemoral ligament reconstruction and tibial tubercle transfer in a 13-year-old girl with recurrent patellar dislocations. Anteroposterior (**a**) and lateral (**b**) radiographs show a track from a bioabsorbable screw (*arrowhead* in both) used to fix the graft to the medial femur. A bone anchor (*white arrow* in both) attaches the graft to its patellar insertion. Lucency is seen around the edges of the repositioned tibial tubercle (*black arrows* in both) ▶



Postoperative radiographs demonstrate the positions of the femoral and patellar fixation hardware or tunnels, although they are not always readily visualized (Figs. 19 and 21). A generally accepted location used by orthopedic surgeons to determine site of placement for the femoral tunnel in skeletally mature patients is referred to as Schöttle's point. This is a radiographic landmark meant to represent the mean center point of the MPFL attachment on a lateral intraoperative image of the knee. This point is found by drawing a line along the posterior cortex of the femur extending inferiorly. Two additional lines are drawn, both perpendicular to the first line, one of which intersects the point where the posterior medial femoral condyle intersects with the cortex of the posterior femoral diaphysis (the more superior line) and the second of which intersects the posterior-most aspect of the Blumensaat line (the more inferior line) [42, 43]. Between these lines is Schöttle's point (Fig. 23) [42]. In a cadaveric study of skeletally immature patients Farrow et al. [44] showed that on average the MPFL attachment is 8.5 mm distal to the medial portion of the femoral physis. These authors concluded that because typical femoral tunnels for MPFL reconstruction are 5–7 mm in diameter, a tunnel drilled directly lateral could result in damage to the more inferior central portion of the distal femoral physis. For these reasons at our institution in skeletally immature patients the tunnel is placed slightly inferior and anterior to Schottle's point, avoiding the growth plate (Fig. 23). Close attention should be given to the location of the

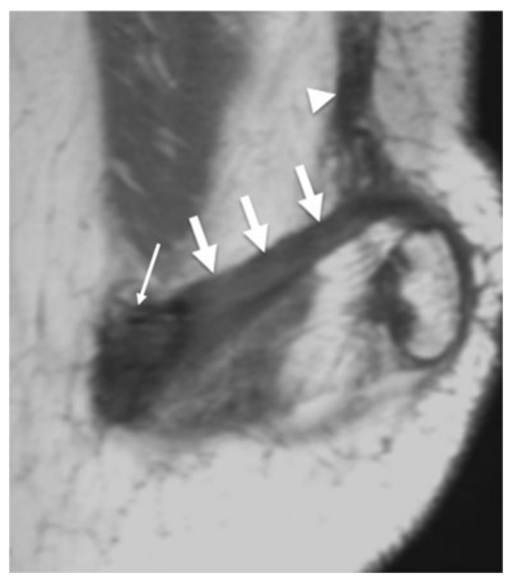


Fig. 22 Medial patellofemoral ligament (MPFL) reconstruction utilizing native quadriceps tendon as an autograft in a 17-year-old girl. Proton-density CUBE MR image reformatted in a coronal oblique plane along the MPFL graft. The MPFL autograft (*arrows*) extends from the quadriceps tendon (*arrowhead*) to its attachment site on the distal femur (*thin arrow*)

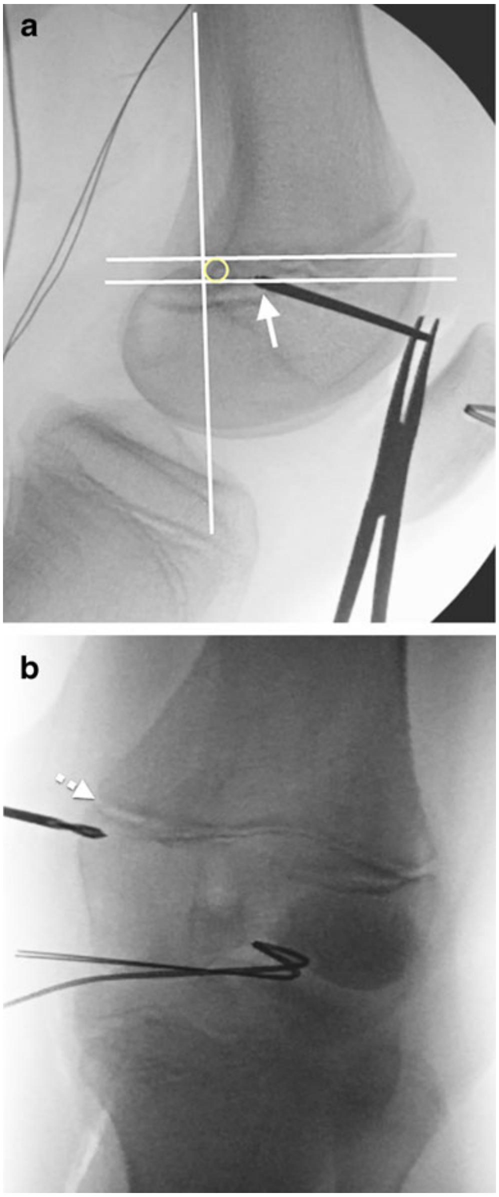


Fig. 23 Graft placement using Schöttle's point in a 10-year-old girl undergoing medial patellofemoral ligament (MPFL) reconstruction. Intraoperative lateral (**a**) and anteroposterior (**b**) fluoroscopic images demonstrate the placement of the femoral attachment of the MPFL graft and Schöttle's point. **a** The lateral image shows the method for determining the position of Schöttle's point. This is found by drawing a line along the posterior cortex of the femur (*vertical line*) and two lines perpendicular to this: one intersects the point where the posterior medial femoral condyle intersects with the cortex of the posterior femoral diaphysis (the *superior horizontal line*) and the second intersects the posterior-most aspect of the Blumensaat line (the *inferior horizontal line*). Between these lines is Schöttle's point (*circle*). The surgical probe indicates the desired location for tunnel placement, which in skeletally immature patients is slightly anterior and inferior to Schöttle's point (*arrow* in **a**) and oriented slightly inferiorly to avoid the distal femoral physis (**b**, *dashed arrow*)

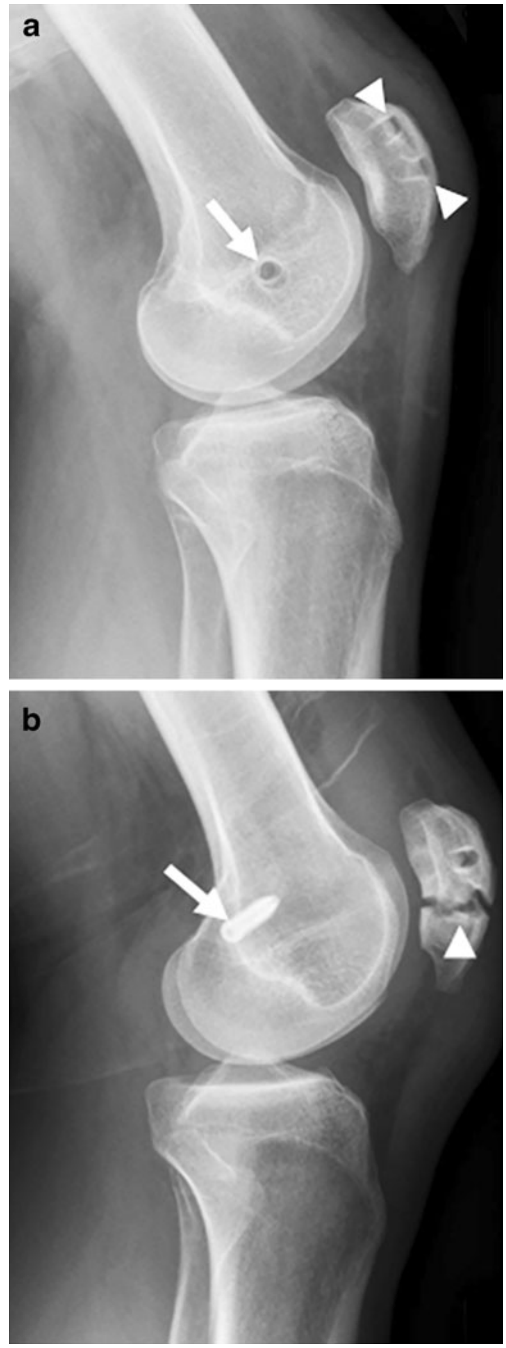


Fig. 24 17-year-old boy who had undergone medial patellofemoral ligament (MPFL) reconstruction, graft failure, and subsequent revision surgery. **a** Lateral radiograph after initial MPFL repair shows patellar tunnels (*arrowheads*) and a screw track within the distal femur from a bioabsorbable interference screw (*arrow*). The obliquity of this radiograph limits accurate assessment of the femoral tunnel, which can only be assessed on a true lateral radiograph. **b** Lateral radiograph after the MPFL revision surgery shows interval development of a transverse fracture through the inferior patellar tunnel (*arrowhead*). The distal femoral interference screw (*arrow*) has been replaced with a radiopaque one

femoral fixation on the lateral view because an anteriorly positioned site will lead to graft laxity [37].

MR images of MPFL reconstructions should show low signal intensity on T1- and T2-weighted sequences throughout the course of the graft (Fig. 20) [37]. The graft should be continuous, taut and oriented along the expected anatomical course of the native MPFL, with patellar and femoral anchor sites near the expected locations of the normal native MPFL insertions [37].

Tibial tubercle transfer or distal realignment involves the repositioning of the tibial tubercle to a more medial or more distal position [37]. This intervention is thought to address two of the anatomical factors that predispose to transient patellar dislocation, namely patella alta and excessive TT–TG distance. An osteotomy is made deep to the tibial tubercle, which is then repositioned and fixed, often with screws (Fig. 21).

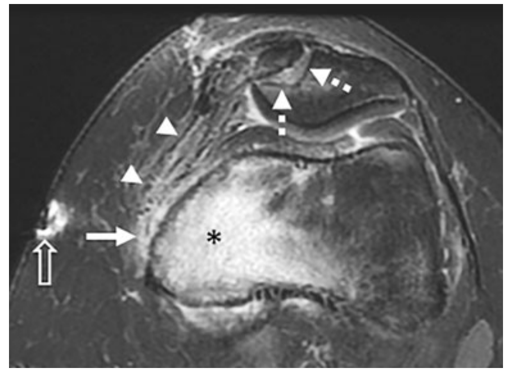


Fig. 26 17-year-old boy who had undergone medial patellofemoral (MPFL) repair and re-injured the left knee. Axial fast spin-echo T2-weighted (TR/TE 3,000/40 ms) fat-saturated MR image shows a poorly defined and attenuated MPFL hamstring auto-graft (*arrowheads*). The graft is completely torn near its femoral insertion (*arrow*). There is edema-like signal within the medial femoral condyle (*asterisk*). The patellar tunnel (*dotted arrows*) and susceptibility artifact (*open arrow*) from the surgery are evident. *TE* echo time, *TR* repetition time

Postoperative complications

The complication rate after MPFL reconstruction has been reported at approximately 26% [45] and includes pain, wound complications, persistent patellar instability, decreased knee flexion, sciatic nerve paresis and septic arthritis [32, 45]. Postoperative imaging can help to identify specific complications [37]. Wound complications are usually minor and typically diagnosed on physical examination, whereas MR imaging might show hematoma, cellulitis, abscess formation, joint effusion and synovitis associated with septic arthritis [37].

Fig. 25 Quadriceps avulsion patellar fracture in a 15-year-old girl with a history of medial patellofemoral ligament (MPFL) reconstruction who re-injured her knee. Sagittal proton-density (TR/TE 3,000/50 ms) MR image of the knee shows an avulsion fracture of the superior pole of the patella. The patellar fracture fragment (*solid arrow*) remains connected to the quadriceps tendon, and the donor site at the superior pole of the patella (*open arrow*) can also be seen. Susceptibility artifact in the patella and distal femur are present from the MPFL reconstruction (*dashed arrows*), and there is a large hemarthrosis with a fluid-fluid level (*arrowhead*). *TE* echo time, *TR* repetition time

Postoperative radiographs and MR images can assess the position of the femoral and patellar fixation hardware. In addition to non-anatomical femoral fixation and potential resultant graft laxity, there is risk for persistent patellar instability [37]. Patellar tunnels can result in patellar fracture (Fig. 24) or quadriceps avulsion fractures (Fig. 25) [37, 45]. Bone anchors or interference screws that have backed out can cause loss of soft-tissue or bone purchase [37].

Recurrent patellar dislocation in children is not uncommon after surgical repair [30]. There is substantial variability in the reported rates of recurrent patellar dislocation after surgical management, some as high as 67% [30]. However, several studies combine data from patients who underwent lateral retinacular release with those who were treated with MPFL repair [30]. Nelitz et al. [46] showed no redislocations at 2 years in their prospective study of 21 skeletally immature children who underwent an anatomical MPFL reconstruction technique. Recurrent dislocation of the patella after MPFL reconstruction can lead to graft failure [37, 45]. On MR imaging, graft tear results in increased signal intensity on fluid-sensitive sequences within and around the graft, with partial or complete disruption of the graft fibers (Fig. 26). As with native MPFL tears, graft tears can occur at the patellar or femoral insertions, mid substance or at multiple sites.

Conclusion

Transient patellar dislocation is a common cause of anterior knee pain in children and adolescents and has a high recurrence rate. In many pediatric athletes, transient patellar dislocation is associated with long-term pain and sport-limiting extensor mechanism impairment. Therefore it is important for radiologists to be aware of the factors that predispose for transient patellar dislocation, the imaging appearance of acute injuries, and the chronic findings following prior patellar dislocation. Furthermore, as more children and adolescents undergo surgical management for recurrent patellar instability, radiologists who help to care for these children must be familiar with the types of procedures performed, the normal postoperative imaging appearances and the potential complications.

Compliance with ethical standards

Conflicts of interest None.

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